Proceedings of a Symposium, Karlsruhe, 6-10 June 1966 jointly organized by the IAEA and FAO

FOOD IRRADIATION

INTERNATIONAL ATOMIC ENERGY AGENCY, VIENNA, 1966
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PROCEEDINGS OF THE INTERNATIONAL SYMPOSIUM ON FOOD IRRADIATION JOINTLY ORGANIZED BY THE INTERNATIONAL ATOMIC ENERGY AGENCY AND THE FOOD AND AGRICULTURE ORGANIZATION OF THE UNITED NATIONS AND HELD IN KARLSRUHE, 6-10 JUNE 1966

INTERNATIONAL ATOMIC ENERGY AGENCY
VIENNA, 1966
FOREWORD

For some years research has been done in several countries, with the object of contributing to the world's food supplies, on the application of nuclear methods to food preservation and processing. The importance of food preservation is of particular relevance in certain regions of the world where up to thirty per cent of harvested foodstuffs are being lost because of damage by animal pests and microorganisms. A series of international meetings have been held on this subject; the first, held in 1958 at Harwell, was followed by further meetings in 1960 in Paris and in 1961 in Brussels.

The International Symposium on Food Irradiation organized by the International Atomic Energy Agency and the Food and Agriculture Organization of the United Nations through their Joint Division of Atomic Energy in Agriculture, and held at the Karlsruhe Nuclear Research Centre, Karlsruhe, from 6 to 10 June 1966, at the generous invitation of the Government of the Federal Republic of Germany, is the most recent of this series of meetings. It was held for the purpose of exchanging the most up-to-date results of research, of contributing towards co-operative efforts between Member States, and of stimulating trade in the international exchange of irradiated products between nations.

Papers describing research over the past fourteen years were given by outstanding authorities; the results point to a breakthrough having been achieved in the use of ionizing radiation in food preservation, notwithstanding some problems still to be solved, such as overcoming changes in colour, flavour, odour or texture. The Symposium was attended by over 200 scientists from 25 countries and four international organizations. Sixty-nine papers were presented. It was shown that a wide variety of foodstuffs exist for which radiation could be used for three different purposes: to produce indefinitely stable products, to rid food of organisms that constitute health hazards, and to extend the normal shelf or market life of perishable food products. Different radiation sources, particularly $^{60}$Co and electron accelerators, can be used. Different types of foodstuffs react differently: ripening is delayed in some fruit, the cooking time of dehydrated vegetables can be shortened, and the shelf life of fish and some varieties of fruit and vegetables can be more than doubled. The applicability of irradiation depends on economic factors, as well as on climatic, technological, transport and food-growing conditions in given areas.

The main subjects covered at the Symposium were: radiation sources and dosimetry, the wholesomeness of irradiated food, the chemical and physical effects of ionizing radiation, microbiology, virology and quarantine problems, the status of various irradiated commodities, including meat and meat products, poultry and eggs, grain and stored food products, fish and sea foods, and fruit and vegetables. In the broader
application of radiation to food preservation, the participants discussed present programmes in operation, facilities used, and economics, together with national legislation and clearances for irradiated items. Some countries are already using radiation for the prevention of sprouting in potatoes and onions and for the sterilization of bacon. In the near future its use for the disinfestation of grain will be implemented.

The irradiation of food — described as the first truly novel food preservation method since Nicolas Appert well over one hundred years ago invented food preservation by bottling — will doubtless play a very important role in the life of mankind, in many instances in conjunction with conventional food treatment methods, such as heat and refrigeration.
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OPENING ADDRESS
HISTORICAL DEVELOPMENT OF FOOD IRRADIATION*

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Abstract — Résumé — Аннотация — Resumen

HISTORICAL DEVELOPMENT OF FOOD IRRADIATION. This paper presents the historical development of the field of radiation preservation of foods from the basis of a sequence of ideas.

The debt owed by the New World to the Old, in terms of the origin and discovery of radiation, isotopes, and X-rays, and the development of these into potentially useful processes, are described. The author also shows that these discoveries would not have been possible without the knowledge acquired in this subject and outlines the potential impact of these new developments on improving man's estate in the future.

The important milestones passed at an international level are described and their influence discussed.

HISTORIQUE DE L'IRRADIATION DES DENRÉES ALIMENTAIRES. Le mémoire expose l'évolution historique des méthodes relatives à la conservation des aliments par irradiation, à partir d'un certain nombre de concepts de base.

Il fait ressortir combien le Nouveau Monde doit au Vieux Continent en ce qui concerne tant l'origine et la découverte des rayonnements, des isotopes et des rayons X que les applications dans divers procédés pouvant se révéler utiles. L'auteur montre aussi que les découvertes n'auraient pas été possibles sans les connaissances acquises dans ce domaine, et à quel point ces faits nouveaux pourraient contribuer à améliorer la condition de l'homme dans l'avenir.

Le mémoire signale les importantes étapes qui ont été franchies à l'échelle internationale et examine leurs effets sur le problème étudié.

ИСТОРИЯ РАЗВИТИЯ МЕТОДОВ ОБЛУЧЕНИЯ ПИЩЕВЫХ ПРОДУКТОВ. Описывается история развития методов сохранения пищевых продуктов путем облучения с точки зрения развития различных идей в этой области.

Говорится о том, что Новый Свет оставался в долгу перед Старым пока не открыл излучения, изотопы, рентгеновские лучи, а также не разработал процессы их использования с тем, чтобы поставить их на службу человеку. Подчеркивается важность знаний в вышеупомянутых областях для успешного выполнения программы по сохранению пищевых продуктов путем облучения, которая позволит улучшить благосостояние человечества в будущем.

Излагаются основные этапы этого процесса, а также их влияние на прогресс в данной области в мировом масштабе.

DESARROLLO HISTORICO DE LA IRRADIACION DE ALIMENTOS. En la memoria se expone el desarrollo histórico de la conservación de alimentos por irradiación partiendo de una serie de consideraciones fundamentales.

Se pone de manifiesto la deuda del Nuevo Mundo para con el Viejo en lo que atañe a los orígenes y al descubrimiento de las radiaciones, de los isótopos y de los rayos X, y se relata cómo se han ido encontrando aplicaciones prometedoras. Se indica lo mucho que los progresos actuales deben a los conocimientos adquiridos y el influjo benefico que los modernos adelantos pueden tener con el tiempo en el nivel de vida del hombre.

Se señalan las efemérides más notables y se examina su influencia en el ámbito internacional.

* Contribution No. 893 from the Department of Nutrition and Food Science, Massachusetts Institute of Technology, Cambridge, Mass., 02139, United States of America
"Quia mihi pulchrum in primus videtur non pati occidere"

Pliny the Younger, circa C.E. 98

INTRODUCTION

In the information sheet attached to the invitations to attend this program it was stated that "the purpose of this symposium is to review the present status of development of food irradiation on a world basis and to assess its potentialities for future use."

To me it is most fitting that such a symposium be held here in Karlsruhe where a laboratory was first set up as part of Professor Kuprianoff's Institute for Food Preservation in 1958, and where today we see the culmination of his dream in the completion of the first Institute for Food Irradiation Research. To Prof. Kuprianoff, Dr. Diehl, the Director of the Institute, and to all associated with it go the good wishes of us all.

The road traversed by scientists in the development of a given field contains milestones or significant discoveries which are important in the sequential development of the ideas from which the field is made up. No single discovery is usually the "sine qua non" of any field although, as the eminent French physiologist, Claude Bernard, has stated, "A great discovery is a fact whose appearance in science gives rise to shining ideas, whose light dispels many obscurities and show us new paths". Nevertheless, the same Bernard has judiciously stated that "We stand on the shoulders of those who have gone before in order to peer into the future". Thus, milestones become important not only for their per se significance but also because, in the aggregate, the passage of milestones becomes history. It is this historical development of food irradiation that I have been asked to develop for you today.

There is an old German saying by Schlegel (circa 1799) "Der Historiker ist ein rückwartsgekehrter Prophet" (The historian is a prophet looking backwards). Thus my job should be much easier than he who is charged with prophesying the future.

EARLY BEGINNINGS

To me there are two important general observations that should be made relative to the historical development of the field of radiation preservation of foods. First, the early history of food irradiation is, indeed, the history of radiation itself. Second, by a careful and critical review of the historical development of the field, one notes not only the cosmopolitanism of the field but, indeed, the dependence of and the debt that discovery owes to knowledge. As one further evaluates the historical development of the field, one is struck with a realization that Pasteur was so right when he put forth the idea that there is no such thing as science and applied science. There is science and the applications of science and they are the same (1).
The period from 1895 to 1935 was one of the most exciting periods in the history of physics, especially as it pertains to the topic of this paper. Advances came at a rate faster than at any period since that of Sir Isaac Newton. In 1895 W. K. von Roentgen discovered X-rays (2), in 1896 Becquerel discovered radioactivity (3), in 1903 Madame Curie isolated radium and determined its atomic weight (4) and Rutherford and Soddy proposed their theory of radioactive disintegration (5-7). The history of science is full of certain summits of achievements—the formulation of certain general laws which command the respect of all following generations. Rutherford and Soddy's theory of radioactive disintegration is in this category. The three different types of radiation (alpha, beta and gamma) and their behaviour in a magnetic or electric field was shown by Curie (4); and although in 1899 Rutherford found only two types of radiation from uranium (8), he later described three types (9). In 1897 J. J. Thompson demonstrated the nature of cathode rays (10) and determined the ratio of charge to mass of the electron (a name first given to the "corpuscles" which made up the cathode stream by Johnstone Stoney (9,11). In 1897 Chadwick discovered the neutron (12) as a result of the interpretations of the experimental results of Curie and Joliot (13).

In 1905 Einstein proposed his special theory of radioactivity (14) after Planck (1901) had stated his quantum theory (15). In 1913 Bohr developed the atomic model (16-18) and in 1924 de Broglie (19,20) showed the duality of waves and particles. The above represent but a few of the important high points in the development of radiations and matter.

NUCLEAR FISSION

The latter 1930's began to present some new exciting discoveries in a field which was to have much influence not only in science but in politics as well—nuclear fission. Hahn and Strassman (21) discovered nuclear fission by observing that an isotope of barium was formed by neutron bombardment of uranium. The energy release from the fission of uranium was shown by Frisch (22). The fact that a chain reaction could occur in this process was observed by Szillard, Zinn, Anderson, Fermi and Hanstein who withheld the observations from publication as did others in America for obvious reasons.

However, von Halban, Joliot and Kowarski observed this same phenomenon and published the paper in 1939 in Nature (23).

Thus, the basic discoveries of importance in ultimately making available large quantities of $^{60}$Co as a by-product of nuclear fission were, by and large, originated in the "Old World". The significance of these discoveries, although appreciated by European scientists, was understood also and acted upon by physicists from America and those who had but recently come to the "New World". The discoveries described in this and in the previous section represent the basic and fundamental knowledge of the field of radiation preservation of foods. There are a large number of important pieces of work that perhaps should have been mentioned but have not been due to space limitation. The above, however, are the most important milestones which represent those important
facets which are germane to a history of this field. They represent not only the discovery of new phenomena such as radioactivity but this era also witnessed the development of relativity and the quantum theory which, as Segre has so aptly stated, revolutionized "the very intellectual basis of physics" (24).

**BACTERICIDAL EFFECTS OF IONIZING ENERGY**

Almost as soon as X-rays were discovered, work was begun on studying their biological effect. Among the many aspects of the biological effects that were studied were the microbicidal effects. The early work in the field, by and large, as one could have predicted, yielded negative results due mainly to the probable intensities of the radiation sources available. The early work on X-rays and their effects on bacteria dealt with lethal effects only. The first paper apparently was by Minck of Germany in 1896 and thus has other historical significance as well (25,26). Its very title "On the Question of the Effect of Roentgen Rays on Bacteria and the Possibility of their Eventual Application" clearly forecasts the present application. Findings similar to those obtained by Minck were obtained in the United States by Prescott in 1904 in studying the bactericidal effects of radium rays (27). Wyckoff, in two papers, demonstrated the quantitative effects of X-rays on bacteria and showed the kinetics of the lethal effects to be semi-logarithmic (28,29).

Perhaps the greatest contribution to our understanding of the mode of actions of ionizing energy came from the work and writings of D. E. Lea. Douglas Lea was a physicist working at the Strangeway Laboratories of the University of Cambridge and will be long remembered for his theories on the mode of action of ionizing energy on biological systems and for his opus magnus (30).

Coolidge (31) and Coolidge and Moore (32,33) were the first to report on the biological and chemical effects of an intense cathode ray beam. Although they had also observed the bactericidal effects, they too were limited because of the equipment of that time. In the case of Coolidge and his associates, this was due to limitations in energy level as well as in intensity of the beam. Nevertheless it is interesting to note that at 350,000 volts, dosages of approximately 1 megarad were delivered to organisms and their demise observed.

**THE BEGINNINGS OF RADIATION PRESERVATION OF FOODS**

The late 1930's and early 1940's witnessed the development of sources of intense beams of high energy radiations. The Resonant Transformer was developed by Charlton and his associates (34,35), the Van de Graaff Electrostatic Accelerator by Dr. Van de Graaff (36), and the Capacitron by Brasch and Huber (37). The development of nuclear fission made available large sources of fission by-products and the availability of pile-produced isotopes such as $^{60}$Co was of great significance. These developments now provided for the necessary sources of ionizing energy to achieve the necessary depth of penetration as well as the needed intensity of radiation.
In 1943 Proctor, Van de Graaff and Fram (38) reported on their work on the preservation of hamburger meat using X-rays produced by a one million-volt Van de Graaff electrostatic accelerator. Apparently this was the first real and successful attempt at using ionizing energy for food preservation, although there are a number of patents in the literature such as those by Appleby and Banks (39), Lieber (40), Wust (41,42) and probably others which predate the work of Proctor et al. None of the patents cited are at all meaningful, however.

On July 21, 1944 Dr. Lyle B. Borst, one of the key developers of the nuclear pile at Oak Ridge, filed for a patent on the use of radiations from fission products in a pile for the preservation of foodstuffs. This was filed under wartime secrecy but later the application was withdrawn from the patent office.

In 1945 shortly after World War II ended, scientists in the United States began in earnest their researches on the possibilities of using ionizing energy for the preservation of foodstuffs. The initial intensive efforts were carried out by three groups—one at the Electronized Chemicals Corporation in Brooklyn, New York, using a pulsed accelerator, the Capacitron, as the radiation source (43-45); this work was done in conjunction with the Research Laboratories of Swift & Co.; the second at the Massachusetts Institute of Technology, a joint effort between the Department of Food Technology and the High Voltage Research Laboratories of the Department of Electrical Engineering (46-48). The third group was at the General Electric Company Research Laboratories at Schenectady, New York (49-51).

THE ENTRANCE OF THE UNITED STATES ATOMIC ENERGY COMMISSION INTO FOOD PRESERVATION RESEARCH

In about 1950, the United States Atomic Energy Commission (USAEC) began to support a coordinated research program on the use of ionizing energy for food preservation (52,53). This program was particularly directed, at first, towards the utilization of the fission by-products (54). The USAEC made available kCi60Co sources to several institutions, at least one fission product source, and supported research programs on the use of ionizing energy for food preservation.

THE ARMY QUARTERMASTER PROGRAM

In 1953 as a result of a feasibility study by Siu (55), the U.S. Army Quartermaster Corps began an intensive research program, both internally and externally, on food preservation by ionizing energy. This program was multifaceted in approach, covering sources, utilization, and basic and applied research as well. The work, which was coordinated by the Office of the Surgeon General of the Department of the Army in cooperation with the U.S. Food and Drug Administration (USFDA), covered for the first time the all important question of the wholesomeness of irradiated foods. The Army program is in effect to this day, although different in scope.

One of the important values of the Army program in its initial stages was to train and educate scores of scientists
in nuclear techniques, to teach them to apply these techniques to food preservation by ionizing energy, to learn to understand the manifold problems attendant thereto and to seek solutions for some of these. In this, the program was admirably successful.

With the initiation of the Army program, the Atomic Energy Program was phased out. An interagency (interdepartment) committee was later set up among the several agencies of the United States Government to coordinate the research programs. It is estimated that perhaps some 25 to 30 million dollars were spent in the Army program over the 10 year period from 1953 to 1963.

During the late 1950's, plans were made for a large-scale plant for the radiation preservation of foodstuffs, to be located at Stockton, California. This plant was to contain a 2.5-MCi $^{60}$Co source and a 24-MeV Linear Electron Accelerator. This plan was postponed by the Office of Research of the Department of the Army in 1959 until more adequate research data were at hand. Later, a smaller (1 M Ci) $^{60}$Co pilot plant and a 24-MeV $^{60}$Co source were built at Natick, Massachusetts, at the Natick Laboratories of the U. S. Army (dedicated in early 1963).

Over the years, the Army program changed from one consisting mostly of extramural work to one where it is at present almost entirely intramural research. The program has had much influence on the radiation preservation research programs of a number of countries (56).

At the present time, the U.S. Army program on radiation preservation of foods is particularly directed to the sterilization aspects.

THE REENTRANCE OF THE UNITED STATES ATOMIC ENERGY COMMISSION INTO FOOD PRESERVATION WORK

In 1959 the USAEC, through its Office of Isotopes Development, began to have some studies carried out to ascertain the feasibility of preservation of certain species of marine products and of some fruits and vegetables (57,58). In 1960 a so-called "low-dose" radiation preservation program had been initiated in the U.S.A. at a number of institutions under USAEC sponsorship. One petition to the USFDA based on the work done on this program has now been submitted requesting that a regulation be issued for the treatment of fish filets with a dosage of 150,000 rad for preservation purposes thus permitting consumption by humans.

THE COSMOPOLITANISM OF FOOD IRRADIATION

Obviously, with the background of the writer, this paper has been written mainly from the point of view of and familiarity with his own country. Yet the field of radiation preservation of foods is a cosmopolitan one and a great deal of effort has been expended by scientists from a number of countries in Europe and Asia in this field. It should be stated, however, that although the early basic work on the characteristics of ionizing radiations and their effects on
matter originated in Europe, much of the developmental work was carried out in the United States. One cannot but be reminded of a letter that the famed Louis Pasteur wrote when he quoted with pride that his process (on the pasteurization of wine) was used with success in faraway California. He stated that it was inspiring to hear from the citizen of a country where the grapevine did not exist twenty years ago that, to credit a French discovery, he has experimented at one stroke on 100,000 liters of wine. As Pasteur stated "Ces hommes marchent à pas de géants, tandis que nous posons timidement un pied devant l'autre, plus occupés souvent à dénigrer qu'à honorer les services rendus" (59).

Nevertheless, we in America owe much to Europe not only for the basic discoveries of its scientists but also for some of the findings in the applied areas which have made possible the present state of radiation preservation of foods. It was not until work began in earnest in England and Germany in particular that radiation preservation of foods really became of age.

The first work following World War II carried out in England, was done by Hannan and coworkers (60-65) at the Low Temperature Research Station, and later in conjunction with workers at the Wantage Research Laboratories of the Atomic Energy Research Establishment. An excellent and critical summary of this has been provided by Jefferson (66). Large-scale radiation sources have been developed at Wantage for cooperative programs with the Low Temperature Research Station and with the Torrey Research Station at Aberdeen, Scotland. In addition both Cambridge and Wantage, England have served as focal points for the training and education of numerous foreign scientists in this field. The personal involvement of the author of this paper is keenly felt inasmuch as Hannan came to the U.S.A. to spend some time working with the late Professor Bernard E. Proctor and himself at MIT in the early 1950's.

In the early 1950's several symposia were held in England dealing with this field, including one before the Society of Chemical Industry (67) and one at Harwell on the utilization of fission products (68). The work in England was not limited to the Low Temperature Research Station, nor Wantage, but industry participated as well, as is evidenced by the many papers from the Research Department of the Metropolitan-Vickers Electrical Co., of Trafford Park, Manchester (69,70). Also during the 1950's, several contractors' meetings were held at Chicago, Illinois and at Gatlinberg, Tennessee, sponsored by the U.S. Army Radiation Preservation of Foods program and at several of these meetings there was a great deal of interchange among numerous workers from the United Kingdom and Germany, in particular.

In Germany, Kuprianoff and his coworkers began their studies in the mid-1950's with some highly significant publications appearing (71-74). In 1958 the Federal German Government constructed a laboratory adjacent to the Federal Food Preservation Research Institute directed
by Professor Kuprianoff for the radiation preservation of foods. Professor Dr. K. Lang at Mainz has collaborated with Professor Kuprianoff's group in work on food preservation. Of historical significance is the fact that a man named Otto Wüst (75) of Germany received a French patent on the use of X-rays for food preservation in 1931.

In Scandinavia work has been carried on for the past decade at Risø, Denmark and at Roskilde at the Meat Research Institute (76,77); and work has also been carried out at the Swedish Food Preservation Institute under Professor Von Sydow's general direction, by Dr. Molin, Mrs. Abrahamsson and others. Much of this work has been reported in the two Scandinavian conferences held on the Radiation Preservation of Foodstuffs, the first held in April, 1960 at Risø, Denmark and the second held at Stockholm in September, 1963 (78).

In January, 1960, a study group on food irradiation was set up by the Organization for Economic Cooperation and Development's (OECD) European Nuclear Energy Agency (ENEA). It is composed of experts on food irradiation from 16 OECD countries as well as representatives from the International Atomic Energy Agency (IAEA) and the Food and Agriculture Organization (FAO) of the United Nations. The activities of this group have been well described in a paper by Lévéque (79). In addition, this group, in conjunction with the French Commissariat à l'Energie Atomique, is co-sponsor of the Quarterly Newsletter, "Food Irradiation", now in its sixth year of publication. To Dr. Lévéque goes a great deal of credit for this important means of keeping all concerned informed of many of the advances which are taking place.

In a review of this type it is difficult to mention all the important workers or even the countries. But certainly the work of Proost (80) and Lafontaine (81) in Belgium, of Mossel and coworkers in Utrecht, Holland (82), of DeZeuuw and his group at Wageningen (83) is well known. In France work has also been carried out by Vidal at Conservatom, near Lyon.

In recent years, through the OECD and the IAEA and in conjunction with the Oesterreichische Studiengesellschaft für Atomenergie, a food irradiation center has been set up near Vienna at Seibersdorf. The work of this organization will, at first, be primarily associated with fruit juices.

Poland has had an active program underway at several institutes since the latter part of the 1950's. This has been described by Bednarczyk (84,85) and by Pijanowski (86).

The radiation preservation of foods program in Russia has also been extensive, although not as well known to the author. At the meeting of the International Atomic Energy Agency Panel on the Application of Food Irradiation in Developing Countries held in Vienna during August 1964, Dr. A. V. Kardashov of the All-Union Scientific Research Institute for Marine Fisheries and Oceanography (VNIRO) reported on the applications of ionizing energy in the U.S.S.R. for preservation of marine products, and
Dr. V. I. Rogachev of the All-Union Scientific Research Institute for the Conservation Industries reported on much of the other work that has been done in the Soviet Union on the applications of ionizing energy to other food products. As these papers as presented contain a number of references to earlier work in the Soviet Union, the proceedings of this conference will be of great interest to all here. In addition the book by Bednarczyk (85) describes some of these extensive programs which have included not only meat and fish preservation but also the treatment of potatoes on a large scale for sprout inhibition.

Work in Canada on potatoes and on onions for sprout inhibition has gone on at a large scale. This represents also the birth of the world's first commercial food irradiator at St. Hilaire, Quebec (Newfield Products, Ltd.), a $1.2 million venture.

The Japanese scientists have done a great deal of work on the use of ionizing energy for food preservation. Much of this has been reported at the annual or bi-annual meetings of the Japan Conference of Radioisotopes sponsored by the Japan Atomic Industrial Forum and the Japan Atomic Energy Commission. These meetings not only attract scientists from the U.S.A. but, also, from all the countries of the Far East and do much towards obtaining adequate scientific knowledge spread among the various countries.

As is always the case in a paper of this type, one attempts to hit the high spots and yet quite often forgets some of the more important events or pieces of work. In trying to review the work of so many countries over such a long period, it is difficult for one person to be cognizant of all the developments; and thus, it is too easy to overlook some of the milestones which are indeed important. The audience is asked to be compassionate in this respect for as Alexander Pope wrote in his Essay on Criticism in 1711: "Authors are partial to their wit, 'tis true, But are not critics to their judgement too?"

WHOLESOMELESS

One of the biggest problems that needed answers in the early 1950's related to the problem of the wholesomeness aspects of irradiated foodstuffs. One of the earliest papers in this and which deserves particular note is that of Poling (86a) of Swift & Co. in the U.S.A. A large proportion of the funds of the U.S. Quartermaster Corps during the decade from 1953 to 1963 was spent on determining the safety and wholesomeness of 21 foodstuffs which they were interested in sterilizing. Suffice it to say that to date all of those that have been studied have proven to be safe and wholesome. Lehman and Laug (87) in 1954 presented the experimental protocols that would be required to show the safety of irradiated foods. As of this date several foodstuffs have been cleared by the U.S. Food and Drug Administration for human consumption and a number of others are being considered at this time for such clearance.

PUBLIC HEALTH ASPECTS

One of the important milestones was in 1953 when Proctor and his associates (88) demonstrated that Salmonellae could be destroyed by relatively low doses of ionizing energy. This has important
implications for eggs, poultry and animal feeds as well, and an important meeting on the control of Salmonellae by irradiation was held in 1962 in Vienna under the sponsorship of the IAEA (89). Thus not only is radiation an important tool for food processing per se, but may also be of even more significance in improving the public health status of the world.

INTERNATIONAL ASPECTS

The importance of an international program has been alluded to in detail earlier. This is of particular importance with respect to uniform and yet stringent guidelines for legislation for each country. A meeting on this aspect was held in Rome, Italy in April, 1964 and a report with the recommendations of this committee should issue shortly. This, too, will be another important milestone.

In the early part of 1962 a working party was appointed by the Chief Medical Officer of the Ministry of Health of Great Britain to study the present situation and determine whether there was need for control of irradiated foodstuffs and possibly the principles which should govern any official control. In 1964 a report was issued by the working party under the chairmanship of Professor F.G. Young (90) which recommended that, in Great Britain, the sale of irradiated foods be prohibited with exemptions to be granted under conditions to be specified by application therefore, supported by adequate evidence. Thus, the British recommendation by and large, is similar in effect to the regulations in existence in the United States as a result of the Food Additives Amendment of 1958.

It is expected that, once the guidelines are set by the Rome meeting, uniform legislation will be enacted by the several governments involved. Then there is a possibility that the true impact of irradiation may begin to be felt in the economy.

I would like to make a few general statements on the international aspects of food irradiation.

Internationalism and its cosmopolitan characteristics have become a by-word in our modern age where we are all but hours apart by jet aircraft, but minutes apart by the new manned satellites and but seconds apart by radio and television.

In this respect I would be remiss were I not to mention the role of some of these international organizations in the development of this field in bringing together, under their aegis, experts from all over the world. For example, in November, 1958, at Harwell, England, the Food and Agriculture Organization of the U.N. called the "European Meeting on the Use of Ionizing Radiations for Food Preservation". In April, 1960, it sponsored a meeting on the Microbiology of Irradiated Foods in Paris, France, and a meeting on the Wholesomeness of Irradiated Foods was held in Brussels, Belgium in October, 1961.

Panels were set up by the IAEA in 1962 on the "Irradiation Control of Harmful Organisms Transmitted by Food and Feed
Products, with Particular Reference to Salmonellae", and on "Radiation Disinfestation of Grain". In 1964 a panel was organized on the "Application of Food Irradiation in Developing Countries".

Since the formation of the Joint FAO/IAEA Division of Atomic Energy in Agriculture, these two international organizations have jointly sponsored the International Panel on the Technical Basis for Legislation on Irradiated Food (Rome, 1964); and the panel on Microbiological Specifications and Testing Methods for Irradiated Food (Vienna, 1965). This long list of useful meetings is culminated by the present meeting here in Karlsruhe.

TEXTBOOKS

One of the important items which should be considered in a review of this type is the development of the literature in the field. I have, throughout this paper, just given reference to relatively few of the important highlights. There are some other types of references that have been most helpful from a pedagogic point of view. In addition to the several review articles and chapters that have been written, there are several outstanding books of which I would like to take note and compliment the authors. I refer particularly to the excellent texts of Hannan (91), of Kuprianoff and Lang (92), of the Army Quartermaster Corps (93) and of Bednarczyk (85). To all of these authors go the thanks of all of us in the field of radiation preservation.

EQUIPMENT

Basic to all the work carried on here have been the tremendous strides in the development of equipment. I have alluded earlier to the developments of Van de Graaff, the improvements in his equipment by Trump, the developments of Charleton of the Resonant Transformer, etc. These developments in equipment deserve especial attention inasmuch as they have been basic to the success of this process. Moreover, these developments, by and large, have been carried out by private industry. In recent years, Cleland has developed the Dynamitron, and Van de Graaff has developed the Insulated Core Transformer. Both of these have made possible relatively inexpensive ionizing energy in the form of electrons and X-rays.

CONCLUSIONS

In closing may I once again emphasize and apologize for my own inadequacies in covering this vast field in so short a space. May I also once again acknowledge the debt that we in the "New World" owe to you in the "Old", the debt that discovery owes to knowledge. And may I once again point out the importance that international collaboration and cosmopolitanism has had on the development of this field. Meetings of this type breed such cosmopolitanism with its synergistic qualities and complementary effects on producing new ideas, elucidating old problems and educating a new corps of scientists in this great adventure of using the atom for the good of mankind. In this the IAEA and the FAO of the United Nations have played an important role for which they deserve the congratulations of us all.

In a true spirit of cosmopolitanism so characteristic of the present-day community of scholars in the field of food irradiation, scientists from near and far representing their governments, universities or research institutes join these international
organizations and the Federal Republic of Germany in celebrating the completion of the Institute of Food Irradiation Research. This can augur only well for the future of this institute.

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RADIATION SOURCES AND DOSIMETRY

(Session I)
HIGH-ENERGY ELECTRON AND GAMMA RADIATION PLANT — DESIGN, CONSTRUCTION AND ECONOMICS

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Abstract — Résumé — Аннотация — Resumen

HIGH-ENERGY ELECTRON AND GAMMA RADIATION PLANT — DESIGN, CONSTRUCTION AND ECONOMICS. Industrial uses of ionizing radiation are now well established; existing installations in the United Kingdom are described. The plants designed to process pre-packaged and bulk material are the most relevant to food processing. Both high-energy electrons and gamma rays are being used on an increasing scale for the sterilization of medical supplies. The relative merits of both types of plant are discussed.

The economics of operation are largely influenced by the cost of radiation, the throughput handled, the dose required, the efficiency of utilization of the radiation and the uniformity of loading throughout the year. When specific installations are being considered, attention must be given to additional costs, such as packaging of the product prior to irradiation, transport, dwell-time in the plant, and the possible need for a buffer store.


La rentabilité des opérations dépend essentiellement du coût du rayonnement, de la quantité traitée, de la dose nécessaire, du rendement de l’utilisation du rayonnement et de l’uniformité de la charge dans le temps. Lorsque l’on considère des installations particulières, on doit tenir compte des frais additionnels, tels que l’emballage du produit avant irradiation, le transport, la durée du séjour dans l’usine et la nécessité éventuelle d’un magasin de stockage pour disposer d’un volant.

ВЫСОКОЭНЕРГЕТИЧЕСКАЯ ЭЛЕКТРОННАЯ И ГАММА-ИЗЛУЧАЮЩАЯ УСТАНОВКА. ПРОБЛЕМЫ ПРОЕКТИРОВАНИЯ, СТРОИТЕЛЬСТВА И ЭКОНОМИКИ. В настоящее время хорошо разработаны вопросы использования ионизирующего излучения в промышленности; дается описание установок в Соединенном Королевстве. Установки, спроектированные для обработки предварительно упакованного и насыпного материала, являются наиболее подходящими для обработки продуктов питания. Как электроны высокой энергии, так и гамма-лучи используются в возрастающем масштабе для стерилизации медицинских запасов. Рассматривается относительное достоинство обоих видов установки.

На экономичность работы в принципе влияют стоимость излучения, количество обработанного сырья, требуемая доза, эффективность применения излучения и единообразие загрузки в течение года. Когда рассматривается конкретные установки, следует уделить внимание дополнительным расходам, таким как упаковка продуктов перед облучением, перевозка, время пребывания в установке и вероятную потребность в резервных запасах.

INSTALACIÓN DE IRRADIACION GENERADORA DE ELECTRONES DE ELEVADA ENERGÍA Y DE RAYOS GAMMA: DISEÑO, CONSTRUCCIÓN Y aspectos económicos. Las aplicaciones industriales de las radiaciones ionizantes se hallan ya firmemente establecidas; en la memoria se describen las instalaciones existentes en el Reino Unido. Las plantas destinadas a tratar productos envasados y a granel son las más interesantes desde el punto de vista de la irradiación de alimentos. Los electrones de elevada energía y los rayos gamma se utilizan cada vez más para esterilizar material sanitario. Se examinan las ventajas relativas de las plantas de uno y otro tipo.
La rentabilidad de dichas plantas depende en gran parte del costo de las radiaciones, del volumen de material tratado, de la dosis requerida, del grado de aprovechamiento de las radiaciones y de la uniformidad del volumen de trabajo durante el año. Cuando se consideran instalaciones específicas, hay que tener en cuenta los costos suplementarios, tales como los inherentes al envasado del producto antes de la irradiación, al transporte, al tiempo de permanencia en la planta y a la eventual necesidad de un almacen regalador.

There are now sufficient installations in industry using high-energy electrons and gamma radiation as a routine process to reassure potential users that earlier prejudices were unfounded. Ionizing radiation has been accepted as a process suitable for use within a factory by all parties concerned, from factory inspectors to the operatives. In the early days of the British programme on the uses of massive radiation, it was realized that no new industrial interest would be aroused until materials could be processed on a commercial scale. At the time, the quickest way of acquiring a powerful isotope source of radiation was by using the spent fuel elements from two high-flux reactors. The Spent Fuel Element Pond [1] was therefore built at Harwell, and normally runs with a total activity of about two million curies. The installation came into operation in 1958, and was used for sterilizing several medical items, chiefly plastic syringes and rubber catheters. A 4-MeV linear accelerator [2] with a 2-kW electron output was also ordered early in the Wantage programme and came into operation in 1956. It was fitted with a conveyor belt system because it was expected that routine irradiations would be carried out. Some years later the conveyor belt was removed to make room for extra beam bending equipment and a moveable irradiation table, because the machine had been used principally for very high total dose work in connection with material testing.

The Package Irradiation Plant (PIP) [3] was designed while the general pattern of its use was uncertain, and versatility was stressed at the expense of the efficiency of utilization of the gamma radiation. The general layout of the plant is shown in Fig. 1. The main features of the plant are a concrete shield, a conveyor system and a cobalt-60 source, which is currently over 300,000 Ci. The plant has been designed to accept packages of one size only (34 X 29 X 22 cm) and these are placed inside light gauge plywood boxes to achieve a close tolerance on the overall dimensions. This requirement arose from the need for a line of 12 packages to have a constant length within ± 5 mm so that the end box was correctly positioned in a lift. There are two separate circuits, having input buffer stores, which are manually loaded; once loaded, the packages are automatically handled until they reach the output store. Both conveyor systems are driven by variable-speed hydraulic motors and incorporate gear-boxes which can be changed if major changes in speed are required.

The PIP has been used to treat many foods, including potatoes, grain, fish, bacon, ham and fruit. It has also been used to inactivate Salmonellae in frozen horse meat and high-protein animal feedstuffs, both in ton quantities. The plant is normally run continuously without supervision outside normal laboratory working hours so that the input and output stores were designed to be capable of holding 3200 packages. It is now used principally for a sterilizing dose of 2.5 Mrad and is able to run unattended for five days and nights, which is very useful at holiday times.
FIG. 1. The Package Irradiation Plant at Wantage Research Laboratory
The PIP commenced regular operation in 1960, with 100,000 Ci of cobalt-60, but within a few months more cobalt was required to handle the demand. Using the PIP, several firms began to build up worthwhile markets for sterilized medical products, and it was not long before Johnson's Ethical Plastics realized that it would be advantageous to have their own installation for sterilizing plastic hypodermic syringes. The Johnson plant\[4\] is shown in Fig. 2. It was designed to give a 2½-Mrad dose to packages of less than 0.2 density. The monetary value of the packaged syringes is sufficiently low to permit a large number of them to be in circulation in the irradiation chamber as a means of obtaining a high figure for radiation utilization efficiency. The packages are moved round the source in carriers suspended from a monorail; again to improve the utilization of the radiation, each bank of carriers is made roughly twice the length and height of the source plaque.

To dose each package uniformly the carriers are designed so that a half-load can be inserted at each circuit of the conveyor. The carriers are hinged about their mid-point and are given their half-load from a flat conveyor belt by means of a hydraulic ram, as shown in Fig. 3.

The Slough plant was the first installation to be fitted with a dry store for the cobalt-60 source plaque. A dry store is cheaper both in initial cost and in upkeep because it is smaller than a water pond needs to be and avoids the circulating pumps, filters and ion exchangers which are necessary with a water store. Another advantage of the dry store is that it permits rapid loading and unloading of source rods when used in conjunction with a special transport container. The loading system is

1 Built at Slough by H. S. Marsh, Ltd., Reading.
Monorail carriers used in the Slough plant (Fig. 2). At the package transfer station, the tubular section of one carrier at a time is tilted horizontally. Four, untreated packages are pushed in and move four partially treated packages along the tube, causing four fully treated packages to be ejected.

Source frame loading system. The source transport flask is accurately located at the end of the loading tube, which is embedded in the concrete wall of the shielding cell. A long push-rod is used to move the radioactive sources from the transport flask along the loading tubes into the chosen tube in the source frame, shown in Fig. 4. The source frame embodies thin stainless-steel tubes into which the cobalt-60 rods (doubly encapsulated) are fed from a loading tube which passes through the shielding wall and continues to within a few centimetres of the source frame. It is quite usual for a supplementary load of cobalt to be added to the source frame with less than one hour's loss of production time. A dry store is recommended when there is a risk of earth tremors which might crack the walls of a water store, letting the water escape and so leaving the source without any shielding inside the cell.

The next gamma radiation plant was built in Edinburgh [5]. This plant was designed principally for sterilizing catgut sutures which, on
account of the high monetary value and bulk density, made a double layer of boxes on each side of the source more appropriate. The layout of the conveyor system is shown in Fig. 5.

The next installation arising from work at Wantage Research Laboratory was at the Birmingham factory of Smith and Nephew, Ltd. It uses a Van de Graaff machine, supplied by the High Voltage Corporation, which has an electron energy of 4 MeV and a power of 4 kW. The reason for finally choosing an electrical machine in this case may have been because the firm wanted to minimize the oxidative effect which is noticeable when unstable adhesives, and some plastics, are treated at very low dose-rates, typical of a cobalt installation. The conveyor belt is horizontal and the material to be treated is placed in trays. Apart from sterilizing medical equipment the plant is used to irradiate polyethylene slabs as part of the manufacture of polyethylene foam sheets.

Gillette Surgical, of Reading, was the next firm to build up a throughput in the PIP which was large enough to justify an installation of their own. This is shown in Fig. 6. This plant was also built by H. S. Marsh, Ltd. and bears a strong resemblance to the plant shown in Fig. 2. The amount of metal in the monorail carriers is reduced, and the size of the
source plaque increased, so that a maximum of 750,000 Ci can be accommodated.

In addition to the automatic plants so far described, a batch plant has been installed recently at the Sheffield factory of Swann Morton, Ltd., where it is used for sterilizing disposable scalpels. The source is contained in a lead shield, which is also the transport container, and the product is mounted in six frames which rotate as they move round the source.

A British-made automatic plant has recently been completed by H. S. Marsh, Ltd. for Ethicon G.m.b.H. in Hamburg. Other British-made plants are being built, including one at Wageningen, Netherlands, which is described in the paper by Dr. de Zeeuw in these Proceedings.

The Australian goat-hair irradiation plant should be mentioned because the product is handled in a different way from that in other installations. The general layout is shown in Fig. 7. A line of bales is fed into the lower, shielded corridor, and after the outer door has been closed the bales are automatically fed one by one into the irradiation chamber; processed bales (not the same ones) are conveyed into the upper, shielded corridor. The inner doors of the corridors are then closed and the outer doors opened, so that the processed bales can be removed and fresh bales fed in. This system was evolved because the large size of the bales made the design of an effective labyrinth inconveniently large and complex.

Regarding the processing of food, a great deal can be learned from gamma-radiation plants which have been designed for sterilizing medical equipment, and also from the Australian plant. There may, however,

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3 Manufactured by Vickers Armstrong, Ltd.
be many points of difference, perhaps the most important being the time which may elapse during the process. When treating pharmaceuticals, it is not inconvenient to have a buffer store of material waiting for processing, and the time taken for any one package to go through the complete process is only important if the interest on the monetary value of the material, held up in the process, becomes considerable. There are designs of gamma-radiation plants under development, which can be used for food, which minimize the dwell-time of the product in the irradiation zone.

There has not yet been sufficient experience in food processing to establish the standards of packaging which will be required. If the process is being used to inhibit mould growth, or to disinfect, it is clear that the packaging or canning must protect the processed material from further contamination. There may be some products for which an average reduction in contamination is acceptable; here it may be possible to package the material after the irradiation process. In the irradiation of potatoes to inhibit sprouting, problems of this kind do not arise, but the tubers must be protected from rough handling because of their reduced resistance to bruising.

High-energy electrons and gamma rays have been compared many times regarding their suitability for various industrial processes [6]. The principal difference between the two is in penetration power, and hence the overdose ratios which result from different thicknesses and densities of material. In Fig. 8 is shown a comparison of the penetration of 1-MeV gamma rays and electrons. For treating surfaces, and thin films, particularly in the flat and in large quantities, there is no doubt that high-energy electrons show marked superiority. In contrast, in treating large packages of dense material, gamma rays are more advantageous. It is possible to achieve deeper penetration with high-energy electrons if their energy is increased. When the Australian plant for processing bales of goat-hair was being planned, both gamma rays and 20-MeV electrons were considered. Cobalt-60 was finally chosen.
FIG. 8. Attenuation of 1-MeV electrons and 1 MeV-gamma rays in water. In practice, the gamma-ray sources are enclosed in sealed metal containers which produce enough forward scattering to eliminate the depression of the dose at the surface of the target largely on the grounds of simplicity, but also to some extent because the high energy of the electrons would have produced some radioactivation in the product.

It can be shown that the amounts of radioactivity which could possibly be induced in articles which have been sterilized by $^{60}$Co gamma rays, or electrons up to 5 MeV, or X-rays up to 5 MeV, are negligible. The sterilized material and packaging can be handled with complete safety because any dose of radiation which could possibly be received must be very small in comparison with the natural background radiation. The facts supporting this statement are as follows:

(a) The photon energy of $^{60}$Co radiation is well below the level needed to cause the emission of nuclear particles from any element. The only type of activation which need be considered, therefore, is that due to the production of metastable atoms.

(b) The yields of such reactions are low, most of the active products have short lives, and nearly all the elements concerned are comparatively rare.

(c) The rare metal, indium, which is predominant in this connection, produces per gram of element during a normal $^{60}$Co sterilization, about one-tenth of the activity naturally present in an equal weight of potassium. The indium activity falls with a half-life of 4.5 h, while that of potassium is many millions of years.

(d) Cadmium, strontium and silver follow at about 1% of the potassium level. Silver has a half-life of less than one minute, cadmium less than one hour, and strontium less than three hours.

(e) Tin and barium, the most common susceptible elements, give activities of no more than a few millionths of that of potassium—so small that they have never been detected with certainty after irradiation with $^{60}$Co.

If electrons or X-rays up to 5 MeV are used, the above general statements still apply, although the levels of radioactivity may be slightly higher.
If materials are treated with X-rays or electrons with energies up to 15 MeV, there is a greater possibility of induced radioactivity. If any of the materials became significantly radioactive, then it would be necessary to allow a storage period for the radiation levels to decay; the periods range from one hour to one day, depending on the probable concentration of indium and, to a lower degree, of other elements which are made radioactive.

The reliability of electrical machines is now of a high order, particularly in the energy range up to 4 MeV, but planned maintenance is necessary to achieve reliability, and may occupy one week every few months. Duplication of machines may be needed where continuous operation is required. Where large vacuum or pressure vessels are used, the length of time taken to outgas, or to fill with special gases, can be more than 10 h. Cooling water and air supplies also require maintenance. Isotope sources have a unique quality of certainty, because there is no possible way of preventing a radioactive isotope from emitting radiation of the characteristic energy; in consequence, the reliability of $^{60}\text{Co}$ installations is almost entirely that of the lower speed conveyor system, which requires little maintenance.

The type of source affects the monitoring arrangements, which are a vital part of most industrial processes. When using high-energy electrons, it is necessary to monitor the energy of the electrons, the total electron current, the distribution of electrons and the conveyor speed. The monitoring gear must be able to record very short duration changes because a fraction of a second's irradiation of any one spot is typical.

In an installation using a radioactive isotope source, it is only necessary to record the speed of the conveyor, and whether the source is exposed or not. A clock-driven recorder with a single pen is a simple means of achieving a record of this kind. The level of the line drawn by the pen is used to indicate the position of the source, and each time a package enters the plant the pen makes a momentary excursion. The spacing of these marks gives an obvious indication of any change in the conveyor speed, and precise measurements can be taken from the chart.

The dose-rate in an electron accelerator is usually much higher than in an isotope installation. The higher dose-rate produces a smaller oxidative effect and the time spent by the product in the plant is shorter. Ozone production tends to be higher with electrons than with gamma rays owing to the higher dose-rate to air. If the conveyor belt comes to rest for a short period, a high dose-rate can produce a fire risk, unless there are proper safeguards.

The running costs of electron sources and isotope sources are made up differently. In both cases, interest and amortization must be charged on all capital investment. The electron source itself costs very little in electrical power input, but consumable items, such as klystrons, magnetrons, rectifiers and discharge tubes, form a large part of the cost. The labour cost is higher for electron installations because more highly qualified personnel is needed. The cost of maintaining an isotope source is unaffected by the proportion of time that it is in use, whereas the costs of consumable items of an electron installation, mentioned above, are related to operating time.

One of the most attractive features of an isotope installation is that the cost does not increase greatly with the maximum curie strength of cobalt which can be accommodated. It is usual to buy a gamma radiation
FIG. 9. Comparison of the running cost per kilowatt-hour of cobalt-60 gamma rays and high-energy electrons based on 8000 h/yr operation. The electron costs are based on the cheapest available machines; this implies a maximum energy of about 3 MeV.

FIG. 10. Comparison of the cost per Megarad-ton over a range of production rates for cobalt-60 gamma rays and high-energy electrons (about 3 MeV) based on 8000 h/yr operation. Electron efficiency is assumed to be twice that of gamma rays; in some applications the efficiencies are more nearly equal.

plant with a potential throughput five times greater than that for which it will be used initially, and then to install cobalt to match the changing throughput. In contrast, the cost of a machine rises rapidly with maximum throughput, and under-running the machine results in economies only in the consumable components.

The cost of processing in both types of plant is greatly influenced by the scale of operation. Figure 9 is an attempt to compare the overall
running costs at different power ratings, and Fig. 10 shows estimates of costs at various continuous rates of throughput.

When very large throughputs are required, more than one installation may be advisable. Electron machines are offered with beam power up to 250 kW, but the beam current per unit area of the window in the accelerating tube is limited by the heating effect. Usually, more than one tube may be used with one high-voltage generator.

There is no real limit to the capacity of a single cobalt installation but since, in the megacurie range, cobalt accounts for the major cost, reasons of convenience will usually limit the source to a maximum of 1-5 M Ci per unit. Division of the throughput between two or more units gives an advantage in reliability. This is more important, and more expensive, in the case of accelerators, where the cost of a unit is approximately proportional to the square root of its power throughout the range.

REFERENCES


DISCUSSION

J. KUPRIANOFF: Do you replace your spent 60Co sources or reactivate them? Which would you say is more economical?

S. JEFFERSON: The spent 60Co source rods are replaced, not reactivated. Reactivation would not be economical. The Radiochemical Centre at Amersham gives credit for rods removed from an industrial irradiation plant when the source plaque is full, so that the user simply pays for the net increase in 60Co.

N. W. HOLM: You have said that most accelerator experiments are concerned with the irradiation of thin films, but I think it would be fair to add that linear accelerators are being quite widely used in other work closely related to food irradiation, namely the sterilization of medical supplies. Such work has been done, for instance, at Ethicon, Natick and Risø. Ethicon decided to switch to cobalt, and their choice may have been dictated in part by the fact that they were previously operating a very early type of generation equipment.

You also expressed the opinion that preventive maintenance is of prime importance. It is our experience, however, that preventive maintenance of the kind you describe is unnecessary, since failures are generally due to a breakdown of components that can be repaired quickly by an experienced crew. Perhaps you would like to comment on these two points.
S. JEFFERSON: First let me thank you for reminding us that accelerators are being used for sterilization. To put the situation in perspective, however, I should point out that far more kilowatt-hours have been devoted to the thin-film work.

As to your second point, I can only say that preventive maintenance is recommended by some manufacturers of electron accelerating machines and is likely to be preferred by industrial users who may not be able to have an expert crew standing by at all times.

N.W. HOLM: Finally, perhaps you could either confirm or deny a rumour that has been going the rounds on the Continent, namely, that you are considering purchasing a linear accelerator of British make?

S. JEFFERSON: We did in fact order a 15-MeV 5-kW linear accelerator from Vickers Armstrong (South Marston) not long ago, which is to be used mainly for high-dose-rate investigations and pulse radiolysis. Our present machine is nine years old and we are running out of suitable magnetrons to energize it. We are not planning to use the new accelerator for sterilizing medical supplies, a process that would be inordinately expensive.
REVIEW OF THE $^{60}$Co SOURCE DEVELOPMENT PROGRAM AT BROOKHAVEN NATIONAL LABORATORY *

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Abstract — Résumé — Аннотация — Resumen

REVIEW OF THE $^{60}$Co SOURCE DEVELOPMENT PROGRAM AT BROOKHAVEN NATIONAL LABORATORY.

Early in the 1950's, at the request of the United States Atomic Energy Commission, Brookhaven National Laboratory (BNL) undertook the development of radiation sources. These sources were mainly of two types: large tubes, and flat strips. Initially these were used for research at BNL. Later, other institutions were permitted to use the irradiation facilities designed for these sources. As interest grew, source-irradiator combinations were made available to other researchers. Shipping containers for sources were developed. Small hot cells and water-filled pools were constructed to utilize the sources. Methods of dosimetry, curie evaluation, and irradiator design for these sources are discussed in this paper.

During the research stages, economics were not usually important; however, the trend toward large-scale radiation processing in the field of food, chemicals and medical supplies will require careful consideration of the technical and economic aspects of source design.

The development of the BNL Standard Mark I and Mark II Sources, already in use in a number of facilities, is to satisfy these important requirements.

The Mark I and Mark II sources are interchangeable. An improvement in the Mark II element design is that the inner cladding is metallurgically bonded to the cobalt core. It is now possible, for the first time, to reactivate these source elements after a period of use. Individual strips are sized for easy arrangement in plaques of various dimensions and shapes.

The design philosophy, fabrication techniques, and test procedures, together with source analysis and curie evaluation, are described. Comparisons are made with other source types currently in use and economical and technical advantages are discussed.

LE PROGRAMME DE MISE AU POINT DES SOURCES AU $^{60}$Co AU LABORATOIRE NATIONAL DE BROOKHAVEN. A la demande de la Commission de l'énergie atomique des Etats-Unis, le Laboratoire national de Brookhaven a entrepris dès les années 50 la mise au point de sources de rayonnement. Ces sources étaient principalement de deux types: tubes de grande dimension et bandes plates. Elles ont été utilisées tout d'abord pour des recherches au Laboratoire national de Brookhaven. Plus tard, d'autres centres ont été autorisés à utiliser les installations d'irradiation prévues pour ces sources. A mesure que l'intérêt grandissait, des ensembles sources-irradiator ont été mis à la disposition d'autres chercheurs. Des châteaux pour l'expédition des sources ont été mis au point. De petites cellules chaudes et des piscines d'eau ont été construites pour utiliser les sources. L'auteur décrit les méthodes dosimétriques, la mesure de l'activité et les caractéristiques des irradiateurs pour ces sources.

La rentabilité était en général sans importance au stade de la recherche; toutefois, du fait que l'on envisageait d'utiliser des sources de rayonnement de grande dimension pour le traitement des produits alimentaires, des produits chimiques et des fournitures médicales, il fallait étudier de près les aspects techniques et économiques de la conception des sources.

La mise au point des sources universelles des types I et II du Laboratoire national de Brookhaven, déjà utilisées dans plusieurs installations, doit permettre de répondre à ces impératifs. Les sources I et II sont interchangeables. La conception de la source II est améliorée en ce sens que la gaine intérieure est métallurgiquement liée à l'âme de cobalt. Il est maintenant possible, pour la première fois, de réactiver les sources après une certaine période d'utilisation. Les sources en bandes ont des dimensions permettant d'en faire aisément des plaques de tailles et formes diverses.

L'auteur décrit les principes de conception, les méthodes de fabrication et les méthodes d'essai ainsi que l'analyse des sources et l'évaluation de leur activité. Il les compare avec d'autres types de sources actuellement utilisés et discute les avantages économiques et techniques respectifs.

* This work was performed under the auspices of the United States Atomic Energy Commission.
ОБЗОР ПРОГРАММЫ ПО РАЗРАБОТКЕ ИСТОЧНИКОВ 60Co В БРУКХЕЙВЕНСКОЙ НАЦИОНАЛЬНОЙ ЛАБОРАТОРИИ. В начале 50-х годов по просьбе Комиссии по атомной энергии США Брукхейвенская национальная лаборатория (БНЛ) приступила к разработке источников излучений. Эти источники были в основном большие трубки и плоские пластинки. Первоначально они предназначались для исследований в БНЛ. Позднее другие учреждения получили разрешение использовать облучатели, предназначенные для этих источников. По мере повышения интереса комбинированные установки, включающие источник и облучатель, предъявились другим исследователям. Были разработаны контейнеры для транспортировки источников и сконструированы небольшие "горячие" камеры и наполненные водой бассейны для использования этих источников. Обсуждаются методы дозиметрии, определение радиоактивности в кюри и конструкция облучателя для этих источников.

В большинстве случаев во время проведения исследований экономические аспекты не имели значения; однако в связи с тенденцией к крупномасштабной радиационной обработке в областях пищевых продуктов, химикатов и медицинских материалов необходимо будет тщательно изучить технические и экономические аспекты конструкции источника.

Разработка стандартных источников Брукхейвенской национальной лаборатории "Марк I" и "Марк II", которые уже используются в ряде установок, призвана удовлетворить этим важным требованиям.

Источники "Марк I" и "Марк II" взаимозаменяемы. Конструкция источника "Марк II" улучшена за счет металлургического соединения внутренней оболочки с кобальтовым сердечником. В настоящее время впервые можно повторно активировать эти источники после некоторого использования. Отдельные полосы доводятся до требуемых размеров с тем, чтобы их можно было легко прикрепить к пластинкам различного размера и формы.

Описываются теоретическое обоснование конструкции, методы изготовления и процедуры испытания, а также анализ источника и определение радиоактивности в кюри. Производятся сравнения с другими видами источников, которые используются в настоящее время, и обсуждаются экономические и технические преимущества.

EL PROGRAMA DE PREPARACION DE FUENTES DE 60Co DEL LABORATORIO NACIONAL DE BROOKHAVEN. A petición de la Comisión de Energía Atómica de los Estados Unidos, el Laboratorio Nacional de Brookhaven (BNL) emprendió la preparación de fuentes de radiación a principios de los años cincuenta. Estas fuentes son principalmente de dos tipos: tubos de gran diámetro y bandas aplanadas. Comenzaron utilizándose para los trabajos de investigación del BNL; más adelante se autorizó a otras instituciones a emplear las instalaciones de irradiación diseñadas para esas fuentes. A medida que aumentó el interés por ellas, se fueron proporcionando a otros investigadores juntamente con sus dispositivos de irradiación. Se idearon recipientes para transportarlas y se construyeron pequeñas celdas calientes y piscinas para utilizarlas. En la memoria se examinan los métodos de dosimetría, de cálculo de la dosis en curies y de diseño del dispositivo de irradiación para estas fuentes.

Durante los estudios se prescindió de los aspectos económicos; sin embargo, la tendencia hacia la irradiación en gran escala de alimentos, productos químicos y material sanitario exigirá un examen cuidadoso de los aspectos técnicos y económicos del diseño de las fuentes.

El BNL ha preparado las fuentes tipo Mark I y Mark II, ya en servicio en buen número de instalaciones, para responder a estos importantes requisitos. Las fuentes Mark I y Mark II son intercambiables. El diseño de los elementos de la fuente Mark II presenta la ventaja de que el revestimiento interior va metalúrgicamente unido al alma de cobalto. Así es posible, por primera vez, reactivar estos elementos después de utilizarlos durante cierto tiempo. Las bandas se fabrican en tamaños que permiten montarlas fácilmente formando placas de varias formas y dimensiones.

El autor describe los principios seguidos en el diseño, las técnicas de fabricación, los procedimientos de ensayo, el análisis de las fuentes y la evaluación de la dosis en curies. Hace comparaciones con otros tipos de fuentes en servicio y examina sus ventajas económicas y técnicas.

Early in the 1950's, when the United States Atomic Energy Commission requested Brookhaven National Laboratory to undertake the development and use of radiation sources, there was a dearth of information pertaining to source and irradiator design, and to high level dosimetry techniques. Today, although a tremendous amount of information has been developed at Brookhaven and other institutions, there is still much to learn in these areas.
The original purpose of Brookhaven's commission was to create an interest in the use of radiation by designing and fabricating an interim source and simple irradiator device which could be used by scientists to develop possible radiation applications. Eventually, if widespread interest and utilization were achieved, it was planned to package, in some suitable form, the waste residue from the processing of spent fuel elements. It became apparent, rather early in the program, that this type of source would not be acceptable because of the spread of energies and half-lives present, as well as the mixture of types of radiation. However, it should be mentioned here that a more practical approach has been taken, that of the extraction from the waste of potentially useful isotopes, such as $^{137}$Cs, $^{90}$Sr, etc. Cobalt-60, a reactor-produced isotope, seemed to be an acceptable radiation source, from the standpoint both of half-life, 5.27 yr, and radiation type, gamma-emitter of energies 1.17 and 1.33 MeV. Most of the work at Brookhaven to date has been done with $^{60}$Co.

The first kilocurie cobalt sources produced were irradiated in the Brookhaven Graphite Reactor. They were tubular in shape (Fig. 1), about 13.5 in. long, 2.25 in. o.d. and 1.75 in. i.d., after encapsulation. The tubular sections of cobalt were placed between two concentric tubes of 2S aluminium and the ends heliarc welded. Corrosion of the aluminium presented a problem; therefore, the encapsulation material was changed to type-304 stainless steel. The cobalt tubes were originally 1/4 in. wall thickness with an i.d. of ~1.85 in. and a length of 13 in., and contained about 2500 to 2600 g. Reactor experiments indicated a flux depression of ~80%, and subsequently the cobalt tubes were decreased in wall thickness to 1/16 in., which halved the flux depression and decreased the total cobalt content in a source to about 850 g. Sources of this type were activated to specific activities ranging from 0.25 to 3.5 Ci/g. A container was designed to serve as a shipping cask and as the irradiator device. Samples could be exposed to an irradiation field by placing them in a canister attached to a plug and then lowering this assembly into the container, as shown in Fig. 2. Radiation flux at the geometric centre of the source was established as 200,000 rad/h for each 500 Ci of activity.

Dosimetry methods available in the early 1950's for high-level dosimetry were inaccurate. The calibrated air chambers used had a limited dose range which necessitated a very short exposure time. This, combined with the time required to get the dosimeter into and out of the radiation field, led to inaccurate results. Use of X-ray film was also attempted and found inadequate for practically the same reasons cited above. Although it had been known for some time that an aqueous solution of ferrous ions will oxidize to ferric ions when exposed to ionizing radiations [1, 2], it was not until this system was analyzed by Weiss [3] and others, and standardized, that it came into common use as a method of gamma dosimetry. This dosimeter then became the standard for all our gamma flux measurements. A dose-rate ion chamber was also developed at Brookhaven [4] and calibrated against the Fricke dosimeter. It served as a useful device in plotting the gamma fields in the tubular sources and later in underwater source arrays.

As interest grew throughout the country, about forty of these simple irradiators were made available to other institutions. The need to expose larger volumes and for better controlled experiments led to the design
and building of a pool-type facility (Fig. 3), and further development of source design. Large, flat $^{60}$Co sources were made (Fig. 4) and irradiated in the Brookhaven reactor. These sources contained 225 g of cobalt, were $13\frac{1}{2}$ in. by $1\frac{1}{2}$ in. by 0.040 in. in size, and when encapsulated in stainless steel, $13\frac{3}{4}$ in. by 2 in. by $\frac{3}{4}$ in. in size. Containers were designed to use these sources. A typical one was that used in the US Department of Agriculture’s Screwworm Fly Eradication Program (Fig. 5). These sources, containing up to 1000 Ci, have also been used for the US Atoms for Peace Exhibit in a simple, pool-type facility, the first of which was designed and built at Brookhaven (Fig. 6). This facility has been used in many places throughout the world and, most recently, in March 1966, in Utrecht, The Netherlands.

During the early research stages economics was not an important factor, because the amounts of activity used were small and the irradiation facilities relatively simple and inexpensive. If, however, the radiation applications developed by research are to reach fruition as industrial processes, industry must be presented with an attractive economic picture. Initial investment, combined with overall operational costs, will determine the economic feasibility of any application. The original, as well as the replacement costs, of the $^{60}$Co required, which may range from a few hundred thousand to megacurie amounts, will be an important financial consideration. The BNL Mark I and Mark II Standard cobalt sources were developed in an attempt to minimize costs in this area.

The Mark I source [5] is a 65-g strip of cobalt encapsulated in a 316L stainless-steel envelope. Four of these are contained in an irradiation slug (Fig. 7) and activated in a Savannah River Plant Reactor. After activation the elements are removed from the slug and a second encapsu-
Fig. 2. Tubular source container

Radiation is applied. The final dimensions are 13 in. by 0.150 in. by 0.80 in. These sources, assembled into radiation plaques, are used in the High Intensity Radiation Development Laboratory at Brookhaven (Fig. 8), the Marine Products Development Irradiator at Gloucester, Mass., research irradiators located at six universities (Fig. 9), the Bulk Grain Irradiator and the Mobile Gamma Irradiator, and will be used in the US Army.
FIG. 3. Brookhaven pool facility

Quartermaster's Food Irradiator at Natick, Mass. Specific activities of sources currently in use range from 10 Ci/g to 125 Ci/g.

Economic advantages which are obtained by the use of this type of source are:

(a) fabrication and testing methods are standardized and can be set up for good quality and quantity production at minimum costs;

(b) since these sources can be used in a wide variety of irradiators without modification, they do not become obsolete and, therefore, have a longer useful life. For example, users requiring higher specific activities can, after a period of time, realize a return from replaced sources that can be re-used in facilities requiring lower specific activities;

(c) the self-absorption of these sources is about 7%, as compared with other source designs having up to 30%. Self-heating is minimized and a higher utilization efficiency is obtained. To illustrate this point, assume that an application requires 500,000 Ci to satisfy production requirements. If the source absorbs 10% of the available energy it would be necessary to start with 550,000 Ci; if, however, the source absorbed 30% of the available energy it would be necessary to employ 650,000 Ci, or about 100,000 additional curies; and
(d) the thin, rectangular design, as compared with some tubular and rod geometries, will provide a greater radiation flux per curie in the useful areas, i.e. in front of a plaque source, where material is being exposed.

The Mark II BNL Standard cobalt source [6] is an improved Mark I source. The first encapsulation of 316L stainless steel is metallurgically bonded to the cobalt (Fig. 10). Dimensionally, it is about the same size as the Mark I element and is interchangeable with it. The cobalt content is 52 g, and the stainless-steel thickness is 15 mil on all sides. A further modification of this source will increase the cobalt content to 70 g by decreasing the stainless-steel cladding thickness to 10 mil. The source is produced by hot co-extrusion in 14-ft lengths which are cut to the specified 12 1/2 in. length. The ends are then chemically milled, after which a 1/8 in. end piece is inserted and welded. A second encapsulation, having the same square-edged rectangular shape and fitting, within a few mils, all the outside dimensions of the element with the exception of the length, is applied after the element has been activated in a Savannah River Plant Reactor. This hot-cell work has been performed in the High Intensity Radiation Development Laboratory facilities at Brookhaven (Fig. 11). Equipment has been designed to remotely weld 15 to 20 of either type source simultaneously (Fig. 12). After welding, each unit is leak-tested by immersion in liquid nitrogen, followed by insertion in warm water. Observation for leaks is through a cell window or a magnifying
periscope. This method was found to be more reliable than others. Source elements used at Brookhaven contain from 4000 to 8000 Ci; future bonded sources may exceed 10,000 Ci per element. Another leak testing method is with a specially designed pressure chamber, incorporating a pneumatic cylinder which permits quick movement of the sources, pressurized to 80 to 100 lb/in² to a warm-water tank. Lack of air bubbling from the welded ends of the sources indicates that an effective encapsulation has been made.

All the advantages cited for the Mark I source also apply to the Mark II source. Additional advantages accruing for the Mark II unit are:

(a) better heat transfer is obtained, since in the first encapsulation there are no air voids and in the second encapsulation containment voids are at a minimum;

(b) the overall integrity of the encapsulation is increased by having the cladding bonded to the cobalt;

(c) less self-absorption can be achieved as encapsulation thicknesses can be safely decreased;
FIG. 6. Foreign exhibit irradiator
FIG. 7. Mark I standard source

FIG. 8. HIRDL plaque
(d) better neutron economy is effected as a minimum of unusable material is irradiated with the cobalt. Sources are not placed into an activation slug, as in the case of the Mark I, but are irradiated, without further canning, in a simple holder (Fig. 13);

(e) less hot-cell time is required. The elements do not have to be removed from the aluminium can, but are easily recovered from the holder by cutting two wires which secure the hold-down device;

(f) sources of this type can be re-irradiated after periods of use by removal of the second encapsulation, placing them in the activation holder, and re-inserting them into the reactor.

The cost of these strips, ready for insertion in the reactor, is \$56 each. This price is high, of course, since the process required
some development. The fabricator, Nuclear Metals, Inc., has indicated that this price will decrease on future production runs by $\sim 50\%$.

The concern of the Radiation Division at Brookhaven is to develop information relative to the use of high-level sources in various irradiator...
FIG. 13. Mark II source in activation holder

FIG. 14. Assay unit - cutaway
The ability to conduct the work requires accurate determination of the curies used in an irradiator and the use of reliable dosimetry systems. Every source element used is analyzed for its curie content and activity distribution to arrange the source elements intelligently in irradiation plaques of various sizes. Curie contents of all sources are based on standardizing one of the source elements by determining its curie content calorimetrically [8], and measuring curies established against it in an assaying unit designed and constructed at Brookhaven [9]. This device is remotely operated (Fig. 14). A motor-driven source conveyor moves the source into a lead cask and under a collimating tube above which the sensing element, an 'n' on 'p' silicon solar cell (Fig. 15) is mounted. The output is fed to amplifying and integrating circuits, then to a recorder. In the forward motion the activity distribution is recorded on a strip chart (Fig. 16); in the reverse direction the solar cell-output is integrated and the total activity is indicated on the recorder (Fig. 17). Each source strip bears an identification number on its encapsulation. The results and date of the assay are recorded for each source. With this record various source plaques, ranging from several hundred thousand curies to megacuries, can be assembled and used experimentally in the HIRDL facility.

The objectives of the dosimetry program at Brookhaven are directed toward evaluation and improvement of existing methods, and the develop-
ment of promising, new systems. The systems are evaluated as to both their application to the source development program, as indicated by the assay device, and measurement of absorbed dose in various target materials useful in the radiation processing field. Because most of the
### TABLE I. SUMMARY OF DOSIMETRY SYSTEMS

<table>
<thead>
<tr>
<th>Dosimeter</th>
<th>Type</th>
<th>Range</th>
<th>Applications and Limitations</th>
<th>Ref.</th>
<th>Radiation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Standard Fricke</td>
<td>Integrating</td>
<td>$1 \times 10^4$ to $4 \times 10^4$ rad gamma dose</td>
<td>Accepted standard for gamma dose exposure dose measurement absorbed dose measurements in any medium</td>
<td>[10]</td>
<td>Gamma and charged particle</td>
</tr>
<tr>
<td>De-aerated Fricke</td>
<td>Integrating</td>
<td>up to $9 \times 10^5$ rad gamma dose</td>
<td>Exposure dose measurements absorbed dose measurements in any medium</td>
<td>[11]</td>
<td>Gamma and charged particle</td>
</tr>
<tr>
<td>Ferrous-cupric</td>
<td>Integrating</td>
<td>up to $9 \times 10^5$ rad gamma dose</td>
<td>Exposure dose measurements absorbed dose measurements in any medium</td>
<td>[12]</td>
<td>Gamma rays and charged particles</td>
</tr>
<tr>
<td>Ultraviolet Transmitting</td>
<td>Integrating</td>
<td>$10^4$ to $3 \times 10^6$ rad gamma dose</td>
<td>Exposure dose measurements absorbed dose measurements in any medium</td>
<td>[13,14]</td>
<td>Gamma rays and charged particles</td>
</tr>
<tr>
<td>(UVT) Lucite</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Blue Cellophane Dye</td>
<td>Integrating</td>
<td>$1 \times 10^4$ to $6 \times 10^6$ rad gamma dose</td>
<td>Exposure dose measurements absorbed dose measurements in any medium</td>
<td>[15]</td>
<td>Gamma rays and charged particles</td>
</tr>
<tr>
<td>Dosimeter</td>
<td>Dose-Rate</td>
<td>up to $10^4$ R/h gamma rays</td>
<td>Exposure dose measurements absorbed dose measurements in any medium</td>
<td>[16]</td>
<td>Gamma rays</td>
</tr>
<tr>
<td>Dosimeter</td>
<td>Type</td>
<td>Range</td>
<td>Applications and Limitations</td>
<td>Ref.</td>
<td>Radiation</td>
</tr>
<tr>
<td>--------------------</td>
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</tr>
<tr>
<td>Victorin Condenser</td>
<td>Integrating</td>
<td>up to 250 R</td>
<td>(1) Calibration standards</td>
<td></td>
<td>Gamma rays</td>
</tr>
<tr>
<td>Ionization Chambers</td>
<td></td>
<td>gamma rays</td>
<td>(2) Exposure dose measurements</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>(3) Absorbed dose measurements in any medium</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Victorin Roentgen</td>
<td>Dose-Rate</td>
<td>up to $5 \times 10^4$</td>
<td>(1) Exposure dose measurements</td>
<td>[17]</td>
<td>Gamma rays</td>
</tr>
<tr>
<td>Rate-Meter</td>
<td></td>
<td>R/min gamma dose</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Anthracene Scintillator</td>
<td>Dose-Rate</td>
<td>0.1 to 1 R/h</td>
<td>(1) Exposure dose measurements</td>
<td>None</td>
<td>Gamma rays</td>
</tr>
<tr>
<td></td>
<td></td>
<td>gamma dose</td>
<td>(2) Absorbed dose measurements in any medium</td>
<td></td>
<td></td>
</tr>
<tr>
<td>'n' on 'p' solar cell</td>
<td>Dose-Rate</td>
<td>up to $10^3$ R/h</td>
<td>(1) Exposure dose measurements</td>
<td>[18]</td>
<td>Gamma rays</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Gamma dose</td>
<td>(2) Absorbed dose measurements in density 2.0 g/cm$^3$ material only</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>(3) Area monitoring</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>(4) Source comparisons</td>
<td></td>
<td></td>
</tr>
<tr>
<td>'p' on 'n' solar cell</td>
<td>Integrating</td>
<td>$10^4$ to $10^5$ R/h</td>
<td>(1) Exposure dose measurements</td>
<td>[19]</td>
<td>Gamma rays</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>(2) Area monitoring can be used above 200 keV only</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
target materials used in these processes are of low density and atomic number, dosimeters, which resemble these materials, have been of great interest. Some of the dosimetry systems which satisfy these requirements are: the Fricke dosimeter, used as a standard; the Ultraviolet Transmitting Lucite (UVT); the Blue Cellophane Dye dosimeter; the Thimble Ionization Chamber; Victoreen Ionization Chambers and the Anthracene Scintillation Dose-Rate Meter. Two types of silicon solar cell dosimeters have been developed — the 'n' on 'p' dose-rate meter, and the 'p' on 'n' integrating dosimeter. These have had a wide range of usefulness in the laboratory for applications of exposure dose measurements and absorbed dose measurements in density two material. The integrating solar cell has been used for estimating the total dose to which various cell components have been exposed to assess radiation damage.

Table I summarizes some of the characteristics of these dosimeters and, where possible, cites references.

The source development program at Brookhaven National Laboratory will continue. The philosophy of optimizing the utilization and minimizing the overall source costs, as applied to $^{60}$Co, will be expanded to include other potentially useful isotopes, such as $^{137}$Cs, $^{90}$Sr and others. Obviously, dosimetry of all types, as applied to source calibration and measurement, as well as dose distributions in materials, will also be of major interest in our development program.

REFERENCES:


DISCUSSION

B. RAJEWSKY: What is the maximum dose rate you can attain, and what do you estimate the cost of 1 Mrad to be?

O. A. KUHL: In our present system the dose rate at the centre of a 6 in.-thick unit-density package is about $6 \times 10^6$ rad/h from an 865 000 Ci source. The cost of 1 Mrad naturally depends on the type of material being irradiated, but it should normally lie between 1 and 1½ cents per Mrad/lb.
MACHINE SOURCES IN FOOD IRRADIATION

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Abstract — Résumé — Аннотация — Resumen

MACHINE SOURCES IN FOOD IRRADIATION. Machine sources, in contrast to radioactive sources, are X-ray generators and electron generators (Van de Graaff generator or linear accelerator).

It is possible to compare all these radiation sources, giving their power in watts and their capacity in Mrad x kg/h. The capacity is

\[ L \ [\text{Mrad} \times \text{kg/h}] = 0.36 \times \eta \times P \ [\text{Watt}] \]

Conversely, for a given capacity, the needed output of a radiation source can be calculated by this equation.

For comparison with radioactive sources, 1000 Ci \(^{60}\)Co = 14.8 W and 1000 Ci \(^{133}\)Cs = 3.6 W.

For machine sources the efficiency of beam utilization depends on the thickness of the samples, the radiation geometry and the utilization factor of the conveyor for the samples.

In contrast to radioactive sources continuity of utilization is not an important factor.

Soft X-ray generators are used especially for research, although either their penetration depth, or their dose-rate, is small. It is a great advantage, however, that the dose-rate can be changed in a ratio of about 1:2000 by changing the beam current and the distance. In addition, the dose distribution in samples can be adapted to a given shape by using filters, in particular by using slitted rotating filters.

High beam X-ray generators have an anode with a large area, or a rotating anode. Notwithstanding the use of hard filters, a beam power of up to 40 W can be reached. As these plants provide for irradiation of larger quantities, or bigger samples, special attention must be given to the problem of homogeneity of dose distribution. This can be done as follows: the samples are moved several times through the beam, or sample containers with high back-scattering are used. It is also possible to arrange some anodes opposite so that irradiation is given from all sides. The dose-rate can be altered by changing the beam current in a ratio of 1:2, and much more by changing the speed of the sample conveyor.

Compared with X-ray generators, electron generators have a much higher capacity. With Van de Graaff generators, values up to 1.5 kW have been reached, and with linear accelerators up to 18 kW.

Contrary to X-ray generators, the aperture angle is changed when the beam enters the air. Therefore, the dose distribution in the samples depends on the distance between the samples and the window of the unit. By scanning the beam and moving the samples, the irradiation area can be enlarged. To obtain minimal inhomogeneity, some discrete velocities of the conveyor have to be used, which depend on the beam diameter and the scanning frequency. With linear accelerators there are additional difficulties arising from pulsing of the beam. But in this case it is also possible to calculate the discrete velocities of the conveyor, which result in equal dose distribution in the moving direction of the beam and the moving direction of the samples.

The dose-rate is a special problem for biological systems, with their dependence of the radiation effect on the dose-rate. It has to be distinguished between mean dose-rate and the instantaneous dose-rate, which can be essentially higher.

The mean dose-rate can be altered in a ratio of 1:10^6 by changing the beam current, the scanning amplitude and the speed of the conveyor.

The total efficiency and the efficiency of beam utilization of some operating generators is described. In some cases it compares favourably with that of X-ray generators so that irradiation is economically feasible.

IRRADIATION DE PRODUITS ALIMENTAIRES AVEC DES RADIOGENERATEURS. On peut appeler radiogénérateurs, par opposition aux sources radioactives, les générateurs de rayons X et les générateurs d'électrons (générateur Van de Graaff ou accélérateur linéaire).
On peut comparer toutes ces sources de rayonnement d'après leur puissance en watts et leur capacité en Mrad·kg/h. La capacité s'obtient en appliquant la formule suivante:

$$L = 0.36 \cdot T \cdot P$$

Cette formule permet également, connaissant la capacité demandée, de calculer la puissance correspondante.

Les deux équivalences suivantes permettent de comparer les radiogénérateurs et les sources radioactives:

1000 Ci $^{60}$Co = 14.8 W et 1000 Ci $^{137}$Cs = 3.6 W.

Pour les radiogénérateurs, le rendement du faisceau dépend de l'épaisseur des échantillons, de la géométrie du rayonnement et du facteur d'utilisation du passeur d'échantillons.

Contrairement aux sources radioactives, les radiogénérateurs n'exigent pas une utilisation continue.

Les générateurs de rayons X mous sont utilisés spécialement pour la recherche, mais leur pénétration ou leur débit de dose sont faibles. Toutefois, il est très avantageux que ce débit de dose puisse être modifié dans un rapport de 1:2000 en changeant l'intensité du faisceau et la distance. En outre, la distribution de dose dans les échantillons peut être adaptée à une forme donnée à l'aide de filtres, notamment de filtres rotatifs à fentes.

Les générateurs de rayons X à faisceau intense ont une anode de grande surface ou une anode tournante. Même si l'on utilise des filtres durs, on peut atteindre une puissance de 49 W. Comme ces installations sont prévues pour l'irradiation de grandes quantités ou d'échantillons de grandes dimensions, il faut veiller spécialement à assurer une distribution homogène de la dose. On peut y parvenir de la manière suivante: les échantillons sont passés plusieurs fois dans le faisceau, ou bien on utilise des porte-échantillons ayant un pouvoir de rétrodiffusion élevé. On peut également placer des anodes du côté opposé, l'échantillon recevant ainsi une irradiation sur plusieurs faces à la fois. On peut modifier le débit de dose en modifiant l'intensité du faisceau dans un rapport de 1:13, et encore plus en changeant la vitesse du passeur d'échantillons.

Les radiogénérateurs ont une capacité beaucoup plus élevée que les radiogénérateurs de rayons X.

Les générateurs Van de Graaff ont des valeurs de 1,5 kW et avec des accélérateurs linéaires on atteint 18 kW.

À ce qui se passe pour les générateurs de rayons X, l'angle d'ouverture du faisceau se modifie lorsque celui-ci pénètre dans l'air. Par conséquent, la distribution de la dose dans les échantillons dépend de la distance entre ces échantillons et la fenêtre de l'appareil. En balayant avec le faisceau dans le faisceau et en déplaçant les échantillons, on peut augmenter la surface irradiée. Pour réduire le plus possible des inhomogénéités, il faut utiliser différentes vitesses du convoyeur selon le diamètre du faisceau et la fréquence du balayage. Avec des accélérateurs linéaires, on rencontre des difficultés supplémentaires provenant de la pulsation du faisceau. Mais dans ce cas il est possible de calculer diverses vitesses du convoyeur qui donnent une distribution de dose égale dans la direction du déplacement du faisceau et dans celle du déplacement des échantillons.

Le débit de dose pose un problème spécial quand il s'agit de systèmes biologiques, puisque l'effet du rayonnement sur eux dépend du débit de dose. Aussi faut-il distinguer entre le débit de dose moyen et le débit de dose instantané, lequel peut être beaucoup plus élevé.

Le débit de dose moyen dans la proportion de 1:10$^5$ en modifiant l'intensité du faisceau, l'amplitude du balayage et la vitesse du passeur d'échantillons.

L'auteur expose le rendement total et le rendement du faisceau de certains des générateurs utilisés. Dans certains cas, il se compare favorablement à celui des générateurs de rayons X, si bien que l'irradiation est rentable.

**АППАРАТУРА ДЛЯ ОБЛУЧЕНИЯ ПИЩЕВЫХ ПРОДУКТОВ.** Излучающей аппаратурой в противоположность радиоактивным источникам являются рентгеновские установки и электронные ускорители (ускоритель Ван-де-Граафа или линейный ускоритель).

Можно сравнить все эти радиационные источники, выражая их мощность в ваттах, а интенсивность — в мегарадах-kg/час. Интенсивность равняется:

$$L = 0,36 \cdot \eta \cdot P$$

Напротив, в зависимости от требуемой интенсивности необходимый выход радиационного источника может быть вычислен с помощью этого уравнения.

Для сравнения с радиоактивными источниками: 1000 кюри кобальта-60 = 14,8 вт и 1000 кюри цезия-137 = 3,6 вт.

Для излучающей аппаратуры эффективность использования луча зависит от толщины образца, радиационной геометрии и коэффициента использования конвейера для образцов.

В отличие от радиоактивных источников продолжительность использования не является важным фактором.
Рентгеновские установки с мягким излучением используются в основном для исследований, хотя как глубина их проникновения, так и мощность дозы являются незначительными. Однако большое преимущество в том, что мощность дозы может изменяться в соотношении порядка $1:2000$ путем изменения тока луча и расстояния. Кроме того, распределение дозы в образцах может быть изменено путем использования фильтров, особенно щелевых вращающихся фильтров.

Рентгеновские установки с интенсивным пучком имеют анод с большой площадью или вращающийся анод. Несмотря на использование твердых фильтров можно получить мощность луча до 40 кВт. Поскольку эти установки предназначены для облучения больших объемов или крупных образцов, необходимо обратить особое внимание на проблему гомогенности распределения дозы. Это можно осуществить путем изменения: образцы перемешиваются через пучок, или используются контейнеры для образцов с высокими обратными рассеянием. Зеленый анод также обладает некоторыми особенностями, с тем чтобы облучение было более равномерным.

Мощность дозы может меняться путем изменения тока луча в соотношении 1:3 и в гораздо большей степени — путем изменения скорости конвейера для образцов.

Сравнивая с рентгеновскими установками, электронные генераторы имеют гораздо более высокую мощность. С помощью ускорителей Ван-де-Граафа была получена мощность до 1,5 кВт, а с помощью линейных ускорителей — до 18 кВт.

В противоположность рентгеновским установкам, интенсивный пучок имеет анод с большой площадью или вращающийся анод. Несмотря на использование твердых фильтров можно получить мощность пучка до 40 кВт. Поскольку эти установки предназначены для облучения больших объемов или крупных образцов, необходимо обратить особое внимание на проблему гомогенности распределения дозы. Это можно осуществить путем изменения: образцы перемешиваются через пучок, или используются контейнеры для образцов с высоким обратным рассеянием. Зеленый анод также обладает некоторыми особенностями, с тем чтобы облучение было более равномерным.

Мощность дозы представляет собой специальную проблему для биологических систем с их зависимостью радиационного эффекта от мощности дозы. Следует делать различие между средней мощностью дозы и мгновенной мощностью дозы, которая может быть значительно выше.

Средняя мощность дозы может изменяться в соотношении $1:10^6$ путем изменения тока луча, амплитуды и скорости конвейера. Дается описание общей эффективности и эффективности использования пучка в некоторых рабочих генераторах. В некоторых случаях, эта эффективность может быть значительно выше от эффективности рентгеновских установок, что облучение является практически осуществимым с экономической точки зрения.

АПАРАТОВ ДЛЯ ИЗУЧЕНИЯ БИОЛОГИЧЕСКИХ СИСТЕМ. Как правило, установки для изучения биологических систем используют в основном для изучения, хотя как глубина их проникновения, так и мощность дозы являются незначительными. Однако большое преимущество в том, что мощность дозы может изменяться в соотношении порядка $1:2000$ путем изменения тока луча и расстояния. Кроме того, распределение дозы в образцах может быть изменено путем использования фильтров, особенно щелевых вращающихся фильтров.

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Мощность дозы представляет собой специальную проблему для биологических систем с их зависимостью радиационного эффекта от мощности дозы. Следует делать различие между средней мощностью дозы и мгновенной мощностью дозы, которая может быть значительно выше.

Средняя мощность дозы может изменяться в соотношении $1:10^6$ путем изменения тока луча, амплитуды и скорости конвейера. Дается описание общей эффективности и эффективности использования пучка в некоторых рабочих генераторах. В некоторых случаях, эта эффективность может быть значительно выше от эффективности рентгеновских установок, что облучение является практически осуществимым с экономической точки зрения.

АПАРАТОВ ДЛЯ ИЗУЧЕНИЯ БИОЛОГИЧЕСКИХ СИСТЕМ. Как правило, установки для изучения биологических систем используют в основном для изучения, хотя как глубина их проникновения, так и мощность дозы являются незначительными. Однако большое преимущество в том, что мощность дозы может изменяться в соотношении $1:2000$ путем изменения тока луча и расстояния. Кроме того, распределение дозы в образцах может быть изменено путем использования фильтров, особенно щелевых вращающихся фильтров.

Рентгеновские установки с интенсивным пучком имеют анод с большой площадью или вращающийся анод. Несмотря на использование твердых фильтров можно получить мощность луча до 40 кВт. Поскольку эти установки предназначены для облучения больших объемов или крупных образцов, необходимо обратить особое внимание на проблему гомогенности распределения дозы. Это можно осуществить путем изменения: образцы перемешиваются через пучок, или используются контейнеры для образцов с высоким обратным рассеянием. Зеленый анод также обладает некоторыми особенностями, с тем чтобы облучение было более равномерным.
grandes cantidades de productos o muestras de gran tamaño hay que prestar particular atención al problema de la distribución homogénea de la dosis. Esta distribución puede lograrse moviendo repetidas veces las muestras a través del haz o irradiándolas en recipientes que provoquen una retrodispersión elevada. También se pueden colocar algunos átomos en el lado opuesto. La intensidad de la dosis se puede variar de 1 a 3 alterando la corriente del haz, y de manera más acentuada cambiando la velocidad del mecanismo de transporte.

Los generadores de electrones tienen una capacidad muy superior a la de los aparatos de rayos X. Los generadores Van de Graaff alcanzan 1,5 kW, y los aceleradores lineales llegan hasta 18 kW.

A diferencia de lo que ocurre con los generadores de rayos X, el ángulo de apertura varía al penetrar el haz en el aire y, por consiguiente, la distribución de la dosis en las muestras depende de la distancia a que éstas se encuentren de la ventana del aparato. El área de irradiación puede extenderse barriendo con el haz y moviendo las muestras. Para que la homogeneidad de la dosis sea máxima es preciso emplear unas velocidades discretas del mecanismo de transporte, que dependerán del diámetro del haz y de la frecuencia del barrido. En el caso de los aceleradores lineales se tropieza con nuevas dificultades ocasionadas por la pulsación del haz. Pero también en este caso es posible calcular las velocidades discretas del mecanismo de transporte que permitirán lograr una distribución uniforme de la dosis en la dirección del movimiento del haz y en la del movimiento de las muestras.

La intensidad de dosis constituye un problema especial en el caso de sistemas biológicos porque los efectos de las radiaciones dependen de ella. Es preciso distinguir entre la intensidad media de la dosis y la instantánea, que puede ser muy superior.

La intensidad media de la dosis se puede variar de 1 a 10$^4$ modificando la corriente del haz, la amplitud del barrido y la velocidad del mecanismo de transporte.

La memoria se indica la eficacia total y la eficacia de utilización del haz de algunos de los generadores en funcionamiento. En ciertos casos aventajan a los aparatos de rayos X, de lo que se desprende que la irradiación es rentable.

INTRODUCTION

In this paper the author surveys the machines used for food irradiation and describes their advantages and disadvantages so as to facilitate the selection of a feasible generator. Comparison of such radiation sources is possible with respect to their capacity, dose distribution and dose-rate. The machines discussed are X-ray generators and electron accelerators, such as a soft X-ray generator like that described, for instance, by Bardwell [1], a high-power X-ray generator, as installed in the Institute of Irradiation Technology in Karlsruhe [2], the well-known Van de Graaff generators with an energy of up to 3 MeV [3], and finally linear accelerators with an energy of up to 20 MeV with a correspondingly high beam power, as installed for example at Risö [4], Natick or Karlsruhe.

CAPACITY

By the effective capacity, L, shall be understood that part of the beam power, P, per hour, which is actually used for irradiation and absorbed by the samples. It is

\[ L \text{ [Mrad x kg/h]} = 0.36 \times \eta \times P \text{ [Watt]} \]

The dimension of the capacity can be considered as an integral dose-rate.

The determination of the beam power of electron accelerators in Watts is easy, because it is determined by the product of current and voltage.
More difficult is the situation with X-ray generators, because their data must be generally obtained by experiments. For radioisotopes there are fixed quantitative relations, e.g.

\[ 1000 \text{ Ci } ^{60}\text{Co} \approx 14.8 \text{ Watt} \]
\[ 1000 \text{ Ci } ^{137}\text{Cs} \approx 3.6 \text{ Watt} \]

The efficiency, \( \eta \), in the above equation which, according to definition, does not give the total efficiency but only the efficiency of the beam utilization, is composed of several factors, namely

\[ \eta = \eta_t \eta_s \eta_c (\eta_T) \]

In this equation

- \( \eta_t \) depends on the thickness of the sample,
- \( \eta_s \) depends on the scanning width,
- \( \eta_c \) depends on the utilization of the conveyor.

In contrast to radioactive sources the temporal utilization (given by \( \eta_T \)) is not so important, because the machines are switched on for the irradiation time only. The relation between \( \eta_t \) and the thickness of the samples is very simple. In X-irradiation, if the thickness of the samples is equal to the half-value layer, then \( \eta_t \approx 0.5 \). In electron irradiation, if the thickness is two-thirds of the maximal penetration depth, \( \eta_t \) is about 80% for 1 MeV. If the energy is increasing, \( \eta_t \) is increasing somewhat due to the well-known change of the dose distribution curve. The determination of \( \eta_c \), the utilization factor of the conveyor, is no problem.

It is more complicated to find a relation between beam scanning and the efficiency factor \( \eta_s \). To enlarge the irradiation area, the beam is scanned at a right angle to the direction of the movement of the samples. In this case the scanning pattern is an important factor.

Assuming a beam with a very small diameter, that means a point, sawtooth scanning results in homogeneous dose distribution in the plane

\[ \text{FIG. 1. Dose distribution in the irradiation plane of an electron accelerator for two different beam diameters and sawtooth-shape scanning} \]
of irradiation (Fig. 1). With increasing half-value-diameter, a dose distribution curve is obtained which slopes off at the edge of the scanning width. The ratio of usable region, \( B \), to the scanning width, \( A \), that means the efficiency, is determined by the equation:

\[
\eta_s = \frac{B}{A} = 1 - \frac{2d}{A}
\]

With increasing half-value diameter, the efficiency evidently decreases (Fig. 2), but it is possible to increase the efficiency somewhat.

In a sine-shaped beam scanning (Fig. 3) the dose distribution shows a distinct increase of the dose near the edge of the scanning width. With increasing beam diameter a slope can be seen. Theoretically, it is possible to find a scanning shape for each beam diameter, which gives the optimal utilization factor.

It is not easy to change the scanning shape independently of the beam diameter, that is, the distance between the samples and the scanner; a specific distance and a specific beam diameter call for a specific scanning pattern.
It is indeed a very important advantage of the electron accelerators over X-ray generators and radioactive sources that a region with a homogeneous dose distribution can be obtained by scanning of the electron beam. The soft X-ray generator with a small focal point has a bell-shaped dose distribution. It is also impossible to produce a homogeneous dose distribution with the high-power X-ray generator mentioned notwithstanding its anode with an area of 10 by 17 cm (Fig. 4).

![Dose distribution of a high power X-ray generator](image)

**FIG. 4.** Dose distribution of a high power X-ray generator
(a) in the middle of the irradiation field
(b) at the borders of the irradiation field

It is possible to reduce the inhomogeneity in one direction by moving the samples through the beam cone. Homogenization in the other direction is only possible to a small extent by using sample containers with a high back-scattering. The material must, therefore, have a low atomic number [5].

It can thus be seen that the beam utilization factor, that is, the efficiency of the machine sources, can be improved by technical manipulations.

**DOSE DISTRIBUTION**

It is necessary to distinguish between the dose distribution in the direction of the beam and the dose distribution rectangular to the beam in any plane, for example, on the surface of samples.

In X-ray generators the dose distribution rectangular to the beam (on the surface of the samples, etc.) is unchangeable and essentially independent of current and energy. The dose distribution in the inside of the samples however can be changed to an extent not possible with any other radiation source. This can be achieved by the application of the usual filters, effecting a hardening of the radiation and with it homogenization of the dose distribution. If the dose in the inside and the dose on the surface have to be adjusted independently of one another, rotary slotted
filters [6] may be applied, thus superimposing filtered and unfiltered radiation in an adjustable proportion (Fig. 5).

With electron accelerators the dose distribution in the inside of the samples can be changed only insignificantly, by changing the electron energy — if the energy can be changed at all, as is the case with most of the linear accelerators and some of the Van de Graaff-generators. It is possible to generate a mixed radiation of electron and X-rays by using slotted targets [6]. The dose distribution in the inside of a sample has also been studied in relation to the beam diameter, at constant energy. One result is that the level of the maximum of the dose, compared with the surface dose, increases with the beam diameter. Therefore the dose distribution in the direction of the beam also depends on the distance between the samples and the scanner, because the beam diameter quickly becomes larger after entering the air.

As to the dose distribution rectangular to the direction of the beam, the homogeneous range in Fig. 1, that is, on the surface of the samples, applies only to a beam scanned in a sawtooth shape and only at critical speeds \( \nu_n \) of the conveyor according to the equation

\[
\nu_n = 1.64 \times \frac{d f_A}{2^{n+1}}
\]

where

\[ n = 0, 1, 2, \ldots, \]
\[ d = \text{beam diameter}, \]
\[ f_A = \text{scanning frequency}, \]

for an accelerator with continuous current.

This is more complicated with a pulse operation of the beam, as in the case of the linear accelerator. However, the inhomogeneity can be estimated by studying the homogeneity parallel to the direction of the
beam and at right angles to the direction of the beam. The condition of equal homogeneity in both directions also determines the pulse frequency \( f_p \):

\[
f_p = \frac{2 A f_A^2}{\nu_n}
\]

**DOSE-RATE**

The effect of radiation on many biological processes depends on the dose-rate. Therefore, it is also important to study the radiation machines with respect to their dose-rates.

It is easily possible, with a soft X-ray generator, to change the dose-rate by the factor 1000, that is, from 100 kR/min to 100 R/min, by altering the distance and the beam current. With a high-power X-ray generator with a large anode, the distance can be changed only a little and the beam current only in the proportion 1:3. This causes a change in the dose-rate by a factor of about 6, from 60 kR/min to 10 kR/min.

With the electron accelerators, the dose-rate depends only on the beam current and the area hit by it, but not on the energy. High dose-rates are obtained when the beam is not scanned. For example, 250 μA produce 60 Mrad/sec. These are dose-rates for resting samples in a beam cone which is not scanned.

With the high-power X-ray generator and electron accelerators the samples may be run through the beam cone once only, or repeatedly. Thus differentiation is necessary between the mean dose-rate over the total duration of the irradiation time, and the effective, or momentary, dose-rate.

The mean dose rate \( D_{lm} \) in the irradiation field can be calculated easily from the beam power, \( P \), the size of the irradiation field, \( F \), and the penetrating depth \( \alpha [g/cm^2] \):

\[
D_{lm} \approx \frac{P}{F \alpha}
\]

All samples in the irradiation field are irradiated with this mean dose-rate, independently of whether they move at high or low speed, or not at all. In principle, this equation also applies for X-ray generators.

With electron accelerators every point of a sample is irradiated, due to the beam scanning, not at a continuous rate, but in several sections; that is, that even with a continuous current source, the samples are irradiated with pulses. Compared to the mean dose-rate in the total area scanned, the effective dose-rate at the moment of irradiation is higher by a factor, which is roughly equal to the ratio of beam diameter to beam deflection. This ratio can reach a maximum value of about 40.

In addition, the linear accelerators are operated with short irradiation pulses and long pulse sequel times. The effective dose-rate increases further, approximately by a factor which is equal to the ratio of pulse sequel time to pulse duration, having, in general, the value 1000. The possibility that the effective dose-rate is 40 000 times higher than the mean dose-rate has to be considered when the effects of different kinds of radiation are compared.
<table>
<thead>
<tr>
<th>Type of radiation source</th>
<th>Necessary main power (kW)</th>
<th>Beam power (W)</th>
<th>Effective capacity (Mrad/kg h)</th>
<th>Efficiency of beam utilization (%)</th>
<th>Total efficiency (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Soft X-ray generator 60 kV, 20 mA</td>
<td>5</td>
<td>6</td>
<td>0.004</td>
<td>0.2</td>
<td>$2 \times 10^{-4}$</td>
</tr>
<tr>
<td>High power X-ray generator 120 kV, 0.5 A</td>
<td>80</td>
<td>40</td>
<td>2.0</td>
<td>10.0</td>
<td>$5 \times 10^{-3}$</td>
</tr>
<tr>
<td>Van de Graaff generator 1 MeV</td>
<td>3</td>
<td>250</td>
<td>65.0</td>
<td>70.0</td>
<td>6.0</td>
</tr>
<tr>
<td>Linear accelerator 3-15 MeV, 5 kW</td>
<td>110</td>
<td>5000</td>
<td>1250.0</td>
<td>70.0</td>
<td>1.2</td>
</tr>
<tr>
<td>Cobalt-60 100 000 Ci</td>
<td></td>
<td>1500</td>
<td>135.0</td>
<td>25.0</td>
<td>25.0</td>
</tr>
</tbody>
</table>
Details of several radiation sources are given in Table I. For comparison, data of a 100 000 Ci $^{60}$Co source are added.

REFERENCES

X-RAY EQUIPMENT FOR FOOD IRRADIATION

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Abstract — Résumé — Аннотация — Resumen

X-RAY EQUIPMENT FOR FOOD IRRADIATION. To investigate the different problems in radiation biophysics and radiation biology the necessity to develop equipment with a very high output of X-rays became evident at the beginning of the 1940's. This equipment made it possible to produce much higher dose-rates than the technical constructions which existed at that time. Such equipment was developed between 1950-1953 by the author and collaborators at the Max Planck Institut für Biophysik and has been in use since then for scientific research. It later became clear that these X-ray machines are also very suitable for the sterilization and disinfection of drugs, food and other materials. At the Max Planck Institut für Biophysik three types of equipment are used. With the construction of the AEG X-ray equipment of 120 kV and 500 mA, the industrial technique has been adopted and gradually implemented. The equipment constructed by the author and collaborators had three different types of X-ray tubes which can be connected with a high-voltage transformer of 240 kVA. These tubes run continuously, or for a short time, with a tube current of 2A and a voltage of up to 100 kV. The radiation dose-rate amounts to $10^7$ R/min. These tubes permit irradiation with continuous conveyance of a great amount of irradiation material. The corresponding industrial equipment constructed up to now is described.

APPAREIL A RAYONS X POUR L'IRRADIATION DES DENRÉES ALIMENTAIRES. Pour étudier les problèmes de radiobiophysique et de radiobiologie, on a constaté, dès le début des années 40, la nécessité de mettre au point des appareils à rayons X très intensifs. Ces appareils devaient permettre d'obtenir des débits de dose beaucoup plus élevés qu'avec les installations existantes. De telles machines ont été mises au point en 1950-1953 par l'auteur et ses collaborateurs à l'Institut Max Planck de biophysique, et sont utilisées depuis lors pour la recherche scientifique. Par la suite, on a constaté que ces générateurs de rayons X conviennent également très bien pour la stérilisation et l'asepsisation des médicaments, des denrées alimentaires et d'autres matières. Au Max Planck Institut für biophysik, on utilise trois types de radigénérateurs. La construction par la société AEG de générateurs de rayons X de 120 kV et 500 mA a amené la technique industrielle à adopter ces caractéristiques et à réaliser graduellement ce matériel. Les appareils construits par l'auteur et ses collaborateurs sont munis de trois types différents de tubes à rayons X qui peuvent être alimentés par un transformateur à haute tension de 240 kVA. Ces tubes peuvent fonctionner continuellement ou pendant un court laps de temps sous un courant de 2A et 100 kV. Le débit de dose du rayonnement atteint $10^7$ R/min. Ces tubes permettent l'irradiation d'une grande quantité de produits sur un convoyeur à mouvement continu. Les appareils industriels correspondants réalisés jusqu'à présent sont décrits par l'auteur.

РЕНТГЕНОВСКОЕ ОБОРУДОВАНИЕ ДЛЯ ОБЛУЧЕНИЯ ПИЩЕВЫХ ПРОДУКТОВ. Необходимость разработки оборудования для облучения пищевых продуктов с очень высоким выходом рентгеновских лучей для исследований различных проблем радиационной биофизики и радиационной биологии стала очевидной уже в начале сороковых годов. Это оборудование позволило получать более высокую дозу, чем могли дать существовавшие в то время технические конструкции. Такое оборудование было разработано в 1950—1953 годах автором и его коллегами в Институте биофизики Макса Планка и с того времени использовалось для научных исследований. Последнее стало ясно, что эти рентгеновские машины очень подходят также для целей стерилизации и дезинфекции медикаментов, продуктов питания и других материалов. В Институте биофизики Макса Планка используются три вида такого оборудования. После создания рентгеновского оборудования AEG на 120 кВ и 500 мА промышленность восприняла эти идеи и в настоящее время постепенно претворяет их в жизнь. Оборудование, создаваемое автором и его коллегами, имеет три различных вида рентгеновских трубок, которые можно соединять с трансформатором высокого напряжения 240 кВ/а. Через эти трубки непрерывно или в течение короткого времени пропускается ток в 2 а при напряжении до 100 кВ. Доза радиации составляет до $10^7$ рентген/мин. Виды трубок позволяют непрерывно облучать большие ко-
INTRODUCTION

In the past two decades new paths have been opened up in radiobiological and photochemical research, and new problems have presented themselves. The result of this development has been a whole series of fundamental new insights. In like manner, the practical application of these new insights has yielded new, highly significant possibilities — possibilities that are not only of great scientific interest, but also quite important from an economic point of view.

In the course of this development it was already found some time ago that, for the proper investigation of a whole series of questions, considerable expansion of present technical possibilities in the field of radiation generation is required. For, in order to find answers to these questions, radiation doses and dose-rates of very great magnitude are needed. Such doses and dose-rates cannot be attained with conventional technical means, that is, with standard industrial X-ray apparatus and particle accelerators.

A similar state of affairs prevailed, from the point of view of experimentation techniques, in a particularly important practical field of applied radiobiological research, namely in the sterilization and disinfection of objects, foodstuffs and liquids. Although, strictly speaking, the ultra-high radiation doses mentioned above are generally not required here, there is instead another strict demand, namely, that such sterilization or disinfection shall be accomplished speedily. And this, in its turn, again means that very high dose-rates are required here as well. In addition, it is necessary, if for economic reasons alone, for the disinfection or sterilization apparatus to be able to process large quantities of the material concerned in a minimum of time and in a continuous flow!

These same economic considerations furthermore demand that the radiation apparatus concerned should be of the utmost simplicity and sturdiness in both operation and design, hence not be liable to breakdowns. In this respect, too, the technology of conventional X-ray generating equipment was, and still is, inadequate. Several years ago it was tried, particularly in the field just mentioned, to make use of the
ultra-powerful particle accelerators, or of the radioactive fission products obtainable in such great amounts from nuclear reactors or research institutes. However, these attempts must, on the whole, be regarded as having failed, since the radiation generators thus obtained were technologically too involved, too complicated and too liable to breakdowns to satisfy the requirement of economy.

Besides all these considerations, a fundamental statement must be made: The problems of sterilization by radiation, and of food irradiation, are complex ones which cannot be resolved by one kind of irradiation only or by one procedure of irradiation. The reasonable and successful output of the radiation for these aims needs the adaptation of the kind of radiation (penetration power), of the absorbability of radiation, of the dose and dose-rates, and the modes of protection, to the aim of the irradiation and to the kind of object to be irradiated. It is not reasonable to use the same kind of radiation for all irradiations. For instance, the application of an unsuitable quality of radiation can act against the aim of irradiation and can be harmful for the irradiated object. It must be adapted to the object.

EQUIPMENT

The author, therefore, originally for reasons based on problems of pure radiobiological research, and then also to find a feasible, expedient and practicable solution for the tasks mentioned, set out, as far back as 1939, to develop new X-ray-generating equipment. The application of X-rays best fills the necessary requirement. The relative small efficiency of X-rays produced in X-ray tubes is compensated for by the greater absorption of X-rays in the material irradiated. Because of this, the economy of X-ray application will be discussed.

The requirements to satisfy in developing an installation for the generation of X-rays and irradiation of various objects and materials can be summed up as follows:

(a) The radiation generator must be able to supply large radiation doses and dose-rates;
(b) The generator must be simple of design and operation and not be liable to breakdowns. It must be suited for both continuous operation and brief exposure periods, and must not require excessive investment;
(c) Radiation protection equipment for the operating personnel must be easy to manufacture and not too expensive;
(d) The entire installation must be able to process, in a continuous flow, large quantities of material for irradiation;
(e) For the above reasons, and also because of other considerations mentioned below, ultra-high radiation particle energies should be avoided as far as possible.

Regarding the last requirement, physically speaking, all this means is that the X-ray generating voltage should be properly selected. As mentioned before, the use of energies in the MeV range does not appear desirable, since radiobiological and biophysical conditions in this range are complicated by the possibility of the occurrence of induced radioactivity, while the primary processes brought about by the radiation also, to some extent, still present a factor of uncertainty.

Since the material to be irradiated will always be a biological sub-
stance, it will be of the light-atomic type. As a result, the penetrability of the radiation that must be demanded is basically determined by the thickness of the layer of material to be irradiated.

For radiobiological research purposes, the quality of the radiation to be applied is, in general, immaterial. Apart from investigations of special problems where the effects of radiation of various wave-lengths are to be compared, X-rays with a generating voltage of from some 50 to 120 kV are sufficient for the irradiation of biological objects. For the possibility of irradiating large quantities of material, it may be advisable to raise the generating voltage to approximately 180-200 kV.

To realize these considerations, it was first of all necessary (a) to build a high-voltage generator capable of carrying high loads in continuous operation, and (b) to develop a new, high-load X-ray tube. It was only natural, in so doing, to proceed from design elements and units already existing in X-ray equipment technology at the time. The development of the required X-ray tube, which had been started upon in co-operation with H. Beck, had to be interrupted for war-time reasons and could not be resumed again until 1949, when a new start was made in co-operation with O. Heuse [1, 2].

This work led to the construction of the first heavy-current X-ray generator. This unit was operated at a voltage of 60 kV and a tube current up to 2 A. Its high-voltage generator was the first one ever to use a dry rectifier. This meant an essential step forward in overall X-ray equipment design since, up to that time, the use of dry rectifiers had not been customary in X-ray technology. The installation was taken into operation in 1951 and has been in continuous use ever since without any breakdowns. Thus it had become possible to achieve dose-rates of up to two million R/min in continuous operations.

Figures 1, 2a and 2b show the principle of the tube design and an overall view of the installation as a whole. One will note that, in the new tube type, the well-known rotating-anode principle was applied — coupled, however, with water cooling. In view of the heavy tube currents, tantalum was used as material for the filament of the cathode, since a tungsten
 filament becomes brittle under such loads. The high-voltage generator consists of a suitably dimensioned transformer, the aforementioned dry rectifier (mounted in an oil container) and automatic switching and control equipment.

For biological and photochemical research purposes, this first model of a heavy-current X-ray generator meant a great step forward. The installation functioned satisfactorily right after being taken into operation, and has continued to do so ever since.
The author did not consider the capacity of this installation to be sufficient for all the purposes first mentioned. The further chief engineering and design measures taken were as follows:

(a) The capacity of the high-voltage generator was greatly stepped up. To this end, a special transformer and regulating equipment, as well as a high-voltage cable with a capacity of 240 kW at 120 kV were built according to the author's specifications by the Koch and Sterzel A.G. Company in Essen, Federal Republic of Germany. This high-voltage generator, the first one of its kind ever to be used in X-ray engineering, is shown in Fig. 3.

(b) The design of the new X-ray tubes likewise had to be changed with a view to obtaining a larger X-ray output. In determining the shape of the most important elements of the X-ray tube — anode and cathode — the essential point of view was that, for all envisaged applications of the new installation, a large focal-spot area was most expedient. Such a large focal-spot area not only presents technical advantages, in that it reduces the heat stress on the anode, but also brings about a highly favourable distribution of radiant energy within the irradiated material, particularly since, in the case of a large-sized radiation source, radiation intensity at small distances from the source increases inversely with distance itself, instead of with its square. Thus, the entire radiation flux is increased. Realizing this fact, the author used a large focal-spot area, even in the first tube model.

Four types of tube design, all capable of solving the problem concerned, are shown schematically in Fig. 4.

Figure 4 I, gives a schematic view of the cathode-anode system used in model I. A large, water-cooled, rotating anode of 21 cm diam. is installed at right angles to the cathode, which is also of large size. A beryllium plate, 1.5-mm thick, likewise water-cooled, serves as radiation exit window.

A second solution is schematically shown in Fig. 4 II. Here, the cathode is again of large size, whereas the anode is designed in the manner...
FIG. 4. Schematic illustration of cathode and anode system used in the different models of high-current X-ray tube

of a so-called "transmission anode". A combination of the two principles discussed yielded the following solution: the anode is a thin, rotating, water-cooled disc, manufactured from properly selected material. The X-rays are generated inside this disc and emanate directly from it to the outside, without any window being required.

In contrast to the two rotating-anode systems just described, Fig. 4 III shows schematically a technical solution featuring a stationary anode, partly according to earlier suggestions of the author's recent collaborator, H. Beck. Here, the essential characteristic is the shape of the cathode, which consists of numerous hot filaments and surrounds the anode in ring-like fashion. The anode can be so shaped as to serve here as container for the material to be irradiated. Accordingly, it may be either thin-walled or thick-walled. Of course, it may be water- or oil-cooled and be equipped with selective radiation filters. The container anode can be given either a cylindrical, or some other shape. In Fig. 4 III the shape of an obtuse cone has been selected to emphasize the principle of Fig. 4 I as well as the possibility of utilizing the radiation in the direction indicated in the figure.

In Fig. 4 IV this idea has been developed further. Here, there is a so-called "continuous-flow X-ray tube". The anode of this tube has been given cylindrical shape. It is into the inside of this cylinder that the useful radiation is emitted. The material to be irradiated is passed through this cylinder, if need be in a continuous flow. The cathode is arranged outside the anode in the form of a mantle surrounding the anode cylinder. This solution obviously is particularly suited for the irradiation of large quantities of material. The hole of the cylindrical anode guarantees practically homogeneous irradiation of the material inside the cylinder.

It is, of course, also possible to conceive of other embodiments to the four basic solutions already described for the technical task to be undertaken. Thus, for instance, the anode may be given the form of a plate, or of two plates facing one another, as was actually done some
time later. However, the basic idea, namely the use of a large-sized anode and a large-sized cathode (hence a large focal-spot area) remains the same in all embodiments. The cathode may be split up also into several individual cathodes, suitably distributed and arranged around or opposite the anode.

Of the solutions described, those indicated by numbers II and IV have been actually realized by the author at the Max Planck Institut für Biophysik. This has led to two new designs of heavy-current X-ray installations. The design according to solution II was mainly developed with O. Heuse [3, 4], whose work was supplemented and completed by K. Heuss [5]. In both cases the work consisted not only in designing the X-ray tube but also — and that was one of the main difficulties — in making this tube operate properly in combination with the large high-voltage generator of 240 kW capacity and 120 kV voltage already described. At present, four heavy-current X-ray sets built on the lines previously described, are in operation at the Max Planck Institut für Biophysik. Two of these sets are described below:

Figure 5 shows schematically a second heavy-current tube model, built by O. Heuse and K. Heuss according to principle II, that of the transmission anode. The significance of the individual component parts will be readily evident from the explanations in Fig. 5. The tube is always connected to a high-vacuum pump, which is combined with the tube proper into one single structural unit. A high-voltage cable connects the tube with the large high-voltage generator, which is separated from the tube. The transmission anode, a rotating aluminium disc cooled by a thin film of running water, is gold-plated. It can be manufactured in various thicknesses depending on what radiation hardness is desired, and, if necessary, may contain special radiation exit windows.

Figure 6a, b shows the same tube in actual operation. The dimensions of the entire installation are readily evident from a comparison with the
size of the staff members shown. The tube is 1.5 m high and 1.2 m wide. It weighs approximately 300 kg. The tube is hydraulically adjustable upward and downward and, with the aid of a mechanical device, may be tilted to any angle from the vertical axis of the installation up to 90°. Accordingly, the material samples may be irradiated, whether in a vertical downward or in a lateral direction, at various distances from the focal spot.

The optimum results achieved so far by these sets are: tube voltage up to 100 kV; tube current in continuous operation up to 2A; dose-rate up to $1 \times 10^6$ R/s. Admittedly, this dose-rate can so far be attained only with a soft radiation mixture in the vicinity of the anode. However, the large size of the focal-spot area ensures that the dose-rate decreases only slowly with the distance from the anode.

These ideas, and their realization in the equipment described, induced the electrotechnical industry also to become occupied with the proposed new paths in X-ray technology. The Allgemeine Elektrizitäts-Gesellschaft (AEG) Valve Works in Berlin, and notably Messrs. Meyer, Hoffmann and Eigl, developed and built a heavy-current tube set supplying 120 kV and 500 mA in continuous operation, maintaining close contact with the author and his co-workers. The X-ray tube of this set likewise has a large focal-spot area and a large-sized (multiple) cathode. Its continuous flow-type anode is a double-walled disc, cooled inside by running water. In Fig. 7a can be seen AEG equipment which is installed in the laboratories of BASF, Ludwigshafen. Several models of this type of technical construction already exist. The very high output of radiation,
like the types mentioned above, is not reached as yet with these technical constructions for irradiation, but good technical installations are already constructed. In Fig. 7a is shown the newest X-ray equipment. This set is already in operation. Its present capacity is approximately one third to one half of that of the sets at the Max Planck Institut für Biophysik. It is intended, however, to step up its capacity still more and particularly to raise the X-ray generating voltage to some 180 kV. Such an increase in voltage is also possible for the other tubes described. Most important, the use of ion grid pumps will facilitate technical operations quite considerably and even further enhance operational safety. Based on the ideas of the author and co-workers, another technical apparatus has been developed by the AEG (Fig. 7b) and is now available. This is a "Topf" X-ray tube with a cylindrical vacuum anode. In the interior of this vacuum anode exists a radiation field which is nearly homogeneous.

The concept of the "continuous-flow X-ray tube" has likewise been realized, by the author and K. Heuss [6], at the Max Planck Institut für Biophysik¹. The first model built is shown in Fig. 8. For the time being this is just a reduced-scale model. The "flow anode" is 48 cm long and 8 cm diam. The cathode is split up into eight tungsten filaments of 0.4 mm diam. and surrounds the cylindrical anode like a cloak. The anode is water-cooled. The operational data of the small model are 60 kV and 100 mA. The dose distribution inside the anode is shown in Fig. 9. It is notable that the distribution of radiant energy inside the cylindrical anode is of quite satisfactory homogeneity. Further splitting-up the cathode will increase homogeneity even more. The construction of a large set (some 100 cm long and 20 cm diam) of corresponding design is in preparation. In the meantime, the AEG has developed and constructed

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¹ In the early period of this development, H. Beck, in particular, took an active part in planning the work concerned.
FIG. 7b. High-current X-ray equipment with "Topf" X-ray tube of AEG (Courtesy of AEG, Berlin)

FIG. 8. High-current X-ray tube with cylindrical anode (continuous flow X-ray tube)

an apparatus of this kind for 200 kV and 500 mA. This construction will soon be available. There is no doubt that the X-ray machine described is fully sufficient for the requirements established for a generator of ionizing radiations, especially for the purpose of food irradiation. In comparison to irradiation apparatus with radioactive nuclides, these machines have the following advantages:
(i) The X-ray machines can be switched on and off while radioactive sources emit continuously; (ii) By varying the X-ray tube voltage and the
FIG. 9. Continuous flow X-ray tube. Distribution of the X-ray dose inside the anode

X-ray tube current, it is very easy to change both the penetration of the radiation and the dose-rate in a simple manner. This is very difficult or impossible in the case of radioactive sources; (iii) The arrangements for radiation protection for the different X-ray machines are easier than for radioactive sources; (iv) In comparison with radioactive sources, it is possible, in the case of X-ray machines, to obtain very high dose-rates — therefore, short irradiation times may be achieved more easily. With radiation sources high dose-rates can only be achieved by using large amounts of radioactive materials which, as is known, is connected with technical difficulties concerning the preparation and accumulation of radioactive materials.

Compared with particle accelerators, X-ray machines have the advantage of simple and solid construction and easy operation. Furthermore, X-ray machines need a smaller area and are lighter than the accelerator. With this type of X-ray machine it is possible to pass big amounts of material to be irradiated through the machine. For these reasons X-ray machines are more economical than other irradiation equipment, for the purpose of food irradiation as well as in other fields. The economy will also be increased in so far as these machines require less operation personnel than the accelerator. The X-ray machines described represent the first step in technical development. There is no doubt that further development will bring essential perfection.

SUMMARY

It has been shown that the application of X-rays for food irradiation is possible by means of the newly-constructed equipment. The apparatus developed by the author and his collaborators is especially suitable for the different aims of food irradiation. Some such apparatus already exists in industrial technical form and is available. There are several important technical and economical advantages compared with the big installations of 60Co-radiation sources. In some cases, the unwelcome change or damage in the irradiated material which is caused by the too high penetration power of the 60Co-radiation is avoided.

REFERENCES

DISCUSSION

O. A. KUHL: How do you measure your dose? And what is the efficiency of conversion, i.e. the ratio of power input to useful power output?

B. RAJEWSKY: The dose is measured by conventional means: ionization chambers, chemical dosimeters and solid-state dosimeters. The relatively low efficiency of the X-ray tube is offset by high absorption in the irradiated material. It is unnecessary and generally uneconomical to generate quanta of very high energy.

E.G. HOFMANN: I should like to add a few remarks to what Mr. Rajewsky has said. Another high-power X-ray unit, with a flat transmission anode, producing about three times the power of the machine described by Mr. Rajewsky, has now been in operation for about two years. The latest X-ray machines developed by AEG in Germany (a pot-anode type, and also a continuous-flow type) are operated at up to 200 kV and at currents of up to 500 mA. These units are self-shielded and have the same useful radiation power as $^{60}$Co sources of as much as 100 000 Ci. They have cylindrical transmission anodes 15 cm in diameter and a nearly homogeneous radiation field. Dose rates of up to 8 MR/h are obtainable. Some further advantages of the new X-ray machines are their light weight, the small space they occupy, and the fact that the radiation can be closely controlled and switched off. It is our opinion that, in spite of the low conversion efficiency, they will be economically as good as, or perhaps even better than, isotope sources of comparable radiation power.

B. RAJEWSKY: It seems, then, that the new AEG models go some way towards confirming our ideas on the subject.


THE ETHANOL-CHLOROBENZENE AERATED SYSTEM AS A NEW HIGH-LEVEL DOSIMETER FOR ROUTINE MEASUREMENTS

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Abstract — Résumé — Аннотация — Resumen

THE ETHANOL-CHLOROBENZENE AERATED SYSTEM AS A NEW HIGH LEVEL DOSIMETER FOR ROUTINE MEASUREMENTS. The radiolytic hydrogen chloride yield for 60Co gamma radiation measured as a function of dose (0.05 to 100 Mrad), dose-rate (0.5 to 2500 rad sec⁻¹) and chlorobenzene (CB) concentration is found to be 5 ± 0.1 for CB concentrations between 20 and 40% in a broad range of experimental conditions. The yield is only slightly sensitive to normal impurities. Analytical and lower-grade components give yields reproducible within a few per cent of this value if 4% water and about 2 × 10⁻³ M benzene and acetaldehyde or acetone are initially present. Higher dosimetric accuracy is obtained if the exact G(C1⁻) is determined for given materials by calibration with the Fricke dosimeter. With 4% CB and 4% water all grades of ethanol give G(C1⁻) = 3.65 ± 0.05, irrespective of additives. The effect of variation of the water content within ±1% is negligible.

The hydrogen chloride concentration in the whole dose range is determined by mercurimetric or alkalimetric titration directly in the irradiated sample with an accuracy of one per cent or better. Incomplete experiments with fast electrons have proved that similar systems are of possible interest for calibration and control of industrial irradiations with intense electron beams. The simplicity of preparation and analysis together with the broad range (covered by only one analytical method) and high overall accuracy give to the new dosimeter all the qualities of the almost unique tool for dosimetric calibration of sources and routine control of industrial radiation processing.

LE SYSTEME ETHANOL-CHLOROBENZENE AERE UTILISE COMME DOSIMETRE POUR LES MESURES COURANTES DE FORTES DOSES. On constate que la quantité d'acide chlorhydrique radiolytique produite par des rayons gamma émis par le 60Co, mesurée en fonction de la dose (0.05 à 100 Mrad), du débit de dose (0,5 à 2500 rad s⁻¹) et de la concentration du chlorobenzène (CB), est de 5 ± 0,1 pour des concentrations de CB comprises entre 20 et 40% dans un très large éventail de conditions expérimentales. Ce rendement n'est que légèrement sensible aux impuretés normales. Avec des composants de pureté analytique et moindre, on obtient des rendements reproductibles compris dans une gamme de quelques pour cent de cette valeur en présence de 4% d'eau et de benzène et d'acétaldéhyde ou d'acétone 2 × 10⁻³ M. On obtient une plus grande précision dosimétrique en déterminant exactement G(C1⁻) pour des matières données par étalonnage au moyen du dosimètre de Fricke. Avec 4% de CB et 4% d'eau, toutes les qualités d'éthanol donnent G(C1⁻) = 3,65 ± 0,05 quelles que soient les adjuvants utilisés. L'effet des variations de la teneur en eau comprises entre ±1% est négligeable. On détermine directement la concentration de l'acide chlorhydrique dans toute la gamme correspondant à la dose par un titrage mercurimétrique ou alcalimétrique dans l'échantillon irradié, avec une précision égale ou supérieure à 1%. Des expériences incompétentes avec des électrons rapides ont prouvé que des systèmes semblables pourraient être intéressants pour étalonner et mesurer des irradiations industrielles utilisant des faisceaux d'électrons intenses. La simplicité de la préparation et de l'analyse, ainsi que la très grande précision en général, font de ce nouveau dosimètre aux multiples qualités un instrument presque unique en son genre pour le calibrage dosimétrique des sources et la mesure courante des irradiations intervenant dans les procédés industriels.

АЗРИРОВАННАЯ СИСТЕМА ЭТАНОЛА-ХЛОРОБЕНЗОЛА В КАЧЕСТВЕ НОВОГО ДОЗИМЕТРА ВЫСОКОГО УРОВНЯ ДЛЯ ПРОВЕДЕНИЯ ОБЫЧНЫХ ИЗМЕРЕНИЙ. Обнаружено, что выход радиолитического хлористого водорода для гамма-излучения кобальта-60, измеренного в качестве функции дозы (0.05 - 100 Мрад), мощности дозы (0.5 - 2500 рад/сек⁻¹) и концентрации хлоробензола (ХБ), составляет 5 ± 0,1 для концентрации ХБ 20 - 40% в широком диапазоне экспериментальных условий. Указанный выход очень мало зависит от обычных загрязнений. Компоненты аналитической чистоты и ниже дают выходы, которые могут быть
воспроизведены в пределах нескольких процентов этой величины, если первоначально имеется 4% воды и около $2 \times 10^{-3}$ М бензола и ацетальдегида или ацетона. Более высокую дозиметрическую точность можно получить в этом случае, если определить точно $G(C_1^+)$ для данных материалов путем калибровки по дозиметру Фрике. При 4% ХБ и 4% воды этиловый спирт всех степеней чистоты дает $G(C_1^+) = 3,65 \pm 0,05$ независимо от присадок. Эффект изменения содержания воды в пределах ±1% является очень незначительным. Концентрация хлористого водорода во всем интервале дозы определяется руттнодосиметрическим или алкалиметрическим титрованием непосредственно в облученном образце с точностью до 1% или выше. Незавершенные эксперименты с быстрыми электронами показали, что аналогичные системы могут представлять интерес для калибровки и контроля промышленного облучения интенсивными электронными пучками. Простота подготовки и анализа, а также широкий диапазон (схватываемый только одним аналитическим методом) и высокая общенная точность придают новому дозиметру все качества почти уникального инструмента для дозиметрической калибровки источников и обычного контроля за промышленной радиационной обработкой.

DOSIMETRO DE ETANOL-CLOROBENCENO SATURADO DE AIRE PARA LA DETERMINACION DE INTENSIDADES ELEVADAS. El rendimiento en HCl obtenido por radiólisis mediante los rayos gamma del $^{60}$Co, expresado en función de la dosis (0,05 a 100 Mrad), de la intensidad de dosis (0,5 a 2500 rad s$^{-1}$) y de la concentración del clorobenceno (CB), es $5 \pm 0,1$ para concentraciones de CB comprendidas entre 20 y 40% en condiciones experimentales muy diversas. Este rendimiento sólo se altera ligeramente con las impurezas corrientes. Los componentes de pureza analítica e inferior dan resultados reproducibles, con ligeros porcentajes de desviación respecto de este valor, añadiendo al principio de la operación 4% de agua y $2 \times 10^{-3}$ M$^{-1}$, aproximadamente, de benceno y acetaldehído o acetona. La exactitud de las mediciones es mayor si se determina el valor exacto de $G(C^1)$ para cada material por calibración con el dosímetro de Fricke. Con 4% de CB y 4% de agua todas las variedades de etanol dan $G(C^1) = 3,65 \pm 0,05$, con independencia de los aditivos. El efecto de la variación del contenido de agua en ±1% es insignificante. La concentración del HCl en todo el intervalo de dosis se puede determinar por valoración mercurométrica o alcalimétrica directa de la muestra irradiada con un error máximo del 1%. Experimentos con neutrones rápidos, todavía en curso, demuestran que podría emplearse mezclas similares para calibrar y controlar irradiaciones industriales con haces electrónicos intensos. La sencillez de la preparación y del análisis junto con el amplio intervalo que se cubre con este solo método y con su elevada precisión, hacen que el nuevo dosímetro sea uno de los más eficaces para calibrar fuentes radiactivas y controlar procesos industriales de irradiación.

1. INTRODUCTION

There are three major advantages of liquid chemical dosimetric systems which are important when applied to dosimetric problems of radiation processing. These advantages are: simple preparation, simple and fast analysis, high accuracy and flexibility of form. The disadvantages of the most popular dosimeters in this category (ferrous, ferrous-cupric and ceric sulphate dosimeters) are the limited range, or sensitivity to impurities. When dosimeters are applied for routine control in a plant, such disadvantages become a serious limitation. If highest accuracy is required, as is the case with dosimetric calibration of sources and radiation fields, and if many measurements have to be done, the sensitivity to impurities is also a serious handicap, because much time is spent for purification of containers and chemicals. These are the reasons for developing liquid chemical dosimeters which, while possessing the advantages mentioned, are free of disadvantages.

When a new chemical dosimeter is proposed, the data should be given about its radiation, chemical, and practical dosimetric properties, according to the well-known criteria of chemical radiation dosimetry [1, 2]. If an organic system is used as a high-level dosimeter, three potential effects upon the yield of the measured radiolytic product are of special interest: the effect of oxygen (and its consumption), the effect of accumu-
lated radiolytic products, and the radiolytic effect upon the measured product itself. The first two effects may be important, even at comparatively low doses ($5 \times 10^4$ rad). The third effect is observed predominantly at higher doses only (several megarads). For the radiation processing of food, medical supplies, or plastics, doses of up to 5 Mrad are mostly used. When gamma radiation is used, dose-rates of up to 1000 rad/sec are encountered. A very small fraction of the total dose is transferred to irradiated objects at dose-rates below 15 rad/sec (well below 5%, as calculated for one of the radiation plants described [3]). This is an important fact, because of the changes in the radiation chemical mechanism, which are usual for organic systems at high doses and at very low dose-rates when the diffusion of oxygen into the system is faster than its consumption. Small doses given at such low dose-rates cannot cause trouble because a too low concentration of oxidative products has been accumulated.

Chlorobenzene solutions in ethanol were chosen for this study as potentially favourable chemical dosimeters. All systems contained 4% water and were initially in equilibrium with air, also present at normal pressure as the gas phase during irradiations. The measured radiolytic product is hydrogen chloride (chloride ion). In the soluble form, HCl is radiolytically stable, even when present in concentrations of up to 0.5 M (see Table II). Chlorobenzene is used as a source of chlorine because of its high thermal stability, its resistance to oxidation, and because of the favourable concentration dependence of radical yields in irradiated chlorobenzene solutions [4]. Ethanol is known as an inhibitor of chain oxidation and as an excellent solvent for hydrogen chloride [5]. Due to its high proton affinity, ethanol reacts efficiently with radiolytically generated positive ions, thus reducing considerably the energy of charge neutralization which modifies the fate of neutralization products [6, 7, 8]. This effect of ethanol is probably an important step leading to efficient solvolytic stabilization of primary chloride ions generated in the system by dissociative electron attachment to chlorobenzene [8].

A comparatively high concentration of water is favourable, since its effect upon the yield of chloride is thus easily controlled. An increase of water concentration from 4 to 8% decreases $G(\text{Cl}^-)$ for 0.1 only [8].

In this paper are presented only those results which are of immediate practical interest for the dosimetry of gamma rays. Available data concerning the radiation-chemical mechanisms, and prospects of the application of similar systems to the dosimetry of electron beams [8] will be published elsewhere. This may be considered as the first step in investigations which could lead to the full development of new dosimetric systems. If successful, it should encourage further research into this class of system for high-level dosimetry.

2. EXPERIMENTS

The system of chlorobenzene, ethanol, 4% water and dissolved air, is examined.
2.1. Materials and methods

2.1.1. Chemicals

Chlorobenzene (CB) was "Fluka", puriss. Ethanol, if not otherwise stated, was a laboratory grade material containing about 0.1% water, $1.6 \times 10^{-3}$ M benzene, $2 \times 10^{-3}$ M acetaldehyde, and other minor impurities. Ordinary distilled water was added to all systems. Mercuric nitrate, sodium chloride, potassium hydroxide, and other chemicals were of analytical grade. Components and systems were stored in darkness.

2.1.2. Containers

Borosilicate glass test tubes and ampules, or silicone-coated glass containers, were used for irradiations without any influence upon the yields of Cl-. Between irradiations all containers were washed with cold ethanol and distilled water and then dried (110 to 150°C). Systems were stored in ordinary glass bottles stoppered with ground glass stoppers not permitting evaporation.

2.1.3. Irradiations and dosimetry

Various cobalt sources of activities between 200 and 75 000 Ci were used. Dosimetry was carried out by the exact imitation of irradiation geometry. All dosimetric measurements performed with various systems were calibrated against a ferrous sulphate dosimeter ($0.8 \, \text{N} \, \text{H}_2\text{SO}_4$) using $G(\text{Fe}^{3+}) = 15.5$. Excellent agreement of the results of many measurements was obtained. Overall absolute accuracy is estimated to be higher than ±2% for all dose-rates, except for the highest, for which the results of dosimetry are uncertain to within ±4%. Irradiations were normally performed at room temperature (20 to 27°C) in stoppered or open test tubes ($16 \, \text{mm} \, \text{o.d.} \times 150 \, \text{mm long}$) containing 5 ml of the system.

2.1.4. Analysis

Hydrogen chloride was determined by alkalimetric or mercurimetric titration, or by both methods on the same sample. Irradiated samples were immediately analysed or stored until a sufficient number of samples had been accumulated. Five to seven days of storage in stoppered test tubes did not influence the results of Cl- determinations. Siliconed test tubes were used if parallel alkalimetric titrations of samples irradiated with doses below 1 Mrad had to be performed. At higher doses, ordinary test tubes were used, and immediate titration was performed in order to avoid losses of H+ by reaction with alkalies extracted from glass. When highest accuracy at lowest doses (below 0.1 Mrad) was required, unirradiated controls were treated and analysed in the same way as irradiated samples. This was normally done in parallel with the calibration of standard mercuric solutions. Care was taken to avoid any contamination with chlorides while the samples were transferred into beakers or flasks for titration. The residues of the samples were washed out with alcohol. The samples were eventually further diluted to avoid phase separation when titrated with water solutions (doses above 5 Mrad). Be-
low 0.5 Mrad only mercurimetric titration was performed, and above this dose alkalimetric titration as the first step (neutralization of the sample with bromphenalblue (BPB) as indicator) followed by mercurimetric titration of the same sample, was sometimes carried out. Alkalimetric titrations in alcoholic medium with 0.015 N KOH and (BPB) are sensitive enough, giving results with an accuracy of ±1% or better at doses above 0.5 Mrad if siliconed semimicro burettes are used. Below 0.5 Mrad the mercurimetric method for the determination of chlorides in alcoholic medium with diphenilcarbazone (DPC) as indicator [9, 10] was modified by applying alcoholic mercuric nitrate solutions of concentrations down to $3.5 \times 10^{-4} \text{N}$ [8]. Very good accuracy is obtained if the end-point of the titration is determined by visual comparison of two samples of equal composition and volume. Daylight is the best illumination for observing a faint colour change from yellow to yellow-orange. A series of 19 measurements was carefully performed on samples irradiated with 0.2 to $1.0 \times 10^5$ rad (chloride concentration 0.8 to $4 \times 10^{-4}$ M) to examine the accuracy and sensitivity of the method. Out of 18 measurements, the mean square deviation of calculated G-values below 0.5% was obtained. This is a limit of sensitivity which can be achieved by a skilful analyst. A similar result would be possible in routine measurements performed on samples containing approximately equal chloride concentrations. The lowest possible error of dose determination would thus be about ±200 rad if analytical errors only are considered. At chloride concentrations above $5 \times 10^{-4}$ M (doses above 0.1 Mrad) comparable accuracy was easily achieved if the titrations of irradiated samples and calibration of the standard solution were performed under similar conditions. The observation of the end-point is no longer a problem. About 50 samples can be analysed during seven hours using one standard solution only, and about 30 samples if different standard solutions are to be used. If parallel alkalimetric and mercurimetric titration is performed, time consumption per sample is 50% higher.

Mercuric nitrate solutions up to $1.5 \times 10^{-2}$ M in ethanol 0.06 M in HNO$_3$ with 10% water are used. Ethanolic solutions are prepared by dilution of more concentrated water solutions. In order to avoid hydrolysis, the desired amount of concentrated Hg(NO$_3$)$_2$ is first added to the necessary amount of water and HNO$_3$. Then ethanol is slowly mixed in. When in ethanolic solution, mercuric nitrate decomposes with a constant rate of about 1.6%/d, forming a disperse white deposit inert to HCl concentrations encountered during titration. The rate of decomposition is possibly dependent on the quality of ethanol. It is determined by periodical (daily) calibration of mercuric nitrate solutions against standard solutions of sodium chloride. Alcoholic standard solutions of chloride are used to calibrate mercuric nitrate solutions of concentrations below 0.005 N.

2.2. Results and discussion

The dose-rate independent initial yields of radiolytically generated chloride, $G_{i1}(Cl^-) = d[Cl^-]/dD = \text{constant}$, i.e. above 4 rad/sec (see Table II), for chlorobenzene concentrations below 40% are given in Table I. Due to the good reproducibility of many experiments performed at different dose-rates, and by separate dosimetric calibration, the absolute combined error of G(Cl$^-$) for CB concentrations above 4% is estimated to be less than ±2%. For 30% CB, the yield is 5.00 (graphical interpolation).
Dose and dose-rate effects are examined in systems with typical CB concentration. At 4% CB, the effect of CB responsible for the initial steep rise of G is nearly saturated. After the saturation of all CB effects, maximum G is reached at 20% CB. Above this concentration a plateau is formed and a slow linear decrease of G is observed \[8\]. The broad concentration range of approximately constant G is of interest for high-level dosimetry and 40% CB is a favourable starting concentration at which the yield is not influenced appreciably by CB consumption during irradiation. The results are presented in Table II. The scheme of the dose effect is shown in Fig.1. Initial yields (G₁) are given by the slope OX. After a transition interval, the secondary yield (G₂-slope BY) is established. The picture is typical of competition reactions of accumulated radiolytic products with one of the precursors of HCl. Characteristic doses D₁ and D₀ are obtained from the curve. D₁ is normally found between 0.5 and \(0.7 \times D₀\). Further experiments are necessary for more precise determination of these limiting doses. The experimental dose D₁ in Table II is lower, or equal to D₁. On the basis of the results the following conclusions were drawn:

(a) A broad range of dose and dose-rate independence is found for the mean initial yields 3.64 and 4.90 with 4 and 40% CB respectively.

(b) The limiting doses D₁, defined as D₀/2, increase with the dose-rate. At dose-rates above 5 or 15 rad/sec they are high enough for dosimetric application. With 40% CB at dose rates above approximately 100 rad/sec the yield is constant up to 100 Mrad.

(c) Within the experimental error the secondary yields are equal for both systems.

Experiments No.14 to 17 in Table II are included to show that appreciable temperature effect is not to be expected if oxygen is present in the system during irradiation. In experiments No.16 and 17 dissolved oxygen has been partly expelled by heating and by the evaporation of ethanol. The yields obtained are identical with those found for de-gassed systems \[8\].

### Table I. Dependence of \(G₁(CI^-)\) upon the Concentration of Chlorobenzene (CB)

<table>
<thead>
<tr>
<th>CB (vol.%)</th>
<th>G(Cl⁻)</th>
<th>CB (vol.%)</th>
<th>G(Cl⁻)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.36</td>
<td>0.99</td>
<td>4.00</td>
<td>3.64</td>
</tr>
<tr>
<td>0.67</td>
<td>1.42</td>
<td>6.67</td>
<td>4.17</td>
</tr>
<tr>
<td>0.92</td>
<td>1.75</td>
<td>10.0</td>
<td>4.55</td>
</tr>
<tr>
<td>1.33</td>
<td>2.15</td>
<td>13.3</td>
<td>4.81</td>
</tr>
<tr>
<td>2.00</td>
<td>2.68</td>
<td>20.0</td>
<td>5.05</td>
</tr>
<tr>
<td>2.67</td>
<td>3.08</td>
<td>40.0</td>
<td>4.90</td>
</tr>
</tbody>
</table>

Dose and dose-rate effects are examined in systems with typical CB concentration. At 4% CB, the effect of CB responsible for the initial steep rise of G is nearly saturated. After the saturation of all CB effects, maximum G is reached at 20% CB. Above this concentration a plateau is formed and a slow linear decrease of G is observed \[8\]. The broad concentration range of approximately constant G is of interest for high-level dosimetry and 40% CB is a favourable starting concentration at which the yield is not influenced appreciably by CB consumption during irradiation. The results are presented in Table II. The scheme of the dose effect is shown in Fig.1. Initial yields (G₁) are given by the slope OX. After a transition interval, the secondary yield (G₂-slope BY) is established. The picture is typical of competition reactions of accumulated radiolytic products with one of the precursors of HCl. Characteristic doses D₁ and D₀ are obtained from the curve. D₁ is normally found between 0.5 and \(0.7 \times D₀\). Further experiments are necessary for more precise determination of these limiting doses. The experimental dose D₁ in Table II is lower, or equal to D₁. On the basis of the results the following conclusions were drawn:

(a) A broad range of dose and dose-rate independence is found for the mean initial yields 3.64 and 4.90 with 4 and 40% CB respectively.

(b) The limiting doses D₁, defined as D₀/2, increase with the dose-rate. At dose-rates above 5 or 15 rad/sec they are high enough for dosimetric application. With 40% CB at dose rates above approximately 100 rad/sec the yield is constant up to 100 Mrad.

(c) Within the experimental error the secondary yields are equal for both systems.

Experiments No.14 to 17 in Table II are included to show that appreciable temperature effect is not to be expected if oxygen is present in the system during irradiation. In experiments No.16 and 17 dissolved oxygen has been partly expelled by heating and by the evaporation of ethanol. The yields obtained are identical with those found for de-gassed systems \[8\].
Several experiments were made with 2-MeV electrons from a Van de Graaff accelerator. The 5-ml sample (system: ethanol, 4% water, 20% CB, 0.5 M diphenilamine) was irradiated in a container loosely covered with polyethylene film at the dose-rate of about $4 \times 10^5$ rad/sec. A constant yield was obtained up to a dose of about 40 Mrad, with exact linearity in the plot $[\text{Cl}^-]$ versus dose.

When stored in darkness, the systems are stable (no chloride could be observed after one year). In systems exposed to full daylight (clear sky, direct sunlight excluded) in pyrex flasks, the free chloride is generated at the rate of 1.2 and $6.6 \times 10^{-7}$ M/l h with 4 and 40% CB respectively. The effect of daylight is thus equivalent to the effect of 30 or 150 rad/h gamma radiation.

Experiments in which the effect of impurities in ethanol was examined are not yet conclusive. With high-purity ethanol ("Merck", aps, p.a.) less reproducible yields (between 4.7 and 5.7) were obtained at CB concentrations above 20%, the highest yields being equal to those obtained for de-gassed systems [8]. Therefore, for dosimetric use, commercial, analytical, or laboratory-grade ethanol, with the addition of 0.2 ml of benzene and 0.2 ml acetone per litre is recommended. If overall dosimetric accuracy higher than ± 5% is required, the exact $G(\text{Cl}^-)$, characteristic of the chemicals used, can be determined by comparison with the Fricke dosimeter. With 4% CB and 4% water, the yield for all grades of ethanol was identical within ±1.5%. The constant yield 4.90 with 40% CB at higher dose-rates appears to be a consequence of the identical effect of oxygen, impurities and radiolytic products.

3. DOSIMETRIC APPLICATION

Ethanolic $\text{Hg(NO}_3\text{)}_2$ solutions can be used for dosimetric measurements in the whole dose range between 0.1 and 5 Mrad. Five millilitre samples of dosimetric systems are recommended for all doses below 1 Mrad. An example of the scheme containing approximate data about doses, concentrations of standard mercuric nitrate, and standard NaCl, volume consumed per titrated sample, and sample volume, is given in Table III. As can be seen, only two concentrations of mercuric nitrate are necessary for the whole dose range encountered in radiation processing. To all samples, 1 ml ethanolic 0.2 M HNO$_3$ and 3 to 8 drops of 0.1% ethanolic diphenylcarbazone are added before titration. All samples are
### TABLE II. DOSE AND DOSE-RATE EFFECTS IN THE SYSTEMS: ETHANOL + 4% WATER + CHLOROBENZENE + DISSOLVED AIR

<table>
<thead>
<tr>
<th>No.</th>
<th>CB (vol.%)</th>
<th>$p$</th>
<th>$G_1$</th>
<th>id</th>
<th>$n_1$</th>
<th>D</th>
<th>$D_1$</th>
<th>$D_{01}$</th>
<th>$G_2$</th>
<th>id (sa)</th>
<th>$n_2$</th>
<th>$D_{max}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.4</td>
<td>5.00</td>
<td>0.03</td>
<td>4</td>
<td>1.4</td>
<td>5.9</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>2</td>
<td>0.4</td>
<td>4.08</td>
<td>0.02</td>
<td>2</td>
<td>17.0</td>
<td>43.0</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>3</td>
<td>1.3</td>
<td>4.09</td>
<td>0.00</td>
<td>3</td>
<td>18.0</td>
<td>20.0</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>4</td>
<td>4.5</td>
<td>3.72</td>
<td>0.08</td>
<td>2</td>
<td>1.6</td>
<td>8.2</td>
<td>40</td>
<td>3.06</td>
<td>0.08</td>
<td>3</td>
<td>257</td>
<td>-</td>
</tr>
<tr>
<td>5</td>
<td>13.0</td>
<td>3.53</td>
<td>0.02</td>
<td>3</td>
<td>3.4</td>
<td>40.0</td>
<td>0.60</td>
<td>3.07</td>
<td>(0.15)</td>
<td>2</td>
<td>225</td>
<td>-</td>
</tr>
<tr>
<td>6</td>
<td>130.0</td>
<td>3.76</td>
<td>0.06</td>
<td>3</td>
<td>8.7</td>
<td>77.0</td>
<td>250</td>
<td>2.93</td>
<td>0.05</td>
<td>3</td>
<td>1470</td>
<td>-</td>
</tr>
<tr>
<td>7</td>
<td>0.4</td>
<td>4.64</td>
<td>0.02</td>
<td>7</td>
<td>3.9</td>
<td>74.0</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>8</td>
<td>0.4</td>
<td>3.51</td>
<td>0.02</td>
<td>2</td>
<td>155.0</td>
<td>106.0</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>9</td>
<td>0.4</td>
<td>5.3</td>
<td>0.15</td>
<td>3</td>
<td>3.3</td>
<td>5.0</td>
<td>10</td>
<td>3.0</td>
<td>(0.2)</td>
<td>2</td>
<td>34</td>
<td>-</td>
</tr>
<tr>
<td>10</td>
<td>13.0</td>
<td>4.87</td>
<td>0.06</td>
<td>3</td>
<td>2.5</td>
<td>44.0</td>
<td>200</td>
<td>2.9</td>
<td>(0.1)</td>
<td>2</td>
<td>225</td>
<td>-</td>
</tr>
<tr>
<td>11</td>
<td>130.0</td>
<td>4.94</td>
<td>0.07</td>
<td>7</td>
<td>4.6</td>
<td>7010.0</td>
<td>-</td>
<td>(dose effect not observed)</td>
<td>-</td>
<td>-</td>
<td></td>
<td></td>
</tr>
<tr>
<td>12</td>
<td>0.4</td>
<td>4.94</td>
<td>0.06</td>
<td>3</td>
<td>1.7</td>
<td>3.5</td>
<td>15.0</td>
<td>2.33</td>
<td>0.07</td>
<td>5</td>
<td>428</td>
<td>-</td>
</tr>
<tr>
<td>13</td>
<td>130.0</td>
<td>4.94</td>
<td>0.06</td>
<td>3</td>
<td>2.5</td>
<td>44.0</td>
<td>200</td>
<td>2.9</td>
<td>(0.1)</td>
<td>2</td>
<td>225</td>
<td>-</td>
</tr>
<tr>
<td>14a</td>
<td>0.4</td>
<td>5.01</td>
<td>0.11</td>
<td>4</td>
<td>246.0</td>
<td>258.0</td>
<td>-</td>
<td>(air at 4 atm. 80°C)</td>
<td>-</td>
<td>-</td>
<td></td>
<td></td>
</tr>
<tr>
<td>15a</td>
<td>0.4</td>
<td>4.80</td>
<td>0.03</td>
<td>4</td>
<td>172.0</td>
<td>515.9</td>
<td>-</td>
<td>(air at 4 atm. 40-100°C)</td>
<td>-</td>
<td>-</td>
<td></td>
<td></td>
</tr>
<tr>
<td>16b</td>
<td>0.4</td>
<td>5.83</td>
<td>1</td>
<td>1</td>
<td>54.0</td>
<td>-</td>
<td>(irradiated open at 60±10°C)</td>
<td>-</td>
<td>-</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>17b</td>
<td>0.4</td>
<td>5.86</td>
<td>1</td>
<td>1</td>
<td>81.0</td>
<td>-</td>
<td>(irradiated open at 60±10°C)</td>
<td>-</td>
<td>-</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

a) Ampoules as a whole cooled to liquid oxygen temperature and sealed at atmospheric pressure.

b) Dissolved air expelled by heating and by evaporation at temperatures denoted.

c) Symbols:
- $P$ - approximate absorbed dose-rate (rad/sec).
- $G_1$ - initial $100 \text{ eV}$ yield of HCl derived from slope OX (Fig. 1), arithmetic mean.
- $G_2$ - secondary yield corresponding to slope BY in Fig. 1.
- $d$ - standard deviation of $G$-values; $a$: estimated uncertainty of $G_1$.
- $n_1$: number of experiments relevant to $G_1$ or $G_2$.
- $D$: lowest absorbed dose used, $10^{-14}$, eV cm$^{-3}$.
- $D_1$: highest dose of the experimental point lying upon OX of Fig. 1.
- $D_{01}$: abscissa of the intersection of OX with BY in Fig. 1.
- $D_{max}$: highest dose used, $10^{-14}$, eV cm$^{-3}$.
TABLE III. A SCHEME FOR THE ANALYSIS OF IRRADIATED DOSIMETERS

<table>
<thead>
<tr>
<th>Dose (Mrad)</th>
<th>Sample volume (ml)</th>
<th>(Hg(^2+) × 10(^3)) (N)</th>
<th>Volume consumed (ml)</th>
<th>(NaCl) (M)a</th>
<th>Volume added to 10 ml ethanol (ml)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.1</td>
<td>5</td>
<td>2</td>
<td>1</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>0.2</td>
<td>5</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>0.4</td>
<td>5</td>
<td>2</td>
<td>4</td>
<td>2</td>
<td>4</td>
</tr>
<tr>
<td>0.8</td>
<td>5</td>
<td>15</td>
<td>1</td>
<td>10</td>
<td>1</td>
</tr>
<tr>
<td>1.5</td>
<td>3</td>
<td>15</td>
<td>1.2</td>
<td>20</td>
<td>1</td>
</tr>
<tr>
<td>2.0</td>
<td>2</td>
<td>15</td>
<td>1.1</td>
<td>30</td>
<td>1</td>
</tr>
<tr>
<td>3.0</td>
<td>2</td>
<td>15</td>
<td>1.6</td>
<td>60</td>
<td>1</td>
</tr>
<tr>
<td>4.5</td>
<td>1</td>
<td>15</td>
<td>1.2</td>
<td>90</td>
<td>1</td>
</tr>
</tbody>
</table>

a) \(2 \times 10^{-3} \text{ M NaCl dissolved in ethanol} + 10\% \text{H}_2\text{O}; \) other concentrations are dissolved in distilled water.

diluted with ethanol to the total volume of approximately 10 ml for lower doses, or 15 ml for higher ones. Any one of chlorobenzene concentrations between 4 and 40% can be used. By changing \([CB]\) the electron density of the dosimeter is changed; it can thus be adapted to the electron density of objects subjected to radiation processing. 4% \(\text{CB}\) is recommended for doses of up to 1 Mrad at dose-rates above 15 rad/sec. Chlorobenzene concentrations of between 20 and 40% are used above 1 Mrad. They are of special interest for dosimetric measurements above 10 Mrad, possibly up to doses of 200 Mrad, or even higher.

Other data useful for dosimetric application are found in this paper in section 2 (particularly sub-sections 2.1.2., 2.1.4. and 2.2., and in Tables I and II).

4. CONCLUSION

As dosimeters for laboratory and industrial use at medium and high dose levels, and at higher dose-rates, the proposed systems ethanol-chlorobenzene have obvious advantages, namely, broad range covered with one simple and fast analytical technique, high accuracy, simple and fast preparation and low sensitivity to impurities. The limitations arising from the dose effect at low dose-rates are of no importance because the dosimeter is applied to higher dose-rates (radiation processing, calibration of strong radiation fields, and large sources). A small fraction of dose absorbed at low dose-rates cannot appreciably influence the overall accuracy of measurements. At low dose-rates the Fricke dosimeter can be applied. Further investigations are necessary for the elucidation of radiation chemical mechanisms governing the effect of impurities and
the dose limits of initial G-values. A very important field of future investigations is opened if these dosimeters are to be applied for measurements of intense electron beams, which seems to be possible and advantageous. The use of plastic (irradiated polyethylene) or metallic containers, and the prefabrication of dosimeters also seem possible. The development of automatic devices for titration, or for colorimetric determination of chloride ions, could be of interest in special cases.

ACKNOWLEDGEMENTS

The authors are grateful to the staff of the Laboratory of the Institute "Ruder Bošković" for having performed part of the dosimetric measurements. In particular, the senior author wishes to thank the Institute for having enabled him to visit the Laboratory for Radiation Sources of the Karpov Institute in Moscow, where most of the experiments were carried out.

REFERENCES


DISCUSSION

J. PAHISSA CAMPA: This is a most interesting dosimeter. Could you tell me, first, whether the efficiency is in any way dependent on the energy of the radiation; and secondly, whether there is any relation between efficiency and the geometry of the dosimeter, or to put it another way, whether the volume of the solution affects the efficiency.

I. A. DVORNIK: We made our measurements in strictly controlled geometry, using samples of 5 ml and 1 ml. No systematic attempt was made to study the effect that smaller quantities of solution might produce. As regards energy dependence, the system contains very little chlorine and the photoelectric effect should therefore be small. Our main concern was to check the linear relationship between product concentration and irradiation time, and there was no systematic calibration of the experiments.
ENERGY DISTRIBUTION IN ROTATING FRUIT UNDER UNIDIRECTIONAL ELECTRON IRRADIATION

K.H. CHADWICK
ASSOCIATION EURATOM-ITAL. WAGENINGEN, NETHERLANDS

Abstract — Résumé — Аннотация — Resumen

ENERGY DISTRIBUTION IN ROTATING FRUIT UNDER UNIDIRECTIONAL ELECTRON IRRADIATION. The paper shows how the energy distribution arising from electron irradiation is altered when the material under irradiation, for instance fruit, suffers a simultaneous rotation. The change in the energy distribution is derived in a semi-theoretical way and the results are compared with experiment. The various factors affecting the change in the energy distribution are considered with special reference to a spherical object. The experimental method used to measure the energy distribution is described briefly and its scope and limitations are discussed.

Both calculated and experimental results indicate that the peak of the energy distribution is shifted nearer to the surface of the material. It is shown that the dose relationship between a rotating and stationary object having the same exposure depends very largely on how and where the electron dose is defined and then to a lesser extent on the same factors which affect the rotational energy distribution. The effect that the change in energy distribution may have on the choice of dose is discussed and a request for a clear and standard definition of electron dose in food irradiation is made.

ROTATION DES FRUITS DANS UN FAISCEAU UNIDIRECTIONNEL D'ÉLECTRONS - DISTRIBUTION DE L'ÉNERGIE. L'auteur montre que la distribution de l'énergie sous une irradiation par des électrons se modifie lorsque le produit sous irradiation, par exemple des fruits, subit un mouvement de rotation. Cette modification est calculée d'une façon semi-théorique et l'on compare les résultats à ceux de l'expérience. Les divers facteurs modifiant la distribution de l'énergie sont étudiés plus particulièrement pour un objet sphérique. L'auteur expose brièvement la méthode expérimentale utilisée pour mesurer la distribution d'énergie, et discute sa portée et ses limitations.

Les résultats du calcul aussi bien que ceux de l'expérience indiquent que la crête de la distribution d'énergie se déplace vers l'extérieur de l'objet. L'auteur montre que le rapport entre les doses reçues par un objet tournant et par un objet fixe sous une exposition identique dépend dans une large mesure de la manière dont la dose d'électrons est déterminée et de l'endroit où elle est déterminée, et aussi, dans une moindre mesure, des facteurs qui influent sur la distribution d'énergie dans le cas de rotation. L'auteur discute les effets de la variation de la distribution d'énergie sur le choix de la dose et demande que l'on donne une définition claire et universelle de la dose d'électrons en matière d'irradiation de denrées alimentaires.

РАСПРЕДЕЛЕНИЕ ЭНЕРГИИ ВО ВРАЩАЮЩЕМСЯ ФРУКТЕ ПОД ОДНОНАПРАВЛЕННЫМ ЭЛЕКТРОННЫМ ОБЛУЧЕНИЕМ. Показано, как изменяется распределение энергии в результате электронного облучения, когда облучаемый материал, например фрукты, подвергается одновременному вращению. Изменение распределения энергии определяется полу-теоретическим путем, и результаты сравниваются с экспериментом. Различные факторы, влияющие на распределение энергии, рассматриваются со специальным упором на сферическую форму объекта. Дается краткое описание экспериментального метода, применяемого для распределения энергии, и рассматривается его диапазон и пределы.

Как вычисленные, так и экспериментальные результаты показывают, что пик распределения энергии сдвигается ближе к поверхности материала. Показывается, что дозовое соотношение между вращающимся и неподвижным объектом при той же экспозиции сильно зависит от того, как и где определяется электронная доза, и затем в меньшей степени от тех факторов, которые влияют на вращательные распределения энергии. Рассматривается влияние, которое может оказаться на выбор дозы изменение распределения энергии, обосновывается необходимость четкого и стандартного определения электронной дозы в области облучения пищевых продуктов.
DISTRIBUTION OF THE ENERGY IN FRUIT UNDER UNIDIRECTIONAL IRRADIATION. In the memory is studied the variation of the distribution of the energy of the radiations of the electronic type when the product that is irradiated — for example, fruit — experiences at the same time a movement of rotation. The variation of the distribution of the energy is deduced by a semi-theoretical procedure and the results are compared with the experimental data. The different factors that intervene in such a variation are considered in relation to an object spherical. It is described briefly the method applied to determine the distribution of energy and it examines its possibilities and limitations.

INTRODUCTION

The surface treatment of fruit and other foodstuffs with electron radiation is becoming more common. One of the requirements of the food technologists is that the surface dose should be uniform. In fruit which is spherical in shape the uniformity of the dose may be obtained by irradiation from several sides, or by rotating the fruit whilst irradiating perpendicular to the axis of rotation.

It is the purpose of this paper to bring to the notice of food technologists the effect of rotation on the distribution of energy in the fruit, and not to solve the practical problems arising from the effect.

THEORY

Consider (Fig. 1) a sphere of major radius, R, rotating about 0, under vertical electron irradiation penetrating to depth h. Then, as the point R moves with the rotation, the energy deposition along a radial section changes, e.g. at PP₁ only the very surface is irradiated, whereas at PP₂ much more of the radial section is receiving irradiation; but the energy distribution along the section depends on the vertical distance, 1, from the surface, the energy distribution varying with 1 as the normal Bragg curve of electrons (Fig. 2). At PP₃ the energy distribution along the radial section is the same as the normal Bragg curve — but only at this point.

Thus it can be seen that the integral energy distribution along any radial section does not follow the normal Bragg curve when rotation is complete.

It is possible to obtain a relationship between the value of 1 and the angle of rotation, and, by introducing an expression for the normal Bragg curve in terms of 1, an integral may be written which, when solved, gives the final energy distribution in the rotating material. This is, however, of purely academic interest as, in a practical case, one rarely has a completely normal Bragg curve in the material due to air scattering between the electron window and the material; also, in practice, the material is often made up of two or three layers of different densities.

It is interesting to know what sort of effect the rotation has on the distribution, and what factors affect it. Figure 3 shows a normal Bragg
FIG. 1. Cross-section of fruit rotating about 0 under electron irradiation penetrating to depth h

FIG. 2. Energy distribution for electrons of 1 and 1.5 MV

curve and two distributions with rotation, one when the radius is ten times the penetration, and the other when the radius is equal to the penetration. This clearly indicates the dependence of the distribution on radius and penetration. It is now important to realize that, in a sphere under rotation about one axis, all cases exist from 0 at (A) through $r_B = h(B)$ to $r_c = kh (C)$ (Fig. 4).
From Fig. 3 it can be seen that the main effect of rotation is to move the point of peak intensity nearer to the surface of the fruit. The question also arises as to what exposure should be given, and at what depth is the dose considered to be important. If the total dose in a radial section is measured during one rotation and compared with the total dose in a fruit which does not move, then the dose in the radial section is $\sim \frac{1}{3}$ of the total dose in the stationary fruit. If, on the other hand, the dose rising to 60% intensity in the rotating fruit is considered important, and is compared with the dose to the same depth in the stationary fruit, then the dose ratio is $\sim \frac{1}{3}$. Also, if the peak intensity is considered to be most important, the dose ratio is again close to $\frac{1}{3}$ in most practical cases, though the depth at which the peak intensity occurs is different.

**METHODS AND INSTRUMENTATION**

A simple method of measuring the energy distribution in rotating fruit has been developed. This makes use of the thermoluminescent property.
of lithium fluoride crystals mixed in Teflon tape\textsuperscript{1}. A small strip of the tape, about 3 mm wide, is pushed into a fine cut in the fruit, along a radius. After irradiation the tape is cross-cut into small slices, 0.5-mm thick, on a handmicrotome. Each slice is weighed accurately and then read out on a Conrad TLD unit. The reproducibility of this method was measured, by giving the whole strip of tape the same dose, and was found to be within 8\%. When smaller slices were used, 0.25 mm., irregularities in the readings were found. The light reading of each slice is normalized to unit weight, and then plotted on graph paper against its position in the strip of tape. The weight is taken as an indication of the thickness of the slice.

The effect that the tape might have on the electron beam was investigated by irradiating strips surrounded by Teflon and Perspex. Two different Bragg curves were obtained, giving penetrations equivalent to the two densities of the Teflon and Perspex. This indicated that the tape has little effect on the electron beam, and the measured energy distribution is caused by scattering of electrons in the tissue surrounding the tape.

In all stationary measurements, however, the first slice was always found to be very high. This is attributed to the fact that the energy deposition is mainly determined by the tape, and not by the tissue surrounding the tape.

The energy distributions measured in a rotating orange, and in a stationary one, at an electron energy of 1.5 MeV, are shown in Fig. 5. Calculation of the rotational effect on the measured stationary distribution, for a radius of 3.75 cm, gives a good agreement with the measured distribution.

DISCUSSION

Two points of importance in the surface treatments of food with electrons are the uniformity of dose, and the maximum dose delivered to

\textsuperscript{1} Marketed by Controls for Radiation Inc.
a cell layer. When the fruit is rotated, the surface uniformity is considerably improved, more than, for instance, the irradiation of fruit from two sides, although the cell layers receiving most energy are closer to the surface. At different rotational radii the energy distribution in the sub- (skin) layers is different. It does not, however, change very much over most of the fruit, and only at the very extremities of the fruit does the distribution change very radically. The cell layer which receives most energy lies at a small spot at the two polar extremities, just below the surface, when the rotational radius $r = h/3$, i.e. the point of rotation at this radius is always at the peak of the normal Bragg curve.

It is relatively simple to consider the theoretical case of a perfect sphere in rotation with only one rotational axis, but with normal fruit the sphere is only approximated — in the author's experience there is a tendency for fruit to rock, or even to change the axis of rotation completely by 90°. When this occurs the uniformity of dose is, of course, further improved, and the spots of high intensity are avoided.

It is beyond the scope of this paper to consider whether the shift of the peak intensity nearer the surface, on rotation, will have any effect on the choice of dose. The author believes that food technologists must now decide just where the electron dose is considered to be measured,
at the surface of the fruit, or at the peak of the distribution, and also if the depth of this peak of intensity is important. Standardization of the electron dose, in definition, would enable easier comparison of experiments and assist in the development of a routine dosimeter system.

DISCUSSION

P. VIDAL: While listening to Mr. Chadwick's most interesting paper I was struck by two problems that might arise if this system were used on an industrial scale. Firstly, has anyone considered how rotating fruits could be processed in quantities of, say, 1 to 1½ ton/h? Secondly, some fruits, such as peaches, apricots and strawberries, are too delicate to bear much handling, and one wonders whether they could survive this process in good condition.

K. H. CHADWICK: As a physicist I do not feel qualified to give anything like a definite answer to these questions. However, the difficulty of handling large quantities of fruit in this way could perhaps be overcome by devising a continuous roller-conveyor passing through an electron beam. I believe that some work has been done along these lines with oranges. As to the handling of delicate fruits, we have in fact had some damage from rolling. Lately, however, we have been using a foam latex which has rather good radiation resistance and considerably reduces damage from the rotation of the fruit.
WHOLESAOMENESS OF IRRADIATED FOOD

(Session II)
OPENING ADDRESS

J. SPAANDER

(Chairman)

Ladies and Gentlemen, I feel highly honoured that the organizers of this Symposium should have asked me to take the chair at this session. However, my first act as Chairman must be to apologize for the fact that I do not really understand the meaning of the word "wholesomeness", to which this Session is entirely devoted.

The word "wholesomeness" has been haunting this and other symposia for several years. At an international symposium in 1961, in Brussels, we agreed that the term implied nutritional value and safety for consumption. One difficulty is that there is no one-word equivalent of "wholesomeness" in any of the languages with which I am acquainted. In 1964, in Rome, we again discussed the problem and concluded that "wholesomeness" also contained the idea of microbiological safety.

From the public health point of view, which is important in so far as irradiated products may eventually be exported from one country to another and public health officials thereby involved, I would say that there are three aspects to "wholesomeness": safety for consumption, nutritional adequacy, and microbiological safety.

If, some day, irradiated food circulates within a community (national or international), potential consumers are going to ask whether it is safe for consumption. I therefore suggest that the word "wholesomeness" be replaced by the term "safety for consumption", which is easier to understand and which equally well covers the aspects of nutritional value and microbiological safety.

Perhaps this Symposium can help to define the word "wholesomeness" more closely. Otherwise, it should be replaced by a term which is clearly understood and can be used by legislators in different countries.
UNITED KINGDOM FOOD IRRADIATION PROGRAMME — WHOLESOMENESS ASPECTS

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Abstract — Résumé — Аннотация — Resumen

UNITED KINGDOM FOOD IRRADIATION PROGRAMME — WHOLESOMENESS ASPECTS. Tests for wholesomeness carried out in the United Kingdom as a part of the food irradiation programme are described. Both short-term animal feeding studies in rats, chickens and pigs, and long-term studies in rats and mice, have failed to demonstrate any adverse effects attributable to the consumption of irradiated food by the animals. The animal feeding tests have been designed with specific irradiation processes in mind, and all of these processes have involved the use of low, or moderate radiation doses. Thus, grain treated with 20 000 and 200 000 rad gamma radiation, and frozen egg (irradiated to kill Salmonellae) treated with 0.5 and 1.0 Mrad have been tested by feeding to animals. Ham, irradiated with 250 000 rad to prolong its shelf life, has been tested, and also ham irradiated with 2 Mrad. Currently, long-term studies are in progress to investigate the wholesomeness of fish treated with 0.6 Mrad (the maximum dose likely to be used to provide extended refrigerated (0°-4°C) storage life). Short-term tests have also been undertaken with potatoes (10 000 rad) and horse flesh (0.65 Mrad).

The nutritional quality of irradiated grain, egg, fish and some animal feedings-stuffs has been investigated, using microbiological assay techniques. Losses in the B vitamins have been found comparable with those reported by workers in the United States and are of the same order of magnitude as losses occurring on heating, although differences were observed in the sensitivity of individual vitamins towards heat and irradiation. The losses in B vitamins occurring on irradiation and cooking were found to be additive. No effects on the nutritional value of protein have been found.

In 1962 the United Kingdom Ministry of Health set up a Working Party to review the effects of irradiation on food, and to report on the necessity for official control. The report of the working party, published in 1964, is discussed in relation to the wholesomeness tests carried out in the United Kingdom.
PROGRAMA DE IRRADIACIÓN DE ALIMENTOS: EL PROBLEMA DE LA COMESTIBILIDAD. En la memoria se describen las pruebas de comestibilidad realizadas en el Reino Unido como parte del programa de irradiación de alimentos. Se han efectuado estudios a corto plazo con ratas, pollos y cerdos, y a largo plazo con ratas y ratones, y no se han observado efectos perniciosos que puedan atribuirse al consumo de alimentos irradiados por dichos animales.

Estas pruebas se efectuaron pensando en procesos específicos de irradiación con dosis bajas o moderadas. Se utilizaron, en efecto, cereales sometidos a 20 000 y 200 000 rad de rayos gamma y huevos congelados, irradiados con 0,5 y 1,0 Mrad para eliminar las Salmoellae. Además se han realizado pruebas con jamón tratado con dosis de 250 000 rad, para prolongar el período de almacenamiento, y con dosis de 2 Mrad. Se están ejecutando estudios a largo plazo con el fin de investigar la comestibilidad del pescado tratado con 0,6 Mrad (la dosis máxima que probablemente se administrará para prolongar el período de almacenamiento en frigorífico (0°-4°C)). También se han emprendido pruebas de corte duración con patatas (10 000 rad) y carne de caballo (0,65 Mrad).

Se han investigado, por análisis microbiológico, las propiedades nutritivas de los cereales, los huevos, el pescado y algunos alimentos de consumo animal irradiados. Las pérdidas de vitaminas B son análogas a las indicadas por investigadores de los Estados Unidos, y son del mismo orden de magnitud que las que ocasiona el tratamiento térmico, aunque se ha observado que la sensibilidad de determinadas vitaminas al calor y a la irradiación es diferente. Las pérdidas de vitaminas B producidas por irradiación y cochinera son acumulativas. No se ha observado efecto alguno en el valor nutritivo de las proteínas.

En 1962, el Ministerio de Sanidad Pública del Reino Unido constituyó un Grupo de trabajo encargado de estudiar los efectos de las radiaciones en los alimentos y de presentar un informe sobre la necesidad de controles oficiales. En la memoria se examina el informe del Grupo de trabajo, publicado en 1964, en relación con las pruebas de comestibilidad efectuadas en el Reino Unido.
INTRODUCTION

If sufficient food is to be available to maintain a rapidly growing population of consumers in good health, advantage must be taken of modern developments in food technology, and especially of improved methods of food preservation. Plans to increase world food production will be thwarted if a large part of the increased production is spoiled due to bacterial activity or the depredations of insects before it can be consumed, or if it cannot be safely consumed because it is contaminated with pathogenic organisms.

Many of the new preservation processes are direct developments from the older, traditional methods, such as heating, drying, refrigeration and curing. The underlying principles of these processes have been used for preserving food since antiquity and, by reason of their long use, they are generally accepted as safe. In contrast, processing by irradiation involves a novel principle and, in an atmosphere of increased caution stimulated by the increasing use of chemical food additives and pesticides, the consumer demands reassurance that no hazard to his health will arise if he eats irradiated food. Even at the earliest stages in the development of the process it was realized that most stringent tests to determine the wholesomeness of irradiated food would be an essential preliminary to any proposed commercial application of the process. For a number of years animal feeding tests on irradiated food have been in progress in several countries, particularly in the United States; many of these tests are completed and the results support a general conclusion that irradiated food is entirely safe for human consumption. In certain countries, including the United States and Canada, the evidence for the wholesomeness of certain irradiated foods has already been subject to detailed scrutiny by the appropriate authorities who have permitted the use of radiation for the treatment of a few foods irradiated under defined conditions. In other countries, including the United Kingdom, no such permission has yet been granted, but this is because the legislative action necessary before an appraisal can take place has not yet been completed. In no instance has an irradiation process been prohibited officially on the grounds that there is evidence that the treated food is harmful.

In the United Kingdom legislation to control food irradiation is awaited. It is expected that this will be enacted in the near future. In 1962 a Working Party on Food Irradiation was set up by the Ministry of Health to consider whether the medical and scientific information available indicated a need for official control of food irradiation processes, and to advise on the principles which should govern any official control. The Working Party concluded that the use of irradiation for the treatment of food intended for human consumption should be controlled. They recommended that control be achieved by prohibiting food irradiation but with provision for exemptions to the general prohibiting regulations. They recommended that a scrutinizing body should be set up to consider applications for exemption from the prohibiting control. The applications must be supported by adequate evidence of the safety of the irradiated food.
TABLE I. TOXICOLOGICAL INVESTIGATIONS ON IRRADIATED FOOD UNDERTAKEN IN THE UNITED KINGDOM

Long-term tests

<table>
<thead>
<tr>
<th>Food</th>
<th>Object of irradiation</th>
<th>Radiation dose tested (Mrad)</th>
<th>Species</th>
<th>Status of experiments</th>
<th>Ref.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wheat</td>
<td>Disinfestation</td>
<td>0.02 and 0.2</td>
<td>Rat, Mouse</td>
<td>Complete</td>
<td>[2-7]</td>
</tr>
<tr>
<td>Frozen whole egg</td>
<td>Elimination of Salmonellae</td>
<td>0.5 and 1.0</td>
<td>Rat, Mouse</td>
<td>Complete, except histopathology</td>
<td>[8]</td>
</tr>
<tr>
<td>Ham a)</td>
<td>Extension of shelf life</td>
<td>0.25 and 2.0</td>
<td>Rat, Mouse</td>
<td>Complete</td>
<td>[9]</td>
</tr>
<tr>
<td>Codfish</td>
<td>Extension of storage life at 0°-3°C</td>
<td>0.6</td>
<td>Rat, Mouse</td>
<td>In progress</td>
<td></td>
</tr>
<tr>
<td>Frozen horse meat</td>
<td>Elimination of Salmonellae</td>
<td>0.65</td>
<td>Rat</td>
<td>In progress</td>
<td></td>
</tr>
</tbody>
</table>

a) This investigation was conducted at the Unilever Research Laboratory. All other investigations listed have been conducted at Wantage Research Laboratory.
### TABLE I (cont.)

**Short-term tests**

<table>
<thead>
<tr>
<th>Food</th>
<th>Object of irradiation</th>
<th>Radiation dose tested (Mrad)</th>
<th>Species</th>
<th>Status of experiments</th>
<th>Ref.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wheat</td>
<td>Disinfection</td>
<td>0.0195</td>
<td>Chicken</td>
<td>Complete</td>
<td>[10]</td>
</tr>
<tr>
<td>Potatoes</td>
<td>Inhibition of sprouting</td>
<td>0.01</td>
<td>Pigs</td>
<td>Complete</td>
<td>[11]</td>
</tr>
<tr>
<td>Codfish treated with anti-drip reagent</td>
<td>Extension of storage life at 0°-3°C</td>
<td>0.6</td>
<td>Rat</td>
<td>Complete</td>
<td>-</td>
</tr>
<tr>
<td>Miscellaneous foods and food components</td>
<td></td>
<td></td>
<td>Various</td>
<td>Complete</td>
<td>-</td>
</tr>
</tbody>
</table>
Feeding tests using animals have been undertaken in the United Kingdom to permit an appraisal of the safety of irradiated food. In Table I the foods already tested, or currently being tested for wholesomeness, are listed. Most of the feeding studies shown have been undertaken at Wantage Research Laboratory (UKAEA) where there is an Animal House suitable for this type of investigation, and also the large radiation sources capable of treating the considerable quantity of food required for the tests. The foods chosen for wholesomeness testing at Wantage have been those for which irradiation appears promising as a result of research at Wantage and other government sponsored laboratories, including the Low Temperature Research Station, Cambridge, and the Torry Research Station, Aberdeen. There has been close collaboration with the food industry which has been encouraged to engage in specific items of research on food irradiation; one extensive series of long-term feeding tests (on irradiated ham) was undertaken by an industrial organization.

Adequate controls have been included in all the experiments shown in Table I. Experiments listed as 'long-term' involved more than six months' feeding studies and many extended over at least two years in rats and 80 weeks in mice. These experiments included studies of growth, food utilization, fertility, lactation, organ function, haematology, mortality and histopathology. The exceptions are investigations on irradiated egg, using rats, where infection caused the experiment to be terminated before two years, and the experiments on irradiated horse meat which it is intended to terminate before two years. Included under the term 'short-term' are those experiments that were of at least four weeks' duration, but not longer than six months' duration.

No adverse effects that could be attributed to the consumption of irradiated food have been observed in any of the experiments listed in Table I.

THE DESIGN OF LONG-TERM FEEDING EXPERIMENTS IN RELATION TO THE CURRENT STATUS OF FOOD IRRADIATION

A great deal of evidence on the safety of irradiated food in general is now available. Although this general evidence is quite convincing it is likely that the Public Health Authorities will demand specific evidence for the safety of individual irradiated foods treated in a well-defined manner that relates directly to the proposed application. In the United Kingdom the Working Party in their report [1] recommended that, "Initially, exemption [i.e. clearance] be granted after consideration of an application therefor, which is supported by adequate evidence, in respect of an individual food product treated by irradiation in a defined manner", and that the evidence should relate, amongst other things, to "the nature and results of tests for wholesomeness carried out on food irradiated under specified conditions, stored, and then cooked if cooking be usual before the food is consumed".

In the past, wholesomeness tests have often been started early in the development of a particular irradiation process because of the time needed to complete the tests. However, factors discovered during
subsequent investigations into the feasibility of the process often result in changes so that the food irradiated for animal feeding tests has been treated under different conditions to those likely to be used in the final commercial plant when it is built.

With so much background information on wholesomeness already available the object of the wholesomeness test is to prove that a food irradiated in a specific manner is not the exception, rather than add to the evidence already available to show the process is likely to be safe. Therefore, it is advisable to delay starting wholesomeness tests until a much later stage in the development of the process, and then to design the investigation on the basis of the detailed knowledge of the proposed process. Scientific judgement should be exercised to decide whether life-span studies are justified, or whether toxicity tests over a period of three or six months might be sufficient to adequately supplement the general evidence available. This decision can only be made when considering an individual food. If considerable evidence of the safety of the specific food and closely related foods in terms of chemical composition, irradiated in a broadly similar manner (e.g. at a different temperature), is already available, the shorter tests would probably suffice. On the other hand, if little evidence is available on the specific food, long-term tests would be indicated. If shorter experiments are envisaged, it would be advisable to design the experiments so that they can be extended to life-span tests, if necessary, and then to submit the evidence from the first few months of the experiment in the application to the authorities; if further data from life-span studies were demanded, the data could then be provided within a short period.

The ideal time for starting wholesomeness tests, and the type of evidence required in support of an application to irradiate food, may change as the process becomes established. An indication of the trend of official thought in the United Kingdom can, perhaps, be gained from another of the Working Party's recommendations: "After experience has been gained of such a procedure consideration [may] be given to the granting of exemption after examination of an application therefor supported by adequate evidence, for groups of similar foods and food products treated in similar ways".

To satisfy the requirements that evidence shall be obtained "in respect of an individual food product treated by irradiation in a defined manner", as recommended by the Working Party, attention must be given to the following factors when the feeding tests are designed:

Food: Specification and other processing; Level of feeding in the diet;

Process: Radiation source, dose (within defined limits), and dose-rate; Temperature and gas conditions during irradiation; Duration of storage, and storage conditions before and after irradiation;

Package: Toxicological considerations.

The author's attempts to incorporate these requirements into the design of recent experiments are illustrated below.
Food

Specification

The food used for animal feeding tests should be of the same quality as that likely to be irradiated for human consumption. If the radiation process is likely to be applied to several varieties of a food, a blend of the different qualities may be used for wholesomeness tests. For example, for feeding tests on irradiated horse meat, samples of each of the four main types of frozen horse meat, hinds, fores, trimmings and BCS\(^1\) were purchased, irradiated, and each type stored separately. Equal quantities of each type of meat were then blended for admixture into the experimental diets.

If the object of the irradiation process is to eliminate pathogenic organisms from the food, problems may arise: the control samples (unirradiated) may be contaminated and there is a danger of infection in the animals consuming the food. For example, experiments on frozen whole egg were frustrated after 18 months' feeding because chronic Salmonellosis was found in the rats. The egg had been purchased from a reputable supplier and all feasible precautions had been taken to ensure that it was Salmonella-free. The egg offered to the rats was in a baked product and strict precautions were taken throughout to avoid cross-contamination from the raw egg to the baked product. Even so, the precautions failed. It was found that the raw, unirradiated egg was contaminated; \(S.\) gallinorum, \(S.\) pullorum and \(S.\) typhimurium were identified in samples of the egg, and all of these strains were present in the gastrointestinal tract of the rats after 18 months' feeding.

Treatments other than irradiation

Many foods are subjected to some form of treatment in addition to the radiation process. The commonest example is domestic cooking before the food is consumed, but other food processes or the use of chemical additives may also be involved. These treatments could influence the wholesomeness of the food and ought, therefore, to be considered when designing the experiments. For example, more than 95% of the frozen whole egg used in the United Kingdom is used by bakers for preparing cakes and other baked products; therefore, before feeding to animals the egg was prepared for use in the diets by baking it into a sponge cake. Since fish is normally cooked before consumption, in the experiments the fillets were steamed to cook them before incorporating them in the diet. Furthermore, prepackaged, filleted fish is liable to exude drip that renders the product unattractive to the housewife and chemical additives may be used to reduce drip formation. In addition to testing the wholesomeness of irradiated, and then cooked, fish, in long-term feeding tests, the wholesomeness of fish treated with an antidrip reagent (tétrapotassium pyrophosphate) that was irradiated, stored and cooked before feeding was also investigated. The latter investigation was of three months' duration.

\(^1\) BCS = clubless forequarters.
Level of irradiated food in the diet

There is a fundamental difference between testing the safety in use of a chemical additive used in food, and in testing the safety for consumption of a processed food, such as irradiated food. With the additive it is known what the potentially toxic material is. The absorption and metabolism of the compound can usually be studied and, in addition, it is normal to feed the compound in exaggerated quantities to animals in long-term tests. Frequently a 100-times factor is applied (the argument being that the most sensitive individuals are unlikely to be more than ten times as susceptible as the average in a population, and another factor of ten times is added to allow for possible species susceptibility, the combination of both of these resulting in a 100-times safety factor). However, with irradiated food where complex chemical changes might occur, the nature of any potentially toxic substances produced on irradiation might not be completely known. It was the practice, therefore, to feed the irradiated food as the highest possible proportion of the diet, with the object of demonstrating that no ill effects can be observed in animals fed under such conditions. However, care must be taken to ensure that the abnormally high intake of one kind of food (regardless of irradiation) does not affect the animals.

It is considered that preliminary tests to determine the optimal proportion of the irradiated food in the diet are worth while; these tests include studies of the growth of young animals, and the reproductive capacity and maintenance requirements of older animals using diets with varying proportions of the food it is intended to study. Although much useful information can be derived from tables of food composition, it has been found inadvisable to formulate the diet merely by equating this information with the known nutritional requirements of the animal. For example, it was calculated that a diet containing 60% fish and 40% of a stock rat diet would be optimal for the rat. In preliminary studies this diet was found to be suboptimal both for the growth of male rats, and for lactation in the females, whereas normal growth and lactation were observed when the diet contained 45% fish and 55% of the stock rat diet. Supplementation with additional vitamins and mineral salts did not correct the effect observed with the 60% fish diet and it was decided to use the 45% fish diet in long-term wholesomeness studies.

It is helpful if estimations of the loss in essential nutrients on irradiation can be undertaken concurrently with the preliminary feeding studies. The diets used in long-term tests can then be supplemented to allow for any loss in nutritive value and avoid any deficiency in animals on the irradiated diet.

Process

The process likely to be used for the treatment of food intended for human consumption should be used, as far as is practicable, for treating the food to be consumed by animals in wholesomeness tests.

Radiation dose (within defined limits) and dose-rate

The selection of the dose of radiation applied to the food used in wholesomeness tests may require some thought. For many processes
the dose will be well defined, and that dose would be used for treating the food for feeding tests. For example, the radiation dose required to eliminate Salmonellae from frozen horse meat is 0.65 Mrad (the dose necessary to give the required degree of inactivation for \textit{S. typhimurium}). With other processes, as in the case of fish irradiated to extend its chilled-storage life, the dose may not be well defined. With fish, the degree of initial contamination with spoilage bacteria, and the time during which it may be required to store the fish, influence the radiation dose required, and if it is required to treat fish that has been filleted and frozen at sea, a lower radiation dose will be required than to treat fish that is several days old on landing at the port and that has not been frozen at sea. To allow for this eventuality the highest dose likely to be used in practice (0.6 Mrad in the case of fish) was used to treat the food fed to animals in feeding tests, although it is known that a lower dose may well be used in practice.

In a commercially-operating plant, food will be irradiated within defined limits of radiation dose. The dose limits will depend upon the design of the plant and the size and density of the units of material being treated. If it is possible, this dose distribution should be simulated in the food being treated for animal feeding tests. Before the feeding studies on irradiated horse meat were started, design studies had been completed on a plant to irradiate frozen horse meat at the Port of London, and it was calculated that the meat will receive an average dose of 0.65 Mrad with dose limits of 0.5 to 0.75 Mrad. Horse meat irradiated for animal feeding trials has been treated at a carefully selected position in a radiation plant so that it received an average dose of 0.68 Mrad within the defined limits of 0.58 to 0.75 Mrad, a close approximation to the conditions that will appertain to the commercial plant.

It is more difficult in practice to simulate the dose-rate that might occur in the commercial plant, but this should be done if possible. However, dose-rate effects only become particularly important with relation to the chemical change in the treated food if there are large differences in the dose-rate. This is likely to be of importance in comparisons of gamma- and electron-irradiation and, thus, if a potential process appears better suited to gamma radiation, this radiation should be used for treating the food used for animal feeding tests, and similarly with electrons.

In the past it has been the practice to include a group of animals fed food irradiated at higher dose levels than those intended to be used in practice, as well as testing on a group of animals fed food irradiated at the proposed dose level. For example, in the tests on wheat, grain treated with 20000 rad (the dose required for disinfestation) and also grain treated with 200000 rad (ten times the disinfestation dose) was used. This procedure seems irrational if the considerations referred to above are taken into account. The safety margin is achieved by feeding high levels of food irradiated at the proposed dose rather than by feeding intentionally over-irradiated food. If the problem were to assess the safety of food baked at 450°F, it is doubtful if many investigators would favour testing food baked at ten times, or even twice that temperature!
Temperature and gas conditions during irradiation

The temperature of the food and the gas conditions when it is irradiated are known to have a marked effect on the extent and nature of the chemical changes that occur. It is evident, therefore, that these factors must be rigidly controlled when food is irradiated for use in feeding tests. It may be possible to irradiate the food in a radiation cell equipped with a means of temperature control, but in practice it is more realistic for most purposes to use a large radiation plant intended for medical sterilization because the dose-rate and the dose limits that can be achieved are closer to those likely to be found in large-scale food irradiation plants. This type of radiation plant is not usually provided with any means of rigid temperature control. In practice, the use of insulated containers for irradiation has been found quite satisfactory. For example, horse meat will be irradiated in the frozen state at about -12°C in commercial practice. Horse meat for animal feeding tests was cooled to -15°C and packed in heavily insulated containers for overnight irradiation; the temperature rise at the surface of the meat was about 3°C during the 18-h period required for transportation to and from the radiation cell, and for irradiation. Similarly, fish which it is proposed to irradiate at a temperature of between 0°C and 3°C in commercial practice, was irradiated in an insulated container surrounded by an ice-water mixture.

The gas conditions will be largely regulated by the type of package intended for the food, and this method of packaging should be used for the food irradiated for animal feeding. For example, the fish was vacuum-packed in a plastic laminate impervious to air, whilst horse meat was irradiated in air, loosely wrapped in polyethylene sheeting, or surrounded by hessian sacking.

Duration and conditions of storage before and after irradiation

Attempts should be made to simulate pre-irradiation and post-irradiation conditions and storage times for the food used for animal feeding tests. For example, the fish used was filleted and frozen at sea (this is the type of fish product that will be treated by irradiation in practice) and it was packaged immediately on delivery. The fish was placed in an ice-water mixture for irradiation and then maintained at 0°-3°C for 12 d before cooking and use in the diet. This post-irradiation storage was designed to simulate the delivery of the irradiated fish to the retail outlet on ice, and to allow a realistic period during which the fish might remain in the chilled cabinet in the shop before sale. It may be difficult to simulate exactly the storage period of foods that have a long life after irradiation as in practice the food might be consumed within a few days of irradiation, or it might remain in store for several months or even years before consumption. In designing animal feeding tests, some reasonable storage period can be used; for example, frozen horse meat used in the experiments is irradiated in batches sufficient to last for four months of the experiment, and whilst meat fed early in the experiment was irradiated only three weeks previously, meat fed after four months had been stored for nearly five months before the animals consumed it.
Although certain foods require no packaging for the radiation process to be efficient (e.g., potatoes irradiated to inhibit sprouting), most food irradiation processes depend on the food being treated in a sealed package to prevent reinfection after treatment. One of the advantages of irradiation is that a very wide range of packaging materials is suitable for use with the process.

Two basic toxicological questions arise: (a) do any toxic substances arise when the package is irradiated and, if so, do they migrate into the food? (b) if toxic compounds are formed, are the quantities likely to be consumed sufficient to cause harm? Various approaches can be used to evaluate the safety of the irradiated package and probably no single approach will give undisputable answers to both questions.

One approach is to investigate the toxicological properties of the irradiated packages per se. These investigations may consist of extraction studies, or feeding studies, or both. These methods are extremely useful for investigating the safety of new formulations of packaging materials. Extraction studies, intelligently planned, rely on a prior knowledge of the nature of any plasticizers, lubricants and other intentional additives that are included in the formulation. A knowledge of the total quantity of extractive is of little value to the toxicologist unless he also knows what compounds are present in the extract. When the problem is to determine the quantities of known compounds leached out of the package it may be difficult enough to provide the answers the toxicologist requires; foods may interfere with the analytical procedures used and food-simulating solvents may have to be used. However, when the package is irradiated the chemical changes occurring in the packaging material may not be fully understood, so there remains an even more difficult analytical problem, identification of the products in the small amounts of extractive. Feeding tests in animals to determine the toxicity of the packaging materials after irradiation provide a much more direct way of ascertaining the safety in use; but these tests are likely to be as costly and time-consuming as the tests applied to the irradiated food itself.

An alternative approach is to test the safety of food that has been irradiated in its package. Provided the experiment is properly designed to take into account both the food and the package, the evidence of safety under these conditions is surely the proof that is required. The proportion of packaging extractive fed to the animals will be exaggerated to the same extent that the proportion of the food item in the total diet is also exaggerated. However, if the results are to be considered valid, certain precautions must be taken, especially with respect to the surface-of-package to weight-of-food ratio. For example, in tests on fish, individual fillets (weighing about ½ - 1 lb) were packaged separately, as they would be in a commercial process. It would not have been realistic to package a block of 28 lb of fillets in one wrapper since the surface area would have been increased only 5 to 10 times for an increase in packed weight of fish of 30 to 50 times.

With the large range of packaging materials available today, it may well happen that different manufacturers will prefer different packaging materials for their brand of a certain irradiated food. However, relatively few materials possess the ideal characteristics for the surface
that will be in immediate contact with the food, so that results from feeding tests on food irradiated in a well-chosen packaging material might well be also applicable for other packaging materials. For example, at least three different formulations of laminates are suitable for vacuum-packing of fish but these all have polyethylene film as the inner layer due to its good heat-sealing properties. One of these laminates was selected for testing, a polyethylene-nylon film, but the results should still have relevance, even if one of the other laminates were to be used in practice.

EVIDENCE ON RADIATION-STERILIZED LABORATORY ANIMAL DIETS

In addition to the carefully-planned experiments described previously, a large amount of incidental evidence for the wholesomeness of irradiated food has accrued from the large-scale use of radiation-sterilization techniques for the treatment of diets fed to SPF2 and germ-free colonies of laboratory animals. In one laboratory a long-term comparison has been made over a two-year period in a breeding colony of SPF rats. One hundred breeding pairs were fed irradiated diet and 100 pairs were fed the same diet that had not been sterilized. Statistical analysis showed the irradiated diet to be as satisfactory for sustaining the colony as the untreated diet [12]. At Wantage the growth of rats fed either radiation-sterilized, or untreated rat diet has been compared; no differences were observed.

Many hundreds of tons of animal diets have now been sterilized with 2.5-Mrad gamma radiation. Most has been fed to rats and mice, but diets for SPF and germ-free guinea pigs, rabbits and chicken have also been sterilized in this manner. Whilst there has been no comparable control group of animals, the animals receiving the irradiated food have been very carefully observed. With a single exception, no evidence of any adverse effect attributable to the radiation treatment of the diet has been observed; the exception concerns very young, hand-reared rabbits that appeared very sensitive towards spray-dried milk which had been irradiated with 5 Mrad of gamma radiation. It is suspected that the increased mortality might be due to an allergic response [13]. This effect is to be investigated further, but it is doubtful, on the basis of present evidence, whether it is relevant to the wholesomeness of irradiated food.

TESTS FOR TOXICITY AND MUTAGENICITY USING LOWER LIFE FORMS: THEIR RELEVANCE TO THE WHOLESOMENESS PROBLEM

It is recognized that any judgement on the safety of irradiated food for man that is based on studies in animals involves a degree of extrapolation that is open to criticism. However, such tests do give a degree of confidence that can only be improved on by feeding irradiated food to man himself. In recent years much controversy has been aroused as a result of tests using much simpler forms of life, such as isolated cells and insects. Cytotoxic effects and mutations have been observed when

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2 Specific pathogen-free.
cells or insects have been grown on irradiated media, or on a medium containing irradiated components. If extrapolation from whole animals (mammals) to man can be criticized, the validity of the findings in the lower life forms, when extrapolated to man, must indeed be suspect. It is perhaps timely to consider the relevance of these results in relation to the wholesomeness of irradiated food.

Recently, the work of Holsten, Sugii and Steward [14] has attracted attention. These workers report that the radiolysis products of sugars are harmful to plant cells and are capable of inducing chromosome abnormalities in *Vicia faba* and in *Tradescantia paludosa*. Similar effects on the chromosomes of plant cells grown on a variety of irradiated media have been reported previously [15-17]. Molin and Ehrenberg have provided evidence of the cytotoxicity of irradiated dextrose to bacteria [18]. In the United Kingdom, Berry, Hills and Trillwood, using two lines of mammalian cells in tissue culture, demonstrated the presence of a cytotoxic agent in radiation-sterilized dextrose and fructose; autoclaved dextrose and fructose solutions also possessed cytotoxicity, but this became less pronounced on storage, whereas the irradiated solutions retained their cytotoxicity for more than six months [19].

A number of investigations have also been completed on the effect of irradiated medium (or irradiated substances added to the medium) on the fruit-fly, *Drosophila melanogaster*. In 1957, Henderson, Baxter and Tuttle observed small differences between an irradiated and unirradiated growth medium when they studied five generations of *Drosophila* reared on them [20]. These workers attributed the differences they observed to a nutritional effect rather than to any toxic manifestation, and they concluded that the effect was of questionable biological significance. More recently, however, Swaminathan, Nirula, Natarajan and Sharm [21], working in India, and Rinehart and Ratty [22] in the United States have reported an increase in mutations in *Drosophila* grown on irradiated media, but this finding is contrary to the results from other Indian work by Reddi, Reddy, Rao, Ebenezer and Rao [23] who were unable to demonstrate genetical effects under similar circumstances. Recent work of Parkash has shown irradiated DNA to be strongly mutagenic to *Drosophila* [24].

In the United Kingdom two laboratories have been engaged in work with *Drosophila* which is intended to investigate the findings of Swaminathan *et al.* [21] and of Parkash [24]. At the Institute of Animal Genetics, Edinburgh, Chopra has been unable to demonstrate mutagenic effects either when *Drosophila* was grown on irradiated medium, or when irradiated DNA was added to the growth medium [25]. Khan and Alderson, working in the Department of Genetics, University of Cambridge, were also unable to show that irradiated DNA produced any significant increase in mutation over unirradiated DNA [26].

The significance of evidence from these simple test systems must be examined carefully, for, if it is accepted that the results from such tests can be extrapolated to man, there are obvious grave implications for the safety of irradiated food. It can be argued that the structure and composition of human chromosomes and cells are basically similar to those of the lower forms of life or to isolated cells in tissue culture; from such arguments it is postulated that the results from the simple test might
be of relevance to man. On the other hand, in the intact animal, or in man, any toxic or mutagenic substance in irradiated food must be absorbed from the gastrointestinal tract and subjected to metabolism. Even if a toxic substance were absorbed, it might well be detoxified or quickly excreted from the body before sufficient concentration to cause a toxic effect could be achieved. In particular, mutagenic substances would have to be transported to the germinal cells before any alteration in the genetic character of the offspring would result.

It is broadly true that substances that are toxic to intact animals are also toxic to simpler forms of life and vice versa, but there are far too many exceptions for this to be a useful rule. Smith, Grady and Northam investigated the correlation between cytotoxicity and whole animal toxicity for a range of 54 compounds and found that the relationship was not one in which toxicity in whole animals could be closely predicted from cytotoxicity data [27]. It is interesting to reflect on the large number of substances commonly found in food that have been shown to possess mutagenic activity when tested in the lower forms of plant and animal life. For example, even acetic acid, with its important role in intermediary metabolism, has been shown to possess weak mutagenic activity under certain conditions [28].

In contrast to the reported effect of irradiated materials on plants, bacteria and the lower forms of animal life, there is a wealth of information from animal feeding studies to indicate that irradiated food is non-toxic. In the United Kingdom alone several thousand rats and mice have been fed irradiated food throughout their life span without ill effect; in the case of irradiated wheat, four successive generations of rats were studied for their life span without evidence of toxicity. In the United States even greater numbers of animals have been observed in similar studies [29, 30], and again no effects attributable to irradiation of their food have been reported. In these circumstances it is difficult to accept that the effects observed, using simple test systems, are likely to be of biological significance to man.

NUTRITIONAL INVESTIGATIONS IN THE UNITED KINGDOM

Nutritive value of protein

Kennedy investigated the effect of irradiation on the nutritive value of the protein in certain animal feeds (fish meal, meat meal, and meat-and-bone meal), frozen whole egg, whole wheat and wheat gluten [31]. There was little change in the protein value of animal feeds irradiated with 0.3 or 1.0 Mrad, or in the protein value of whole egg (0.5 and 5.0 Mrad). The nutritive value of whole wheat proteins was unchanged at 0.2 Mrad; a loss of 6% in relative nutritive value at 1.0 Mrad was not increased by irradiation with 5.0 Mrad. In contrast, wheat gluten prepared from whole wheat and then irradiated was unaffected at 0.02 Mrad, but losses of 5, 7 and 26% in the relative nutritive value were observed with 0.2, 1.0 and 5.0 Mrad respectively, illustrating the increased sensitivity of the protein after extraction from the other food components. Supplementation studies and assay for methionine showed this amino acid to be principally responsible for the effect observed at 5.0 Mrad.
Destruction of vitamins

Several B complex vitamins were estimated in irradiated frozen whole egg and wheat by Kennedy [32]. The vitamin content of frozen whole egg irradiated with 0.5 and 5.0 Mrad was compared with both untreated and heat-pasteurized egg; no change occurred with any of the treatments in the pantothenic acid, biotin or riboflavin content. A 24% loss in thiamine at 0.5 Mrad increased to 61% at 5.0 Mrad. In wheat, irradiation with 0.02 Mrad (the dose for disinfection purposes) caused no change in nicotinic acid, thiamine, riboflavin, biotin, or total vitamin B₆ and only a slight loss was observed in pantothenic acid. At ten times this dose (0.2 Mrad) there was a 12% loss in nicotinic acid, 11% loss in pantothenic acid, and a 10% loss in biotin content.

Vitamin losses occurring in milk irradiated with 1.0 Mrad have been investigated at the National Institute for Research in Dairying [33, 34]. Severe losses in vitamin A, carotene, ascorbic acid, nicotinic acid, vitamin B₆, thiamine and vitamin E were reported, but biotin, pantothenic acid and vitamin B₁₂ were unaffected. Irradiation in a nitrogen atmosphere reduced the loss slightly in those vitamins affected.

Unpublished results [12] have recently shown that irradiation with 2.5 Mrad did not affect the nicotinic acid, biotin or vitamin B₁₂ in a guinea pig diet used in an SPF colony. Very slight losses of thiamine, pyridoxine, riboflavin, folic acid, vitamin A and carotene were observed, and a loss of about 20% of the pantothenic acid and alpha-tocopherol occurred. There was no change in the ascorbic acid.

The results from these investigations support a general conclusion that the sensitivity of individual vitamins towards irradiation cannot be predicted, as the other food components may exert a protective effect; the environmental conditions during irradiation also greatly influence the stability of individual vitamins.

GENERAL CONCLUSIONS AND SUMMARY

1. Most of the evidence concerning the wholesomeness of irradiated food has come from animal feeding tests in which animals have consumed irradiated food as a substantial part of their total diet over a period of about two years. The results have been negative.
2. Foods studied in the United Kingdom for wholesomeness by long-term studies have been wheat, frozen whole egg, ham, codfish and horse meat.
3. Further evidence regarding the safety of irradiated food has been gained from the use of radiation-stereilized diets in laboratory animal colonies.
4. Studies on the nutritional value of irradiated foods have indicated that the protein value is unaffected, but that losses may occur in certain vitamins, depending on the nature of the food and the conditions at the time of irradiation.
5. A Working Party of the Ministry of Health has considered the need for legislation to control food irradiation. It was considered that some form of control is necessary. The main recommendations of the Working Party that affect the design of wholesomeness tests have been described.
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REVIEW OF THE UNITED STATES ARMY WHOLESONEENESS OF IRRADIATED FOOD PROGRAM (1955 - 1966)

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Abstract — Résumé — Аннотация — Resumen

REVIEW OF THE UNITED STATES ARMY WHOLESONEENESS OF IRRADIATED FOOD PROGRAM (1955-1966). The United States Army has been actively engaged in a comprehensive program to study many questions, previously unanswerable, regarding the use of ionizing radiation for the preservation of food. This paper reviews data regarding the wholesomeness (toxicological, nutritional and, in part, microbiological safety) of irradiated foods.

The long-term feeding studies have been completed, and it has been demonstrated that irradiated foods are as wholesome and, in general, as acceptable as conventionally processed foods. Data were obtained through the efforts of more than 30 academic, commercial and government laboratories, and include results from the feeding of 21 irradiated foods (meat, fish, fruits and vegetables) to over 15,000 mice, 5,000 parent generation rats, 300 dogs and 37 monkeys.

The test foods were usually irradiated to 2.79 and 5.58 Mrads with spent fuel rods, 60Co or 10-MeV electron sources, and were stored for a minimum of three months at room temperature before they were fed. Control, non-irradiated foods were stored frozen until fed. Diets containing 35% (dry weight) of the test food were fed to two different species for two years. Growth, reproduction, lactation, hematology, longevity, histopathology and carcinogenicity were studied. To study carcinogenicity more specifically, mice were fed 100% irradiated diets for two years. Other studies included induced radioactivity, nutrient stability and adequacy, tissue enzyme levels, digestibility, vitamin K nutrition and chemical changes. Human subjects were fed fifty-four different irradiated (9.3 krads-3.7 Mrads) foods in diets which contained 32-100% irradiated calories for two-week periods.

The conclusions arrived at were that: (a) Foods irradiated with gamma rays or 10-MeV electrons to 5.6 Mrads are as wholesome as non-irradiated foods; (b) In general, vitamin losses in irradiation processing are comparable to losses in thermal processing; (c) There is no detectable induced radioactivity in foods irradiated with 60Co or with 10-MeV electrons; (d) Irradiated foods are, in general, as acceptable as non-irradiated foods.

In the light of these conclusions, the United States Food and Drug Administration has approved irradiation of the following foods: bacon with 4.5 Mrads – 60Co or 10-MeV electrons; wheat and wheat products with 50 krads – 60Co; potatoes with 10 krads – 2-MeV electrons. Other petitions are pending or are being prepared.

Les études à long terme d'alimentation ont été faites; elles ont démontré que les produits alimentaires irradiés sont aussi comestibles, et dans l'ensemble aussi acceptables, que les produits traités selon les procédés classiques. Les données ont été obtenues grâce aux travaux de plus de 30 laboratoires universitaires, commerciaux et gouvernementaux et comprennent les résultats d'expériences sur plus de 15 000 souris, 5 000 rats d'une même souche, 300 chiens et 37 singes, au moyen de 21 produits alimentaires irradiés (viandes, poissons, fruits et légumes).

En général, les produits alimentaires utilisés ont été irradiés à 2,79 et 5,58 Mrad avec un barreau de combustible épuisé, des sources au 60Co ou des sources d'électrons de 10 MeV, et ont été stockés pendant un minimum de trois mois à la température ambiante avant d'être donnés aux animaux. Des produits alimentaires témoins non irradiés ont été conservés par congélation jusqu'à leur utilisation. Deux espèces différentes ont été nourries pendant deux ans avec des aliments contenant 35% (en poids sec) de denrées irradiées. L'auteur a étudié la croissance, la reproduction, la lactation, l'hématologie, la longévité, l'histopathologie et la carcinogénicité. Afin d'étudier plus spécialement la carcinogénicité, il a soumis pendant deux ans des souris à un régime alimentaire constitué à 100% par des produits irradiés.

D'autres études ont porté sur la radioactivité induite, la stabilité et la valeur des éléments nutritifs, la teneur en enzymes des tissus, la digestibilité, l'action de la vitamine K sur la nutrition et les modifications chimiques. On a alimenté des êtres humains pendant des périodes de deux semaines au moyen de 54 produits alimentaires irradiés différents (9,3 krad à 3,7 Mrad), la proportion de calories irradiées dans les régimes alimentaires variant de 32 à 100%.

L'auteur est arrivé aux conclusions suivantes: a) Les produits alimentaires irradiés par des rayons gamma ou d'électrons de 10 MeV sont aussi comestibles que les produits alimentaires non irradiés; b) En général, les pertes en vitamines dues au traitement par irradiation sont comparables aux pertes résultant du traitement thermique; c) Il n'existe aucune radioactivité induite détectable dans les produits alimentaires irradiés au 60Co ou avec des électrons de 10 MeV; d) Les produits alimentaires irradiés sont en général aussi acceptables que les produits non irradiés.

À la lumière de ces conclusions, le service de contrôle des produits alimentaires et pharmaceutiques des États-Unis a approuvé le traitement des produits alimentaires suivants: lait, 4,5 Mrad, 60Co ou électrons de 10 MeV; blé et produits dérivés, 50 krad; 60Co; pommes de terre, 10 krad, électrons de 2 MeV. D'autres demandes sont en cours d'examen ou de préparation.

**Обзор программы американской армии по вопросу сохранения вкусовых и питательных качеств облученных пищевых продуктов (1955 — 1966 гг.).**

Армия США широко изучала многие вопросы, касающиеся применения ионизирующего облучения для сохранения пищевых продуктов. Рассматриваются данные, относящиеся к вопросам о сохранении вкусовых и питательных качеств (с точки зрения токсикологии, питательности и, частично, микробиологической безопасности) облученных пищевых продуктов.

Было завершено изучение результатов длительного кормления животных и показано, что облученные пищевые продукты сохраняют свои качества в той же степени, и, как правило, даже по-лучше, чем необлучённые. В процессе облучения в пищевых продуктах сохраняются все обычные пищевые качества, в том числе и в процессе длительного хранения.

Исследования, проведённые в течение двух лет, показали, что облучённые пищевые продукты сохраняют свои качества в той же степени, и, как правило, даже лучше, чем необлучённые. В процессе облучения в пищевых продуктах сохраняются все обычные пищевые качества, в том числе и в процессе длительного хранения.

Как правило, продукты были облучены дозами до 2,79 и 5,58 мегарад. Источниками облучения служили отработавшие топливные стержни, установки с кобальтом-60 или электронные источники мощностью 10 Мэв. Перед скармливанием продукты хранились при комнатной температуре не менее 2 месяцев. Контрольные (т.е. необлучённые) пищевые продукты хранили в замороженном виде до момента скармливания. Рацион, содержащий 35% (сухой вес) облучённых пищевых продуктов, скармливали двум различным птицам в течение двух лет. Изучались рост, размножение, лактация, гематология, продолжительность жизни, гисто- патология и канцерогенность подопытных животных.

С целью получения информации для более специального изучения канцерогенности мышам в течение двух лет скармливали рацион 100%-ного облучения. Другие исследования включали индуцированную радиоактивность, питательную стабильность и адекватность, условия тканевого эпизода, усвоенность, наличие витамина K и иммунные изменения. Людей, в отношении которых проходили эксперименты, в течение 2-х недель получали в пищу 54 различных видов облучённых (9,3 килорад — 3,7 мегарад) пищевых продуктов, их рацион содержал 32—100% облучённых калорий.

На основе опытов были сделаны следующие выводы:

a) пищевые продукты, облучённые гамма-лучами или электронами мощностью 10 Мэв до 5,58 Мрад, сохраняют свои вкусовые и питательные качества в той же степени, что и необлучённые; б) как правило, потери витаминов в процессе облучения аналогичны потерям в процессе термической обработки пищевых продуктов; в) в пищевых продуктах,
облученных с помощью кобальтовой установки (кобальт-60) или электронами мощностью 10 Мэв, нет заметной индуцированной радиоактивности; г) облученные пищевые продукты, как правило, так же приемлемы, как и необлученные. В соответствии с этими выводами американская администрация, ведающая пищевыми продуктами и лекарствами, одобрила употребление в пищу следующих продуктов: бекона, облученного дозой до 4,5 Мрад с помощью установки кобальт-60 или электронами мощностью 10 Мэв; пшеницы и продуктов из нее, облученных дозой до 50 килорад с помощью установки кобальт-60; картофеля, облученного дозой до 10 килорад электронами мощностью 2 Мэв. Другие сведения находятся в стадии подготовки.

PROGRAMA DEL EJERCITO DE LOS ESTADOS UNIDOS RELATIVO A LA COMESTIBILIDAD DE LOS ALIMENTOS IRRADIADOS. El ejército de los Estados Unidos ha emprendido la ejecución de un amplio programa encaminado a dilucidar una serie de cuestiones suscitadas por el empleo de las radiaciones ionizantes para la conservación de alimentos. En la memoria se exponen algunos datos relativos a la cuestión de la comestibilidad de los alimentos irradiados (seguridad desde el punto de vista de la toxicidad, de la nutrición y, en parte, de la microbiología).

Concluidos ya los prolongados estudios sobre el consumo de esos alimentos por animales, se ha demostrado que los alimentos irradiados son tan comestibles y, en general, tan aceptables como los tratados por procedimientos clásicos. Los datos se han obtenido gracias a la colaboración de más de 30 laboratorios de instituciones docentes, empresas comerciales y organismos oficiales, y comprenden los resultados de estudios sobre el consumo de 21 productos alimenticios irradiados (carne, prescado, frutas y verduras) por más de 15 000 ratones, 5000 ratas de la misma progenie, 300 perros y 37 monos. En general, los alimentos utilizados para esos estudios recibieron dosis de 2,79 a 5,58 Mrad obtenidas por medio de combustible agotado, cobalto-60 o fuentes de electrones de 10 MeV; antes de darlos a los animales se almacenaron durante tres meses, como mínimo, a la temperatura ambiente. Los alimentos no irradiados utilizados como testigo se mantuvieron congelados hasta el momento de su consumo. Durante dos años se administraron dietas con el 33% (en peso seco) de alimentos irradiados, a dos especies diferentes. Se estudió el crecimiento, la reproducción, la lactación, la hematología, la longevidad, la histopatología y la carcinogénesis. Para examinar más a fondo este último punto, durante dos años se administraron a ratones dietas con el 100% de alimentos irradiados. También se estudió la radiactividad inducida, la estabilidad y la suficiencia de las sustancias nutritivas, la concentración de enzimas en los tejidos, la digestibilidad, la riqueza en vitamina K y las alteraciones químicas. Durante períodos de dos semanas se administraron a seres humanos 54 alimentos irradiados diferentes (9,3 krad - 3,7 Mrad) en dietas cuyos componentes portadores de calorías estaban irradiados en la proporción de 30% a 100%.

Se llegó a las siguientes conclusiones: a) los alimentos irradiados con rayos gamma o con electrones de 10 MeV, en dosis de 5,6 Mrad como máximo, son tan comestibles como los alimentos no irradiados; b) en general, las pérdidas de vitaminas por irradiación son análogas a las que produce el tratamiento térmico; c) en los alimentos irradiados con cobalto-60 o con electrones de 10 MeV no existe radiactividad inducida detectable; d) los alimentos irradiados son, en general, tan aceptables como los no irradiados.

En vista de estas conclusiones, la autoridad competente de los Estados Unidos ha aprobado la irradiación de los siguientes alimentos: tocino, dosis de 4,5 Mrad, cobalto-60 o electrones de 10 MeV; trigo y derivados, dosis de 50 krad, cobalto-60; patatas, dosis de 10 krad, electrones de 2 MeV. Se están estudiando o tramitando otras autorizaciones.

The process of pasteurizing or sterilizing foods for extended storage in essentially their fresh state by treatment with ionizing radiations has reached a stage of development, after more than ten years of intensive investigation, that is stimulating interest and creating an optimism for the future on an international level. However, the concept of radiation sterilization is not new. The lethal effects of ionizing radiations on microorganisms was reported shortly after the discovery of X-rays by Roentgen in 1895. Although a patent was obtained as early as 1930 for the preservation of food by ionizing radiations (1), it was not until the early 1940's that serious considerations were given toward investigating the feasibility of such a process. The first significant publication in this regard was reported in 1947 by Brasch and Huber (2) and was followed by an extensive series of publications by Proctor and Goldblith, Brasch and Huber and others in the United States, as well as
by Hannan and Shepard and others in Great Britain. Hannan (3), in his monograph on food preservation, lists over 400 pertinent references covering the period from 1947 to 1955.

After the initial investigations had demonstrated the feasibility of preserving foods by ionizing radiations, a comprehensive program for its development was initiated by the U.S. Army in 1953. A part of this program, which was under the sponsorship of the Office of The Surgeon General, was that of determining the wholesomeness (toxicological, nutritional and, in part, microbiological safety) of irradiated foods. Prior to this time, only a meager amount of data were available for evaluating the possible toxicity of irradiated foods to mammals. Animal feeding studies by Narat (4) as well as by DaCosta and Levenson (5) had shown that growth or reproduction, respectively, was depressed in such a way as to suggest vitamin deficiencies. Poling et al. (6) reported on the results of observing over 2,600 rats representing three generations of animals which had been fed a diet containing two Mrep irradiated beef (60% of the dietary calories). The observed reduced fertility and viability in the male rats was corrected by vitamin E supplementation.

This briefly was the state of knowledge on the wholesomeness of irradiated food at the start of the U.S. Army's wholesomeness program. Because of the many excellent published reviews and symposia documenting the progress made in food irradiation processing, as well as in the wholesomeness studies, individual references will be cited only if they are specifically discussed (7–14).

Experimental procedures

The general procedures for the feeding of irradiated foods are shown in Table I. At least two species of animals were used for each food tested. Test foods were irradiated to 2.79 and 5.58 Mrads with spent fuel rods, cobalt-60, 1−2 or 10 MeV electrons. Nonirradiated (control) foods were stored frozen and irradiated foods were stored at room temperature for at least three months before being added as 35% dry solids to a nutritionally adequate diet. Parameters studied during the long-term feeding program were growth, food utilization, reproduction, lactation, hematology, longevity, histopathology and carcinogenicity. Reproduction was observed for four generations in rats and for as many litters as possible in dogs during the two- or three-year tests. Monkeys were not bred. In the mouse carcinogenicity studies, the animals were not bred and the parameters studied were growth, longevity and tumor incidence frequency. Histopathologic observations were conducted by the contracting institution conducting the feeding study, and duplicate sets of fixed tissues and slides were sent to the Armed Forces Institute of Pathology for review and compilation of summary statements (15–18).

Acute toxicity feeding studies

In order to assess the suitability of various foods for irradiation and for possible long-term feeding studies, forty-six food items were tested in weanling rats for eight weeks. During this feeding period growth, feed efficiency and any outward signs of obvious toxicity were recorded. Gross pathologic examinations were made at the termination of each study. The foods which were tested are listed in Table II.

Only three of these foods, gelatin dessert powder, vanilla dessert powder and raisins, were unsatisfactory. Irradiated gelatin dessert powder consistently reduced growth rate of rats. Subsequent evaluations had shown that irradiated sucrose was the responsible component. Irradiated gelatin dessert powder and sucrose resembled heat-carmelized sugar in odor and appearance. When heat-carmelized sucrose was
TABLE I
General Experimental Procedures
Irradiated Food Wholesomeness Studies

| Test Animals: | Rats, dogs, monkeys and mice |
| Feeding Period: | Two years |
| Irradiated and Control Foods: | Fed as 35% dry solids in a nutritionally adequate diet |
| Storage: | Control foods - frozen |
| Irradiated foods - room temperature for minimum of three months |
| Irradiation Dose: | 0, 2.79 and 5.58 Mrads |
| Irradiation Sources: | Spent fuel rods, $^{60}$Co, 2 or 10 MeV electrons |
| Parameters: | Growth, food utilization, reproduction, lactation, hematology, longevity, histopathology, carcinogenicity |

tested, it too significantly decreased the growth rate of rats. Growth rate inhibition by irradiated vanilla dessert powder was only of borderline significance at the 5% confidence level. This product was not tested further as was the gelatin dessert powder. Repeat 12-week feeding studies with irradiated raisins did not result in significant growth rate depression; however, growth with a 35% (dry solids) raisin diet, irradiated or not, was less than that observed with other diets (19).

Apparently, irradiation can produce growth inhibitory products in foods such as gelatin powder which contain dry sucrose. The appearance and odor of these irradiated foods are not unlike that obtained with heat-caramelized sugars or heated diets which contain carbohydrates. The growth inhibitory properties of such diets are well known. Because irradiation sterilization (3 Mrads) produces the least amount of change and vitamin destruction, it is preferred to steam for the sterilization of "dry" diets containing sucrose or glucose for germfree animal studies (20).

It is suggested that dry sugar preparations may not lend themselves to irradiation sterilization at 5.58 Mrads; however, this is not irradiation specific since heat will also produce a comparably unacceptable product.

Long-term feeding studies

From the list of foods fed in the acute toxicity studies, twenty-one representative foods were selected for the long-term, multigeneration studies. These food items are listed in Table III. They include meats, fish, vegetables and fruits, as well as flour, jam and evaporated milk. All foods were irradiated to 2.79 and 5.58 Mrads, except flour which was irradiated to 37 and 74 krads, potatoes from 7 to 40 krads and oranges to 140 and 280 krads.
TABLE II  
Acute Toxicity Studies  
Irradiated Foods Fed to Rats for Eight Weeks  
(0, 2.79 and 5.58 Mrad)  

<table>
<thead>
<tr>
<th>Meats</th>
<th>Fish</th>
<th>Cereals</th>
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</thead>
<tbody>
<tr>
<td>Chicken</td>
<td>Haddock</td>
<td>Bread</td>
</tr>
<tr>
<td>Bacon</td>
<td>Salmon</td>
<td>Cereal Bar</td>
</tr>
<tr>
<td>Beef</td>
<td>Shrimp</td>
<td>Crackers</td>
</tr>
<tr>
<td>Beef, Corned</td>
<td>Tuna</td>
<td>Macaroni</td>
</tr>
<tr>
<td>Frankfurters</td>
<td></td>
<td>Rice</td>
</tr>
<tr>
<td>Ham</td>
<td>Vegetables</td>
<td></td>
</tr>
<tr>
<td>Sausage</td>
<td>Asparagus</td>
<td></td>
</tr>
<tr>
<td>Turkey</td>
<td>Beets</td>
<td></td>
</tr>
<tr>
<td>Fruits</td>
<td>Brussel Sprouts</td>
<td></td>
</tr>
<tr>
<td>Apricots, Dried</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cherries, Sour</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Melon</td>
<td>Cabbage</td>
<td></td>
</tr>
<tr>
<td>Peaches</td>
<td>Carrots</td>
<td></td>
</tr>
<tr>
<td>Pears, Dried</td>
<td>Green Beans</td>
<td></td>
</tr>
<tr>
<td>Raisins</td>
<td>Cauliflower</td>
<td></td>
</tr>
<tr>
<td>Strawberries</td>
<td>Green Peas</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Celery</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Corn</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Cranberries</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Peas, Dried</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Green Beans</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Lima Beans</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Mushrooms</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Potatoes</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Potatoes, Sweet</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Spinach</td>
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</tbody>
</table>

In general, there were no significant differences in the parameters studied between the animals consuming irradiated or nonirradiated foods. This is not to imply that doubtful findings had not occurred. These findings will be presented and discussed in regard to their significance to the wholesomeness of irradiated foods.

In the first long-term dog feeding study with irradiated beef, it was reported that fertility was decreased (21). Calculations suggested that the vitamin E supplementation was marginal and probably the contributing cause of the reduced fertility. Two repeat studies were designed to explore this problem. These studies had three males and fifteen females per group instead of two males and two females per group as in the previous experiment. The beef was irradiated to 5.58 Mrads with 10 MeV electrons and was fed for three years. Reproductive performance in the two repeat studies was equal to that of the control animals (22, 23). The only significant finding in one of the studies was the age at first estrus (23). First estrus was shown in the irradiated beef group at 322.8 ± 46.4 days and in the control beef group at 454.8 ± 94.0 days. Since the age in days at first estrus were equal in all of the other dog studies, the significance of this single report cannot be evaluated at this time.

Thyroiditis was reported to occur more frequently in dogs fed irradiated shrimp (24) or flour (25). In subsequent summary reports from the AFIP (15, 16, 18),
reviewing the incidence of thyroiditis in 258 dogs from the wholesomeness studies, it was found that 17.4% of all the dogs had some degree of thyroiditis, but that there was no statistically significant distribution between sex, diets or dietary irradiation levels. Mongrel pound dogs were found to have a 27% incidence of thyroiditis (26). It was concluded that thyroiditis commonly occurs in dogs and is not associated with irradiated foods.

Increased spleen weights were reported in dogs fed irradiated green beans and fruit compote (27). Because of the many variables that influence spleen weights, increased spleen weights cannot at this time be unequivocally related to the ingestion of irradiated foods. Histopathologic examination of the spleens did not reveal any intrinsic changes other than pulp congestion.

Growth rate was significantly reduced in the third generation rats which were fed irradiated whole oranges (28). This growth reduction was more pronounced in the 140 krad than in the 240 krad irradiated orange group. The breeding performance in all of the whole orange dietary groups was poor. It would appear that a 35% whole orange diet is not a very satisfactory diet for rats.

While the growth rate of rats which were fed irradiated carrots was reduced, the irradiated carrot groups had a higher ratio of breedings which produced litters (29). The biopotency of the carotene in irradiated carrots was also impaired to a greater extent than could be accounted for by the decrease in β-carotene content. Subsequent studies demonstrated that the biopotency of irradiated carrot carotene was not impaired if the carrots were stored frozen for 6 months; neither was growth

**TABLE III**

**Long-Term Toxicity Studies**

**Irradiated Foods Fed for Two Years**<sup>a</sup>,<sup>b</sup>

<table>
<thead>
<tr>
<th>Meats</th>
<th>Vegetables</th>
<th>Other</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bacon</td>
<td>Carrots</td>
<td>Flour&lt;sup&gt;c&lt;/sup&gt;</td>
</tr>
<tr>
<td>Beef</td>
<td>Cabbage</td>
<td>Jam</td>
</tr>
<tr>
<td>Beef Stew</td>
<td>Corn</td>
<td>Milk, Evaporated</td>
</tr>
<tr>
<td>Chicken</td>
<td>Green Beans</td>
<td></td>
</tr>
<tr>
<td>Chicken Stew</td>
<td>Potatoes&lt;sup&gt;d&lt;/sup&gt;</td>
<td></td>
</tr>
<tr>
<td>Pork Loin</td>
<td>Potatoes, Sweet</td>
<td></td>
</tr>
<tr>
<td>Fish</td>
<td>Fruits</td>
<td></td>
</tr>
<tr>
<td>Cod</td>
<td>Compote (Dried Mixture)</td>
<td></td>
</tr>
<tr>
<td>Shrimp</td>
<td>Peaches&lt;sup&gt;c&lt;/sup&gt;</td>
<td></td>
</tr>
<tr>
<td>Tuna</td>
<td>Oranges&lt;sup&gt;c,f&lt;/sup&gt;</td>
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</tbody>
</table>

- a. Doses of 2.79 and 5.58 Mrad, except flour, potatoes and oranges.
- b. Fed to rats and dogs, except peaches and oranges.
- c. Fed to rats and monkeys.
- d. Doses of 7 to 40 krads.
- e. Doses of 37 and 74 krads.
- f. Doses of 140 and 280 krads.
reduced when irradiated carrots were fed after being stored frozen for 12 months. Radiation per se, therefore, was not the causative agent of the growth reduction or impairment of the carotene biopotency (30). The room temperature stored carrots sometimes had an acid odor and a jelly-like residue, suggestive of bacterial contamination which could have been responsible for the observed effects on growth and carotene utilization.

In a long-term study in which a 9-component diet supplying 100% irradiated calories was fed to rats, a significant growth decrease was reported for the females of the fourth generation (31). The real significance of this is difficult to evaluate because reproduction had fallen off in all groups, irradiated and nonirradiated diets, in the third generation. Instead of the 20-25 animals per sex per group normally compared, there were only 6 animals per sex per group available in the fourth generation. The control females of the fourth generation had a much higher feed efficiency than females of previous generations, but the feed efficiency of the fourth generation, irradiated diet females was equal to that of previous generations. Because of the different variables which confused the data for the fourth generation, it is not very probable that the irradiated food was the limiting factor.

Carcinogenicity studies

The carcinogenicity studies are listed in Table IV. These studies had the primary objective of determining whether or not carcinogens were formed in foods by irradiation. Over 15,000 mice, representing nine species, were used in studies A, B and C of Table IV. In study A, mice were fed for two years diets in which 100% of the calories were irradiated. These diets were supplemented with nonirradiated vitamins and minerals.

Significant differences were not found with diet 1 of study A between the irradiated and nonirradiated diet in growth, longevity or tumor frequency.

With diet 2 of study A, significant differences were not found in growth or longevity; however, in Swiss males, there was a significantly increased incidence of malignant lymphoma in the irradiated diet group, but this lesion was also significantly more frequent in C57 black females in the control diet group (32).

With diet 3 of study A, a heart lesion described as left auricular dilatation which sometimes ruptured was reported to occur with much greater frequency in the Cb strain fed the irradiated diet than in animals fed the nonirradiated diet (33). It was later reported that this lesion could be produced as readily with nonirradiated milk diets (34). In order to confirm the original heart lesion report, the experiment was repeated in another laboratory with almost 5,000 mice of the same stock strains (35). Not one heart lesion as originally described was found in the repeat study. From 125,000 tissue and 800,000 serial heart sections which were prepared, in addition to detailed breeding, genetic and necropsy reports, it was concluded that irradiated foods were not the cause of the left auricular dilatation. Other lesions were found, but these occurred with equal frequency in all diet groups.

In study B of Table IV, the objective was to attempt confirmation of literature reports which suggested that heated or irradiated steroids can be carcinogenic. Evidence was not found to suggest that the irradiated sterols used in this extensive study were carcinogenic even when the painted irradiated sterols were challenged with croton oil (36).
Significant differences were not observed between mice fed diets containing 20% of lipid which was extracted from 5.58 Mrad irradiated or nonirradiated bacon (37).

Supplementary studies

The supplementary studies which were conducted in support of the long-term feeding trials are listed in Table V. These studies were of importance inasmuch as they supplied data which permitted a more critical evaluation of the feeding trials and irradiated foods. Because some of these topics will be considered in greater detail elsewhere during this symposium, only results of immediate interest to wholesomeness will be discussed.

<table>
<thead>
<tr>
<th>TABLE IV</th>
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<tr>
<td>Carcinogenicity Studies</td>
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<td>Irradiated Foods</td>
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A. Composite Diets: 100% Irradiated, 5.58 Mrad (Mice)

- Diet 1: Codfish, chicken stew, beef stew, green beans, peaches, flour.
- Diet 2: Beef, tuna, corn, sweet potatoes, fruit compote.
- Diet 3b: Pork, chicken, potatoes, carrots, evaporated milk.

B. Sterols: Extracts were painted, injected and fed (Rats and Mice):
Beef and yeast concentrates. Pork brain, egg, vegetable oils and lard. Mixture of meat, fish, cheese and milk. 0.4 to 9.3 Mrad.

C. Bacon Lipid, 20% in diet. 5.58 Mrad (Mice)

- a. Nonirradiated vitamins added to diets.
- b. Heart lesion study.

1. Induced radioactivity: It has been determined that detectable radioactivity is not induced in foods which are irradiated with $^{60}$Co or 10 MeV electrons (38, 39). Depending upon individual interpretations, this statement may or may not be valid if the food is irradiated with high energy electrons and calculated, or zero time post-irradiation induced radioactivity is considered. Calculated values, although possibly high, are, nevertheless, useful for defining the magnitude of the problem. The total yearly body burden from the consumption of diets or meats irradiated to 5 Mrads with 24 MeV electrons has been calculated to be from 0.26 mrem to 11.4 mrem, respectively (40, 41). The lower figure is based on radionuclides which have a half-life longer than 10 days and is primarily due to $^{22}$Na. The higher figure is based on zero time postirradiation and is primarily due to $^{126}$I. Normal yearly body burden from natural background radioactivity has been estimated to be about 150 mrems. From this type of data, it is logical to conclude that foods irradiated to 5 Mrads with 10 MeV electrons should not be a biological hazard from induced radionuclides that cannot be detected.
2. Nutrient stability: In general, it has been determined that vitamin destruction in foods by irradiation sterilization is comparable to destruction by heat processing (11). However, if one compares heat sterilization to irradiation sterilization, particularly if the diets contain sugars, then irradiation sterilization produces a much superior product (20). This is an important point to consider because it is very misleading to attempt direct comparisons between a cooked product and a sterilized product. In any event, the seriousness of the vitamin losses must be evaluated in terms of the feeding situation at hand. Vitamins could be resupplemented as required much in the same way that the milling industry is fortifying refined flour with B vitamins.

<table>
<thead>
<tr>
<th>TABLE V</th>
<th>Supplementary Studies</th>
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<tbody>
<tr>
<td>Irradiated Foods</td>
<td></td>
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<tr>
<td>1. Induced Radioactivity</td>
<td></td>
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<tr>
<td>2. Nutrient Stability</td>
<td></td>
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<tr>
<td>3. Tissue Enzyme Activities</td>
<td></td>
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<tr>
<td>4. Digestibility</td>
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<tr>
<td>5. Chemical Changes</td>
<td></td>
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<tr>
<td>6. Vitamin K Nutrition</td>
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</table>

In this regard, losses of vitamins which are added to sterilized foods post-irradiation have not been adequately evaluated. There is some indication that fat-soluble vitamins may undergo some loss in biopotency when added directly to irradiated meat diets and to irradiated or nonirradiated animal fats (31, 42).

3. Tissue enzyme activity: Tissue enzyme activities were determined in duodenum, intestinal mucosa, organs and blood of rats after various feeding periods with radiation sterilized foods in several of the long-term studies. The only consistent observation was made in rats which were fed pork (30, 31). Liver cytochrome oxidase activity was higher in the animals which were fed irradiated pork than in those fed nonirradiated pork. The reason for this difference was not clear. Some of the data suggested that it may have been due to alteration in the oleic-linoleic acid ratio between the irradiated and nonirradiated pork (30). While the irradiated pork-fed animals had a consistently greater cytochrome oxidase activity than the nonirradiated pork-fed animals, some of the data showed that the cytochrome oxidase activity of laboratory pellet-fed male rats may be higher than that of pork-fed rats. The females fed a pellet diet had a lower cytochrome oxidase activity than those on a pork diet.

It is, therefore, a very difficult task to interpret changes in tissue enzyme activities because changes in diet or dietary components are known to influence significantly enzyme activities. Whether these changes are beneficial or detrimental can at this time only be evaluated by observing the performance of the animal over its normal life span, as was done in the long-term studies being reported.
4. Digestibility: Biologically significant changes in the digestibility of irradiated proteins, fats and carbohydrates were not found. In general, with the exception of fibrous tissues, digestibility may be reduced by irradiation but the magnitude of the reduction cannot be measured biologically.

Of interest for further study are irradiated fats. In an experiment with jejunal fistulated dogs, irradiated lard was fed by intubation (43). It was determined that the irradiated lard was absorbed to a lesser extent and remained a longer time in the stomach than nonirradiated lard. This irradiated lard had an abnormally high peroxide number (176 - 350) which may have influenced the results. From the long-term feeding studies with bacon, pork and bacon lipids, any reduction in available calories was not detectable; therefore, in spite of the conclusion that the rate of utilization of irradiated fats may be decreased, net utilization is not decreased.

5. Chemical changes: Chemical changes that take place in foods with irradiation will not be discussed at this time because they will be considered in more detail elsewhere during this symposium. The only comment of pertinence to wholesomeness which should be made is that while very extensive qualitative chemical changes are known to occur in foods when they are irradiated, the products formed have not been shown to be detrimental with foods which were tested under this program.

6. Vitamin K nutrition: The irradiated food program has made significant contributions to our knowledge of vitamin K nutrition; however, the possibility of inducing vitamin K deficiencies from the ingestion of irradiated foods is very improbable. Hemorrhagic diathesis was induced in rats with irradiated or nonirradiated meats in a laboratory-type diet which was not supplemented with vitamin K. Meats are a very poor source of vitamin K. Foods such as vegetables, which are very rich sources, can be irradiated to 5.58 Mrads without measurable loss of vitamin K (44).

Human feeding studies

Human feeding studies have been limited to short-term experiments of 15 days' duration. In the seven studies, each with 9 to 10 human volunteers, diets supplying 35 to 100% irradiated calories were acceptable and as digestible as the nonirradiated diets. Extensive clinical tests did not reveal any untoward effects (45).

Discussion and conclusions

The magnitude of the wholesomeness studies can be estimated from the total numbers of animals utilized and the number of different contracting laboratories which participated in the program. Over 15,000 mice, 300 dogs and 37 monkeys were fed the various irradiated diets for at least two years. The number of rats is more difficult to evaluate because of the many different types of studies and multigeneration programs; however, a reasonable figure would be in excess of 10,000 rats. Over 30 academic, commercial and governmental laboratories participated in this program.

Irradiation certainly did not produce any obviously toxic or carcinogenic substances in the foods which were tested. A few spectacular findings, such as the heart lesion, congenital blindness (46) and hemorrhagic diathesis were reported during the course of these studies. These findings, however, have been shown not to be related to the irradiated foods. The heart lesion was produced with a nonirradiated diet in one laboratory and not at all in another laboratory, regardless of
diet. The congenital blindness was due to a genetic defect in the Texas A & M rat strain, and the hemorrhagic diathesis was due to vitamin K deficiency. In diets which were not supplemented with vitamin K, nonirradiated pork was more hemorrhagic than irradiated beef.

Nutrient destruction is known to occur, but the magnitude is comparable to that occurring by heat processing and should not present any unusual problems. Small but sometimes measurable decreases in digestion rates were not biologically significant. The decreased growth rate and carotene utilization obtained with irradiated carrots were due more to room temperature storage than to irradiation. The poor condition of the irradiated carrots may have been due to bacterial contamination.

It seems apparent that if irradiated foods must be harmful, then this toxicity in the mammal must be extremely subtle or of such low frequency rate that it would be very difficult to demonstrate experimentally. While the possibility of subtle toxicity and mutagenicity of irradiated foods should not be dismissed entirely, these possibilities should also be considered for our heat processed foods because some of the changes in irradiated foods are similar to those caused by heat.

If it can be assumed that the rat, like the mouse, is fifteen times more susceptible to the genetic effects of radiation than Drosophila (47), then it would not be reasonable to assume that somewhere during the many reproduction and feeding studies some hint of genetic or other cellular changes should have been evident? The jam and peach diets, because of their very high sugar content, should have resulted in gross adverse effects if the recent conclusions of Berry et al. (48) and Holsten et al. (49), regarding irradiated sugars, have any validity to the feeding studies being reported at this time (50, 51).

In considering the wholesomeness data, it should be remembered that the irradiated foods were compared to the nonirradiated foods in such a way as to give the nonirradiated foods an overwhelming advantage. Consider the possible results if radiation sterilized foods were compared to heat sterilized foods. Consider also the possible restrictions in our diets if all nutrients, foods or other substances which are mutagenic or growth inhibiting to microorganisms, tissue cultures or Drosophila were legislated off the market-place. This is not a plea in defense of potentially detrimental foods or processes, but until data in the mammal can be presented to establish toxicity, then one should accept the voluminous negative data established with mammals, rather than data based solely on microculture techniques. Nevertheless, it should be emphasized that vigilance should be continuously maintained and experimental procedures kept abreast of our ever progressing technologies for the detection and evaluation of biological signposts which may have escaped our scrutiny.

After careful review of the extensive data amassed in the wholesomeness of irradiated food program, it can be concluded that the foods which were irradiated to doses of 5.58 Mrad with spent fuel rods, cobalt-60, or 10 MeV electrons are as wholesome as nonirradiated foods.

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DISCUSSION

B. RAJEWSKY: Have you considered the possible effects of doses as high as 100 Mrad?

N. RAICA: Doses as high as this will never be used for preserving food. Experiments have been carried out in which 45-Mrad beef was fed to rats; however, the product was so obnoxious that the animals had to be force-fed. The tests were run for about three weeks and the animals showed no toxic effects.

B. RAJEWSKY: What about long-term effects?

N. RAICA: I think the animal studies already carried out show that there is no need for great concern about the long-term effects. In my opinion there is too much concern about the micoculture effects of irradiation, whereas nothing is said about the same effects when they occur in non-irradiated food; for example, the same effects have been shown to be produced in non-irradiated wheat by normal cooking oil.

B. RAJEWSKY: Do you think that the immunological factors can be excluded?
N. RAÏCA: Present evidence would suggest that they can be excluded. Moreover, studies carried out with milk have shown that the allergenicity of milk proteins decreases upon irradiation.

O. KLAMERTH: Have you carried out any experiments in which animals were fed with sugar solutions or sugar-containing solutions irradiated before application?

N. RAÏCA: No, we have not fed animals with irradiated sugar solutions or solutions made with irradiated sugar. In one short-term feeding study, Reference [19] of the paper, both irradiation-carmelized and heat-carmelized sucrose inhibited the growth of rats.

O. KLAMERTH: Although tissue culture experiments are not conclusive for the whole animal, I would like to mention the results of experiments performed in our laboratory with human fibroblasts fed with irradiated glucose solutions or with glyoxal (50 μg/ml of medium). The result was a very marked reduction in protein and DNA synthesis. However, the cell possesses a recovery system, probably xanthine oxidase, which reduces the toxic effect of glyoxal 6–8 hours after application.

N. RAÏCA: Thank you for your interesting data regarding human fibroblasts. The HeLa cells and Strain L human fibroblasts used by Berry and co-workers, Reference [48] of the paper, were not described as possessing a system for recovery from the effects of irradiated sugar solutions in which glyoxal was reported as being the active component.

F. J. LEY: The animal feeding data which you have described were obtained with individual foods irradiated under a certain set of conditions. Do you think it is reasonable to extrapolate the data obtained to cover the same foods irradiated under different conditions; for example, at different doses, at room temperature as opposed to freezing, or with gamma rays as opposed to electrons from electrical machines?

N. RAÏCA: The data reported could, in general, be extrapolated to lower doses than were used in this study and to include foods irradiated at below freezing temperatures, as well as to irradiation with electrons of energies about 10 MeV. This is not to say that toxicity would necessarily develop in foods irradiated to higher doses with higher energies.

B. RAJEWSKY: I would like to say that, in irradiating different kinds of food, the irradiation energy should be adapted to the thickness and density of the food being irradiated.

G. MOCQUOT: Would you say that, with the information we now possess on the non-toxicity of irradiated foodstuffs, it is unnecessary to repeat non-toxicity experiments for each new food preparation capable of being preserved by means of irradiation?

N. RAÏCA: Although a wide variety of foods were tested with favourable results, our present state of knowledge does not permit us to make the general statement that all irradiated foods will be wholesome. For new foods similar to those already investigated, twelve-week feeding tests may be adequate; for others, long-term studies may be advisable.

J. MORRE: I think I can offer an explanation for the difference, referred to in your presentation, between a pure sugar, such as glucose, and one present in jam. Pure sugar has a low buffer action and a pH that varies greatly during irradiation. Sugar present in jam has a high buffer action and yields completely different degradation products.

N. RAÏCA: This is not necessarily the explanation in this case, because in one of the studies, Reference [49] of the paper, irradiated coconut
milk supplement, or irradiated basal media, also suppressed the growth and proliferation of plant cell cultures.

P. PELEGRIN: Do you think that the application to cereals (wheat or maize) of a gamma dose of 100–300 krad may give rise to compounds (harmful or otherwise) such that the United States authorities would require either long- or short-term survival tests on mammals, or other kinds of tests?

N. RAICA: From the large variety of foods which were studied under widely different conditions there is no reason to assume that toxic compounds should arise in wheat or maize irradiated to 100–300 krad. However, this does not mean that organoleptic changes would not occur. It is quite probable that the Food and Drug Administration would require feeding studies of some sort to support petitions requesting clearance for higher doses but not necessarily for petitions concerning lower doses than those tested. I should stress that this is my personal opinion, and naturally not intended as a statement on behalf of the Food and Drug Administration.
WHOLESOMENESS AND PUBLIC HEALTH RESEARCH IN THE UNITED STATES ATOMIC ENERGY COMMISSION FOOD IRRADIATION PROGRAMME

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Abstract — Résumé — Аннотация — Resumen

WHOLESMENNESS AND PUBLIC HEALTH RESEARCH IN THE UNITED STATES ATOMIC ENERGY COMMISSION FOOD IRRADIATION PROGRAMME. To assess the biological safety of foods which are of interest to the Atomic Energy Commission's irradiated food program, studies have been sponsored by the Commission's Division of Biology and Medicine since 1961. Wholesomeness, microbiological and biochemical studies have been undertaken with a view to complementing data derived from developmental, economic and technological research studies sponsored by the Commission's Division of Isotopes Development. When these aspects appear feasible for specific low-dose irradiated foods, studies are initiated to provide relevant data required by the United States Food and Drug Administration before final judgements can be made on petitions for unlimited human consumption.

Toxicity studies on several species of animals which are fed diets containing up to 35% (dry solids basis) of the irradiated food in question have been included in this program. Investigations of two years' duration on animals (rats, dogs and chickens) provide data concerning food consumption, growth rate, enzyme systems, haematology, gross pathology and histopathology. Shorter-term studies of a confirmatory nature on two animal species (rat and dog) are employed in certain cases when the irradiated food in question is sufficiently related to foods which have previously undergone long-term toxicity studies. Results to date of chronic toxicity studies on soft-shell clams and subacute toxicity studies on strawberries, apples, pears, sweet cherries, apricots, plums and onions are discussed.

Microbiological studies have been concentrated primarily on potentially pathogenic organisms. Studies have been in progress to evaluate carefully the conditions governing radiation and heat resistance, sporulation, outgrowth and toxin production of Clostridium botulinum Type E.

The natural incidence of Type E organisms in certain marine products and ocean environments is being investigated. Findings in the microbiological studies are discussed.

Studies to date have indicated that the general outlook for wholesomeness of irradiated foods is favourable. Toxicity evaluations are currently being initiated on bananas, mangoes and papayas. Research efforts on Clostridium botulinum, Types E and F, Salmonellae and other potentially pathogenic organisms will continue.

RECHERCHES SUR LA COMESTIBILITE ET LA SANTE PUBLIQUE AU TITRE DU PROGRAMME D'IRRADIATION DES PRODUITS ALIMENTAIRES DE LA COMMISSION DE L'ENERGIE ATOMIQUE DES ETATS-UNIS. Afin de déterminer le degré de sécurité biologique des produits alimentaires qui présentent un intérêt pour le programme de la Commission de l'Énergie atomique relatif aux produits alimentaires irradiés, la Division de biologie et médecine de la Commission a organisé des recherches depuis 1961. Des études ont été entreprises sur la comestibilité, la microbiologie et la biochimie en vue de compléter les données fournies par les travaux dans les domaines des réalisations, de l'économie et de la technique organisés par la Division des isotopes de la Commission. Lorsque les résultats obtenus semblent applicables à des produits alimentaires particuliers irradiés à faible dose, des études sont entreprises pour fournir les données pertinentes requises par le service de contrôle des produits alimentaires et pharmaceutiques des États-Unis avant que des décisions définitives soient prises concernant les demandes visant à autoriser la consommation illimitée d'un produit par le public.

Ce programme comprenait des études de toxicité sur plusieurs espèces d'animaux soumis à des régimes alimentaires comprenant jusqu'à 35% (en matière sèche) du produit alimentaire irradié considéré. Des recherches d'une durée de deux ans sur des animaux (rats, chiens et poulets) fournissent des données sur...
la consommation alimentaire, la croissance, les enzymes, l'hématologie, la pathologie générale et l'histo-pathologie. Des études à court terme, aux fins de confirmation, sur deux espèces animales (rats et chiens) sont faites dans certains cas lorsque le produit alimentaire irradié considéré a suffisamment de points communs avec des produits qui ont précédemment fait l'objet d'études de toxicité à long terme. Les données fournies jusqu'à ce jour par les études de toxicité chronique sur une variété de palourdes et par les études de toxicité subaiguë sur les fraises, les pommes, les poires, les cerises, les abricots, les prunes et les oignons font l'objet d'un examen critique.

Les études microbiologiques ont porté principalement sur les organismes potentiellement pathogènes. L'auteur a poursuivi des études pour procéder à une évaluation minutieuse des conditions qui régissent la résistance aux rayonnements et à la chaleur, la sporulation, le développement et la production de toxines de Clostridium botulinum E. L'auteur fait actuellement des recherches sur l'incidence naturelle d'organismes du type E dans certains produits marins et dans le milieu marin. Les constatations faites au cours des études microbiologiques font l'objet d'un examen critique.

Les études effectuées jusqu'à présent ont indiqué que les perspectives d'ensemble concernant la comestibilité des produits alimentaires irradiés sont favorables. On entreprend actuellement des évaluations de toxicité sur les bananes, les mangues et les papayes. Les recherches se poursuivront sur Clostridium botulinum E et F, Salmonellae et autres organismes pathogènes.

ИССЛЕДОВАНИЯ БЕЗВРЕДНОСТИ ОБЛУЧЕННЫХ ПИЩЕВЫХ ПРОДУКТОВ И СВЯЗАН­НЫХ С НИМИ ПРОБЛЕМ ЗДРАВООХРАНЕНИЯ ПО ПРОГРАММЕ КОМИССИИ ПО АТОМНОЙ
ЭНЕРГИИ США В ОБЛАСТИ ОБЛУЧЕНИЯ ПИЩЕВЫХ ПРОДУКТОВ. С 1961 года Отдел
биологии и медицины Комиссии организует исследования по оценке биологической безопас­ности пищевых продуктов, которые представляют интерес с точки зрения программы Комис­сии по атомной энергии в области облучения пищевых продуктов. Исследования, связанные
с безопасностью, микробиологическими и биохимическими аспектами облучения продуктов,
проводятся, чтобы дополнить данные технических и экономических исследований, осуществ­ленных изотопным отделом Комиссии. Когда это представляется осуществимым в отноше­нии определенных пищевых продуктов, облученных малыми дозами, то проводятся исследо­вания с целью получения соответствующих данных, которые требует администрация пищевых
продуктов и лекарств в связи с принятием окончательного решения в отношении просьбы о
широком производстве того или иного продукта для населения.

В эту программу включены исследования токсичности на некоторых видах животных,
в рацион которых содержалось до 35% (сухое твердое вещество) указанных облученных пи­щевых продуктов. Результаты двухлетних исследований на животных (крысы, собаки и куры)
дают данные относительно потребления пищевых продуктов, интенсивности развития, фер­ментных систем, гематологии, патологии и гистопатологии. Менее продолжительные ис­следования, связанные с двумя видами животных (крысы и собаками), проводились для
получения подтверждающих данных в тех случаях, когда определенный облученный пищевой
продукт имеет достаточную связь с пищевыми продуктами, которые ранее были подвергну­ты продолжительным исследованиям в отношении токсичности. Обсуждаются последние ре­зультаты исследований хронической токсичности у моллюсков, а также исследований не­острой токсичности клубники, яблок, груш, черешни, абрикосов, сливы и лука.

Микробиологические исследования сосредоточены главным образом на потенциально
патогенных организмах. В настоящее время проводятся исследования с целью установления
оценок, определяющих радиоустойчивость и теплоустойчивость, споруляцию, рост
и образование токсинов у Clostridium Botulinum, тип Е.

Исследуется природная распространённость организмов типа Е в некоторых морских
продуктах и океанской среде. Обсуждаются результаты микробиологических исследований.
Последние исследования показали, что общие перспективы безвредности облучения пи­щевых продуктов являются благоприятными. В настоящее время производится оценка токсичности бананов, манго, папайи и томатов. Будут продолжены исследования, связанные
с Clostridium Botulinum, типы Е и F, а также салмонеллой и другими потенциально пато­генными организмами.

PROGRAMA DE IRRADIACION DE ALIMENTOS DE LA COMISION DE ENERGIA ATOMICA DE LOS
ESTADOS UNIDOS: INVESTIGACIONES SOBRE COMESTIBILIDAD Y SANIDAD PUBLICA. Desde 1961 la
División de Biología y Medicina de la Comisión de Energía Atómica de los Estados Unidos viene patrocinando
estudios con objeto de evaluar la seguridad biológica de los productos alimenticios de interés para el pro­grama de irradiación de alimentos que esté llevando a cabo. Se han emprendido investigaciones sobre
comestibilidad y estudios microbiológicos y bioquímicos para complementar los datos proporcionados por
las investigaciones experimentales, económicas y tecnológicas patrocinadas por la División de Aplicaciones
INTRODUCTION

Potential biological hazards related to the consumption of foods preserved by treatment with ionizing radiation have been studied in a comprehensive manner since the inception of the United States Army Food Irradiation programme in 1953. Discussions in this paper are limited to those areas most pertinent to the wholesomeness and biological safety of low-dose irradiated foods of interest to the food irradiation programme of the United States Atomic Energy Commission (USAEC).

The Division of Biology and Medicine of the USAEC has sponsored investigations relating to the areas of wholesomeness, pathogenic microbiology and certain biochemical aspects of various radiation-pasteurized marine products, fruits and vegetables included in the USAEC's food irradiation programme since 1961. These studies have been pursued in an effort to obtain definitive information concerning the public health safety of this process. Close liaison has been established and maintained with the United States Food and Drug Administration (USFDA) in the planning of these research activities. Constant liaison is also maintained with the Division of Isotopes Development, USAEC, which sponsors studies on the development and technology of radiation-pasteurized foods in the Commission's programme. Results of biologically oriented studies are included, with developmental and technological data, in petition requests submitted to the USFDA for unlimited human consumption of specific classes or types of low-dose irradiated foods.

For clarity, these research considerations are discussed within the two broad categories of wholesomeness and microbiological safety.
WHOLESOMENESS

To assess critically the wholesomeness or "safety for human consumption" of irradiated foods, numerous long-term animal feeding studies on 21 representative foods have been sponsored by the Office of the United States Army Surgeon General. The results of these investigations, now complete, indicate that the irradiated foods tested are wholesome [1].

In certain cases, and with the approval of the USFDA, it has been possible to extrapolate data from the United States Army's long-term, chronic toxicity animal investigations on similar, or related, classes of foods which were treated with sterilizing doses of ionizing radiation. In those instances where the chemical and/or taxonomic characteristics

<table>
<thead>
<tr>
<th>Food</th>
<th>Dose (krad)</th>
<th>Experimental animals</th>
<th>Status</th>
</tr>
</thead>
<tbody>
<tr>
<td>Strawberries</td>
<td>0/300</td>
<td>Rat and dog</td>
<td>Completed</td>
</tr>
<tr>
<td>Apples</td>
<td>0/200</td>
<td>Rat and dog</td>
<td>Completed</td>
</tr>
<tr>
<td>Pears</td>
<td>0/400</td>
<td>Rat and dog</td>
<td>Completed</td>
</tr>
<tr>
<td>Sweet cherries</td>
<td>0/500</td>
<td>Rat and dog</td>
<td>Completed</td>
</tr>
<tr>
<td>Apricots</td>
<td>0/400</td>
<td>Rat and dog</td>
<td>Completed</td>
</tr>
<tr>
<td>Prune plums</td>
<td>0/400</td>
<td>Rat and dog</td>
<td>Completed</td>
</tr>
<tr>
<td>Onions</td>
<td>0/25</td>
<td>Rat and dog</td>
<td>Completed</td>
</tr>
</tbody>
</table>

a) All diets contained 35% (of total dietary solids) of the experimental food, with the exception of onions, which were fed at a level of 10% to dogs.

of foods of interest in the USAEC's programme have been noted to be closely related to such sterilized foods, the USFDA has approved the use of short-term subacute toxicity (animal feeding) studies to substantiate the existing evidence. A number of foods which are of interest to the USAEC's programme, and which bear such relationships, have been subjected to 90-day, subacute animal feeding studies. These foods are listed in Table I. Rations containing the experimental food (35% of total dietary solids) were fed to dogs and rats in accordance with a standard protocol which has been approved by the USFDA. Laboratory determinations on animals included growth rate, haematology, enzyme analysis, gross pathology and histopathology (carcinogenicity). These studies, now complete, showed no differences of biological importance between animals fed on rations containing the high amounts of irradiated and non-irradiated test foods [2, 3].

When the food item of interest bears no distinct relationship to foods previously investigated, chronic toxicity investigations of two years' duration have normally been required on at least two species of animal. These studies are performed in accordance with a standard protocol
TABLE II. LONG-TERM, CHRONIC TOXICITY STUDIES

<table>
<thead>
<tr>
<th>Food</th>
<th>Dose (krad)</th>
<th>Experimental animals</th>
<th>Expected completion date</th>
</tr>
</thead>
<tbody>
<tr>
<td>Soft-shell clams</td>
<td>0/400/800</td>
<td>Rat</td>
<td>August 1966</td>
</tr>
<tr>
<td>Soft-shell clams</td>
<td>0/400/800</td>
<td>Dog and chicken</td>
<td>December 1967</td>
</tr>
<tr>
<td>Bananas</td>
<td>0/20/40</td>
<td>Rat and dog</td>
<td>December 1968</td>
</tr>
</tbody>
</table>

Animal diets contain 35% (total dietary solids) of experimental foods.

which has been approved by the USFDA. Foods which are currently being investigated in this manner are listed in Table II. Animal diets contain 35% (dry weight) of the irradiated or non-irradiated test food. Parameters of investigation include growth rate, haematology, enzyme evaluations, reproduction, gross pathology and histopathology (carcinogenicity).

Preliminary data on radiation-pasteurized soft-shell clams (Mya arenaria) have suggested no evidence of significant differences in any of the biological parameters being tested in animals fed on rations containing irradiated and non-irradiated soft-shell clams [4].

In addition to the animal toxicity studies now completed, or currently in progress, short-term, subacute studies are planned for other foods, such as mangoes and papayas. Two-year chronic toxicity investigations on low-dose irradiated bananas are currently being initiated.

The effects of pasteurizing doses of radiation on the nutritional composition of foods have also been explored. Biological evaluations of protein quality have been made on a number of irradiated marine products (Table III); similar biological assays are currently in progress on irradiated chicken meat. Comparisons of irradiated, non-irradiated and casein control diets have revealed no impairment of the biological quality and availability of protein in the irradiated marine products tested [4]. Foods treated with pasteurizing radiation doses have displayed remarkably small losses of the more radiation-labile vitamins (e.g., thiamine and ascorbic acid) and amino acids. These losses are considered to be of no nutritional significance [5, 6].

Within the broad area of wholesomeness of foods preserved by treatment with ionizing radiation, consideration must be given also to the possible production of small amounts of decomposition products which might conceivably act as toxic agents at the cellular level and cause genetic changes, including chromosome aberrations in biological systems. It has been known for a number of years that ultraviolet irradiation of nutrient broth induces certain compounds which are mutagenic to Staphylococcus aureus [7, 8]. Swaminathan et al. [9] reported that barley embryos cultured in potato mash irradiated to 20 and 40 krad of X-rays exhibited an increased frequency of micronuclei in the root-tip cells. Chopra et al. [10] have demonstrated that a marked increase in the frequency of chromosome breaks was produced when germinating seeds of barley and onion were cultured in orange and apple juices which
TABLE III. BIOLOGICAL EVALUATIONS OF PROTEIN QUALITY

<table>
<thead>
<tr>
<th>Food</th>
<th>Dose (krad)</th>
<th>Current status</th>
</tr>
</thead>
<tbody>
<tr>
<td>Haddock</td>
<td>0/200/400</td>
<td>Completed</td>
</tr>
<tr>
<td>Flounder</td>
<td>0/300/600</td>
<td>Completed</td>
</tr>
<tr>
<td>Crab</td>
<td>0/200/400</td>
<td>Completed</td>
</tr>
<tr>
<td>Shrimp</td>
<td>0/150/300</td>
<td>Completed</td>
</tr>
<tr>
<td>Soft-shell clams</td>
<td>0/400/800</td>
<td>Completed</td>
</tr>
<tr>
<td>Chicken</td>
<td>0/400/800</td>
<td>In progress</td>
</tr>
</tbody>
</table>


had been treated with 200 krad of gamma rays. Pollard et al. [11] reported a decrease in growth rate, enzyme production, protein and DNA synthesis in E. coli when cultured in irradiated media containing glucose and inorganic compounds. Swaminathan [12] reported an increased frequency of sex-linked recessive lethals, dominant lethals and recessive visible mutations in Drosophila melanogaster when the flies were reared on irradiated media. Under similar conditions, Rinehart and Ratty [13] have reported an increased frequency of sex-linked recessive lethals in Drosophila melanogaster, but have found no increase in dominant lethals or recessive visible mutations. Holsten et al. [14] have recently reported that breakdown products of irradiated sucrose are responsible for growth inhibition in a carrot tissue culture system. Shaw and Hayes [15] found a marked depression of mitotic rate and increased chromosome breakage in human leucocyte cultures, in vitro, when irradiated sucrose solutions in a final concentration above 0.2% were added to cultures.

In addition to the above examples, there have also been contradictory results in these areas. Chopra [16] and Reddi et al. [17] have published reports of their experiments on Drosophila which indicate no increase in mutation frequency or chromosome aberrations in flies cultured on irradiated media. Although the reports referred to above are of considerable scientific interest, it does not necessarily follow that degradation products produced by irradiation of foods would behave in a cytotoxic or mutagenic manner when fed to mammals or man. Such compounds may be rendered ineffective from a mutagenic or cytotoxic standpoint by the enzymatic degradation processes to which they would be subjected prior to leaving the gastro-intestinal tract, or to the detoxification processes normally present in mammalian systems. To reach any definitive conclusions in this complex area, however, it appears essential that well-designed in vivo experiments on blood, tissues or organ systems of animals which are fed irradiated food be conducted. An ad hoc committee of mammalian geneticists was recently convened in Washington, D.C., by
the Division of Biology and Medicine of the USAEC to consider the findings in this area and to draft recommendations for future studies.

MICROBIOLOGICAL SAFETY

Microbiological studies sponsored by the Division of Biology and Medicine in this programme have been concentrated predominately on organisms which are potentially pathogenic and of public health significance. *Clostridium botulinum*, Type E has been recognized as a potential public health hazard in low-dose irradiated marine products which are held for extended periods of time at certain temperatures in the refrigeration range [18]. Studies have been sponsored since 1961 to evaluate carefully factors governing germination, outgrowth and toxin production, as well as radiation and thermal resistance characteristics of Type E spores under a variety of well-controlled conditions.

Surveys for the detection of *Clostridium botulinum*, Type E have been conducted in several ocean coastal environments of the United States. Samples of marine sediments, water, algae and fish have been examined in these surveys. Type E organisms have been found in nearly all coastal environments of the United States surveyed so far. The recent isolation of *Clostridium botulinum*, Type F in Pacific coastal areas is also of interest [19]. Physiological studies on Type F isolates are currently in progress.

As part of a joint co-operative agreement with Atomic Energy of Canada, Limited (AECL) and the United States Army Natick Laboratories on research relating to the radiopasteurization of fresh and frozen poultry, considerable interest has evolved in exploring the effects of pasteurizing doses of radiation on pathogenic organisms which may be present (e.g., Salmonellae and *Clostridium perfringens*). Investigations of radiation effects on such organisms, as related to the ecological situations presented by the normal spoilage microflora, are currently being initiated. Work is also under way to explore further the findings of Erdman et al. [20] concerning the effects of repeated treatments of low-dose irradiation on the induction of radio-resistant organisms, with possible changes in biochemical and virulence characteristics of certain pathogenic organisms such as Salmonellae.

Studies involving the inoculation of massive numbers of *Clostridium botulinum*, Type E spores into marine product samples, followed by irradiation and storage at specified temperatures for extended periods of time have been conducted. While these studies are for the purpose of providing information concerning possible Type E spore outgrowth and toxin production in specific types of irradiated marine products under simulated commercial handling conditions, the spore concentrations, storage temperatures and holding times were designed to provide a most severe challenge, far in excess of conditions visualized under actual commercial conditions. Results indicate that no outgrowth or toxin production occurs when haddock fillets are inoculated with these extremely high concentrations of spores, irradiated and held at 33, 35 or 40°F [21]. In a similar study on shucked soft-shell clams, no outgrowth or toxin production was observed under these challenging conditions in samples held at 35°F or below for extended periods [22]. Instances of outgrowth
and toxin production were observed in irradiated, heavily inoculated clam samples which were held for extended periods at several higher refrigeration temperatures. Although no final judgements have been reached so far in the evaluation of results, it is apparent that all inoculated pack data must be carefully scrutinized and considered in the light of practical considerations concerning such factors as low, natural concentrations of Type E, the storage life of irradiated products, storage temperatures and handling methods expected under commercial conditions. Type E-inoculated pack studies on additional types of irradiated marine products are currently under consideration.

SUMMARY AND CONCLUSIONS

Certain aspects of wholesomeness and microbiological safety research which are of direct interest to the low-dose food irradiation programme of the USAEC are outlined in this paper. No attempt is made to report detailed findings of studies supported by the USAEC in these areas. However, attention has been focused on certain main features of past and current investigations within the programme, as well as related research.

On the basis of animal feeding studies conducted to date, the general outlook for the wholesomeness of radiation processed foods appears favourable. No evidence of untoward biological effects on animals or impairment of nutritional quality have been found. Literature reports which have suggested possible mutagenic and/or cytotoxic effects attributable to the irradiation of certain compounds have been followed with interest. Plans are being formulated for the investigation of such possible effects by in vivo experiments on animals which are fed on irradiated food. The outlook for the successful management of any possible public health safety hazards due to Clostridium botulinum in low-dose irradiated marine products appears to be favourable; however, the data now being accumulated on inoculated pack studies of the various marine products of interest to the programme of the USAEC must be carefully assessed in the light of practical considerations.

REFERENCES


DISCUSSION

H. WITTFOGEL: Have you found off-flavours in haddock and flounder irradiated to 200-400 krad?

L. A. WHITEHAIR: Investigations to date have indicated that no objectionable off-flavours occur in haddock and flounder irradiated to 200 000 rad. Doses as high as 400 000 rad may cause detectable organoleptic changes in these fish. The optimum technological dose appears to be approximately 200 000 rad for both species. Doses used in wholesomeness studies normally exceed the optimum technological dose for the product in question in order to avoid any possibility of additional studies being necessitated if the technological dose should be raised in the future.

N. GETOFF: It is well known from radiation chemistry that the mechanism of a number of important reactions is strongly dependent on the dose-rate. I therefore feel that the study of the dose-rate dependence in irradiated food is of considerable importance, and interesting effects can be expected. I would like to recommend more extensive investigations along these lines.

L. A. WHITEHAIR: I certainly agree that the dose-rate may be an important factor. The wholesomeness and microbiological studies conducted within our programme have not placed a great deal of emphasis
on dose-rate variations. We hope to study this aspect in greater detail in certain future work.

A. MATSUYAMA: In connection with mutagenic effects in irradiated food, you mentioned the enzymatic detoxification processes which may be involved in mammalian systems. Have you any experimental evidence for this idea?

L.A. WHITEHAIR: At the present time there is no direct evidence for detoxification of toxic decomposition products of irradiated sugars. Experimental work in this area may be desirable. There is reason to believe, however, that enzymatic processes in the gastrointestinal tract play an important role in the inactivation of various types of breakdown products or compounds, such as caffeine, which in themselves are believed by some authorities to possess mutagenic and/or cytotoxic properties.

A. MATSUYAMA: Have you carried out any studies on the radio-sensitivity or radiolysis of Clostridium botulinum Type E toxin?

L.A. WHITEHAIR: Perhaps Dr. Segner would like to answer this question.

W.P. SEGNER: To my knowledge, no work has been done on the radiation resistance of Clostridium botulinum Type E toxin in the United States. Published work by Dr. Skulberg of the Norges Veterinarhøgskole, Oslo, indicates that the radiation resistance of Type E toxin is of the same order as that reported for Type A toxin by Wagenaar and Dack.

N. GRECZ: Dr. Whitehair has stated that irradiated foods act mutagenically on microorganisms but not on mammals. He has proposed an explanation according to which digestion in the intestinal tract of the mammal may perhaps degrade any mutagenic agents. I would like to propose an alternative, statistical or mathematical, explanation. Let us assume that the mutagens are not degraded. Let us assume that they cause mutations in the mammal's body with the same frequency as in a bacterial population, i.e. approximately 1 in $10^6$. If only 1 in $10^6$ sperm cells mutate, the probability that this one sperm will be involved in the production of the offspring is very small indeed. Since we assay mutagenic action by observing the offspring, the probability of detecting the mutagenic effects of food products on mammals by available assay methods is extremely small. From these considerations it can be seen that the available methods are not sufficiently sensitive to detect the mutagenic action of irradiated foods in mammals.

The situation is quite different with bacteria. In bacteriology there are selective methods available for the specific detection of mutants. This may account for the apparent difference between the results for mammals and bacteria.
BIOLOGICAL EFFECTS OF IRRADIATED FATS

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UNIVERSITY OF MAINZ,
FEDERAL REPUBLIC OF GERMANY

Abstract — Résumé — Аннотация — Resumen

BIOLOGICAL EFFECTS OF IRRADIATED FATS. Rats were fed with a diet containing 20% of irradiated oils. If the oils were irradiated with 2.5 Mrad, there was no indication of detrimental effects during the course of 80 weeks. Oils irradiated with 10 Mrad, however, caused an increase in lethality after a lag period of 9 to 12 months. Irradiation with 50 Mrad caused weight losses after 24 weeks, disturbed liver function, and hypoproteinaemia, with a relative increase in gamma globulins. No animal of this group exceeded a life-span of 75 weeks. Irradiation with 100 Mrad caused immediate toxic symptoms and a high lethality. There is no indication that peroxides are responsible for the toxicity of the irradiated oils. Because of the high content of dimeric products in the irradiated oils, it is assumed that dimerization of fatty acids is the cause of damage.

EFFETS BIOLOGIQUES DES MATIERES GRASSES IRRADIEES. Les auteurs ont soumis des rats à un régime alimentaire contenant 20% d'huiles irradiées. Avec des huiles irradiées à 2,5 Mrad aucun effet nuisible ne s'est manifesté pendant 80 semaines. Toutefois, les huiles irradiées à 10 Mrad ont eu pour effet une augmentation de la mortalité après un délai de 9 à 12 mois. L'irradiation à 50 Mrad a causé des pertes de poids au bout de 24 semaines, des troubles de la fonction hépatique, et une carence de protéines avec accroissement correspondant de gamma-globulines. Aucun animal de ce groupe n'a survécu au-delà de 75 semaines. L'irradiation à 100 Mrad a immédiatement donné naissance à des symptômes d'intoxication et a fait monter le taux de mortalité. Rien n'indique que les peroxydes seraient la cause de la toxicité des huiles irradiées. En raison du contenu élevé des huiles irradiées en produits dimères, on suppose que la cause de ces effets défavorables réside dans la dimerisation des acides gras.

БИОЛОГИЧЕСКОЕ ВЛИЯНИЕ ОБЛУЧЕННЫХ ЖИРОВ. Крысам скармливали рацион, содержащий 20% облученных масел. Если масло были облучены дозой 2,5 Мрад, то не было никаких признаков вредного влияния в течение 80 недель. Однако дозы 10 Мрад вызывали повышенную летальность после дополнительного периода в 9—12 месяцев. Доза в 50 Мрад вызывала потери веса после 24 недель, нарушение функции печени и гипопротеинемию при относительном увеличении гамма-глобулинов. Ни одно животное из этой группы не жило более 75 недель. Облучение дозой 100 Мрад немедленно вызывало токсические симптомы и высокую летальность. Нет никаких признаков того, что перекиси являются причиной токсичности облученных масел. Из-за высокого содержания димерных продуктов в облученных маслах предполагается, что димеризация жирных кислот является причиной их вредности.

EFECTOS BIOLOGICOS DE LOS ACEITES IRRADIADOS. Se ha administrado a ratas una dieta con un 20% de aceites irradiados. En los aceites sometidos a dosis de 2,5 Mrad no se observó ningún indicio de efectos perjudiciales en el transcurso de 80 semanas. En cambio, los aceites sometidos a dosis de 10 Mrad originaron un aumento de la mortalidad después de un periodo de 9 a 12 meses. La irradiación en dosis de 50 Mrad originó pérdidas de peso al cabo de 24 semanas, disfunciones hepáticas e hipoproteínemia con un relativo aumento de las gammaglobulinas. Ningún animal de este grupo vivió más de 75 semanas. La irradiación en dosis de 100 Mrad causó síntomas inmediatos de intoxicación y mortalidad elevada. No hay indicios de que los peróxidos sean la causa de la toxicidad de los aceites irradiados. En vista del elevado contenido de productos diméricos de dichos aceites, se supone que la causa de la toxicidad es la dimerización de los ácidos grasos.

1. INTRODUCTION

Long-term feeding experiments on rats have been performed with oils which had received different degrees of irradiation to observe the effects
on a variety of biological functions. Since polyunsaturated fatty acids are supposed to be the main point of attack by irradiation, soybean oil was used in the author's experiments, as it is comparatively rich in unsaturated fatty acids.

2. IRRADIATION

Irradiation of the oils was carried out in the Institut für Lebensmittelfrischhaltung in Karlsruhe. The source of radiation was a Van de Graaff apparatus with a particle velocity of 1 MeV. During irradiation the oil was cooled so that the temperature never exceeded 25°C. The oil was irradiated in air at doses of 2.5, 10, 50, or 100 Mrad.

3. CHEMICAL CHARACTERISTICS OF THE OILS

The chemical constants and fatty acid composition of the irradiated oils are shown in Tables I, II and III. With increasing doses of radiation the authors found decrease in the iodine value and increase in the peroxide, acid, and hydroxyl values. There is no decrease in dienoic and trienoic acids due to irradiation up to 50 Mrad; with 100 Mrad, however, this decrease is considerable (Table III).

The most striking effect is the production of dimers and corresponding increase in viscosity. The content of dimers after 2.5 Mrad of irradiation was 0.2%, and after 10 Mrad, 1.4%.

4. FEEDING EXPERIMENTS

In a first experiment, rats of the Spraque-Dawley strain were fed during the whole life-time with soybean oils which had been irradiated with 0, 2.5, 10, 50, or 100 Mrad of 6-radiation. Each group consisted of 80 rats (40 males and 40 females). The oils were given in an amount of 20% (wt./wt.) of the diet, corresponding to about 36% of the total calories.

A second experiment was performed to obtain information on the intestinal absorption of irradiated oils and the effects on the fatty acid composition of the liver lipids. In this experiment the rats were fed for eight weeks with soybean oil irradiated with 100 Mrad.

Feeding oils irradiated with 100 Mrad caused immediate adverse effects, such as growth retardation, decreased food efficiency, and an increase in mortality (see Tables IV and V). After 6 months 75% of the animals had died.

Irradiation with 50 Mrad caused no difference, compared with the control, as far as growth, food efficiency and reproduction were concerned for 24 weeks. After this time, however, weight loss and high mortality were observed. No animal in this group exceeded a life-span of 75 weeks.

After a dose of 10 Mrad only, increased mortality was seen after 40 weeks.
TABLE I. CHEMICAL CONSTANTS OF IRRADIATED SOYBEAN OILS

<table>
<thead>
<tr>
<th>Radiation dose (Mrad)</th>
<th>Peroxide value (meq/kg)</th>
<th>Saponification value</th>
<th>Acid value</th>
<th>Iodine value</th>
<th>Hydroxyl value</th>
<th>nD 40</th>
<th>Unsaponifiable matter (%)</th>
<th>Tocopherol (mg%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>4.7</td>
<td>191</td>
<td>0.19</td>
<td>133</td>
<td>3.5</td>
<td>1.4680</td>
<td>0.88</td>
<td>42</td>
</tr>
<tr>
<td>2.5</td>
<td>11.2</td>
<td>190</td>
<td>0.30</td>
<td>133</td>
<td>0.3</td>
<td>1.4681</td>
<td>0.75</td>
<td>33</td>
</tr>
<tr>
<td>10.0</td>
<td>27.7</td>
<td>191</td>
<td>1.38</td>
<td>131</td>
<td>6.8</td>
<td>1.4690</td>
<td>0.90</td>
<td>39</td>
</tr>
<tr>
<td>50.0</td>
<td>71.0</td>
<td>190</td>
<td>3.87</td>
<td>127</td>
<td>12.3</td>
<td>1.4707</td>
<td>1.03</td>
<td>4</td>
</tr>
</tbody>
</table>

TABLE II. FATTY-ACID COMPOSITION OF THE IRRADIATED SOYBEAN OILS

<table>
<thead>
<tr>
<th>Radiation dose (Mrad)</th>
<th>Saturated C 16 C 18 (%)</th>
<th>Monoenoic C 18 (%)</th>
<th>Dienoic C 18 (%)</th>
<th>Trienoic C 18 (%)</th>
<th>Polymers (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>11 3.6</td>
<td>24</td>
<td>49</td>
<td>6.2</td>
<td>0</td>
</tr>
<tr>
<td>2.5</td>
<td>10 3.4</td>
<td>21</td>
<td>50</td>
<td>7.7</td>
<td>0.2</td>
</tr>
<tr>
<td>10.0</td>
<td>11 3.8</td>
<td>22</td>
<td>49</td>
<td>6.7</td>
<td>1.4</td>
</tr>
<tr>
<td>50.0</td>
<td>11 4.0</td>
<td>21</td>
<td>45</td>
<td>8.4</td>
<td>5.7</td>
</tr>
</tbody>
</table>

TABLE III. PROPERTIES OF THE SOYBEAN OILS USED IN FEEDING EXPERIMENT No. 2

<table>
<thead>
<tr>
<th>Composition of soybean oil</th>
<th>Soybean oil untreated (control)</th>
<th>Soybean oil irradiated with 100 Mrad</th>
</tr>
</thead>
<tbody>
<tr>
<td>Iodine value</td>
<td>130.0</td>
<td>115.0</td>
</tr>
<tr>
<td>Peroxide value</td>
<td>1.5</td>
<td>8.5</td>
</tr>
<tr>
<td>Acid value</td>
<td>0.5</td>
<td>4.5</td>
</tr>
<tr>
<td>Tocopherol (mg%)</td>
<td>107.0</td>
<td>0</td>
</tr>
<tr>
<td>Dienoic acids (%)</td>
<td>49.0</td>
<td>29.0</td>
</tr>
<tr>
<td>Trienoic acids (%)</td>
<td>5.5</td>
<td>1.5</td>
</tr>
<tr>
<td>Higher unsaturated fatty acids (%)</td>
<td>1.0</td>
<td>1.0</td>
</tr>
</tbody>
</table>
TABLE IV. EFFECT OF FEEDING IRRADIATED SOYBEAN OIL ON THE LIFE SPAN

<table>
<thead>
<tr>
<th>Experimental animals</th>
<th>Control (d)</th>
<th>Soybean oil irradiated at dose of</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>2.5 Mrad (d)</td>
</tr>
<tr>
<td>Male rats (40 each group)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Average life span</td>
<td>450</td>
<td>482</td>
</tr>
<tr>
<td>Survival period</td>
<td></td>
<td></td>
</tr>
<tr>
<td>75% of rats:</td>
<td>395</td>
<td>384</td>
</tr>
<tr>
<td>50% of rats:</td>
<td>445</td>
<td>480</td>
</tr>
<tr>
<td>25% of rats:</td>
<td>505</td>
<td>549</td>
</tr>
<tr>
<td>Female rats (40 each group)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Average life span</td>
<td>460</td>
<td>487</td>
</tr>
<tr>
<td>Survival period</td>
<td></td>
<td></td>
</tr>
<tr>
<td>75% of rats:</td>
<td>385</td>
<td>375</td>
</tr>
<tr>
<td>50% of rats:</td>
<td>451</td>
<td>511</td>
</tr>
<tr>
<td>25% of rats:</td>
<td>576</td>
<td>578</td>
</tr>
</tbody>
</table>

After a dose of 2.5 Mrad there was no difference to controls during the complete duration of the experiment. The average life span of the animals is shown in Table IV.

5. ABSORPTION AND ENZYMATIC CLEAVAGE OF IRRADIATED OILS

The absorption of irradiated soybean oil (100 Mrad) was only slightly diminished, as can be seen from the data in Tables VI and VII. The enzymatic cleavage of irradiated oils by pancreas lipase and liver esterase decreased with increasing radiation doses [1]. However, the decrease was so small that it could hardly be the cause for the observed decrease in absorption. The latter is probably caused by polymerization of the irradiated oil.

6. BIOCHEMICAL AND PHYSIOLOGICAL ACTIONS OF IRRADIATED SOYBEAN OILS

6.1. Energy metabolism

The data in Table VIII show the oxygen uptake by animals fed with irradiated soybean oil for 40 weeks. There is no change caused by oils irradiated with 2.5 Mrad. Higher radiation doses, however, resulted in a decrease of oxygen uptake which is significant.

In a similar way heart frequency (Table IX) and body temperature (Table X) are lowered in the 40th week of feeding oils irradiated with 10 Mrad or more.
### TABLE V. GROWTH AND FOOD EFFICIENCY ON FEEDING SOYBEAN OIL IRRADIATED WITH 100 Mrad (Feeding Experiment No. 2)

<table>
<thead>
<tr>
<th>Growth, uptake and efficiency</th>
<th>Controls (g)</th>
<th>100 Mrad (g)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Weight gain</td>
<td></td>
<td></td>
</tr>
<tr>
<td>in 2 weeks</td>
<td>58</td>
<td>57</td>
</tr>
<tr>
<td>4 weeks</td>
<td>115</td>
<td>114</td>
</tr>
<tr>
<td>6 weeks</td>
<td>180</td>
<td>174</td>
</tr>
<tr>
<td>8 weeks</td>
<td>220</td>
<td>205</td>
</tr>
<tr>
<td>Food uptake</td>
<td></td>
<td></td>
</tr>
<tr>
<td>in 2 weeks</td>
<td>120</td>
<td>121</td>
</tr>
<tr>
<td>4 weeks</td>
<td>280</td>
<td>292</td>
</tr>
<tr>
<td>6 weeks</td>
<td>465</td>
<td>476</td>
</tr>
<tr>
<td>8 weeks</td>
<td>646</td>
<td>669</td>
</tr>
<tr>
<td>Food efficiency</td>
<td></td>
<td></td>
</tr>
<tr>
<td>in 2 weeks</td>
<td>0.49</td>
<td>0.47</td>
</tr>
<tr>
<td>4 weeks</td>
<td>0.41</td>
<td>0.39</td>
</tr>
<tr>
<td>6 weeks</td>
<td>0.39</td>
<td>0.37</td>
</tr>
<tr>
<td>8 weeks</td>
<td>0.34</td>
<td>0.31</td>
</tr>
</tbody>
</table>

### TABLE VI. DIGESTIBILITY OF IRRADIATED SOYBEAN OIL (Experiment No. 1)a

<table>
<thead>
<tr>
<th>Week of experiment</th>
<th>Controls (%)</th>
<th>Dose of 100 Mrad (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>98.8</td>
<td>92.0</td>
</tr>
<tr>
<td>2</td>
<td>95.7</td>
<td>92.3</td>
</tr>
<tr>
<td>3</td>
<td>96.3</td>
<td>89.7</td>
</tr>
<tr>
<td>10</td>
<td>98.5</td>
<td>89.3</td>
</tr>
<tr>
<td>20</td>
<td>97.3</td>
<td>84.9</td>
</tr>
<tr>
<td>25</td>
<td>97.1</td>
<td>81.8</td>
</tr>
</tbody>
</table>

a Each value is the mean of 5 rats, the period of observation 7 d, and 20% (wt./wt.) soybean oil in the food. The numbers show the amount of oil absorbed as a percentage of the amount given.
TABLE VII. DIGESTIBILITY OF IRRADIATED SOYBEAN OIL (Experiment No. 2)\textsuperscript{a}

<table>
<thead>
<tr>
<th>Weeks of experiment (No):</th>
<th>Controls</th>
<th>Dose of 100 Mrad</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>3</td>
<td>5</td>
</tr>
<tr>
<td>Food uptake (g)</td>
<td>159.0</td>
<td>167.0</td>
</tr>
<tr>
<td>Amount of faeces (g)</td>
<td>33.1</td>
<td>42.1</td>
</tr>
<tr>
<td>Fatty acids in the faeces (g)</td>
<td>2.29</td>
<td>1.54</td>
</tr>
<tr>
<td>Fatty acids in the dried faeces (%)</td>
<td>6.9</td>
<td>3.9</td>
</tr>
<tr>
<td>Digestibility (%)</td>
<td>98.6</td>
<td>99.0</td>
</tr>
</tbody>
</table>

\textsuperscript{a} Each value is the mean of 7 rats. The other conditions are the same as those shown in Table VI.

TABLE VIII. OXYGEN UPTAKE OF RATS ON A DIET WITH 20\% IRRADIATED SOYBEAN OIL IN 40th WEEK OF FEEDING EXPERIMENT

<table>
<thead>
<tr>
<th>Group of animals</th>
<th>Number of animals</th>
<th>(O_2) uptake (mm(^3)/cm(^2) min)</th>
<th>Probability</th>
</tr>
</thead>
<tbody>
<tr>
<td>Controls</td>
<td>10</td>
<td>14.20 ± 0.39</td>
<td>-</td>
</tr>
<tr>
<td>2.5 Mrad</td>
<td>10</td>
<td>13.75 ± 0.49</td>
<td>0.4</td>
</tr>
<tr>
<td>10 Mrad</td>
<td>10</td>
<td>12.27 ± 0.32</td>
<td>&lt; 0.001</td>
</tr>
<tr>
<td>50 Mrad</td>
<td>10</td>
<td>12.60 ± 0.41</td>
<td>&lt; 0.01</td>
</tr>
</tbody>
</table>

6.2. Nervous system

The irritability of the central nervous system is lowered in rats fed on 50-Mrad irradiated oil for 35 weeks (see the values for central chronaxia in Table XI).

6.3. Liver

The liver function was checked by the bromsulphthalein retention test after 16 weeks (Table XII) or 32 weeks (Table XIII) of feeding irradiated
TABLE IX. HEART FREQUENCY OF RATS IN 39th WEEK OF FEEDING EXPERIMENT AFTER FEEDING IRRADIATED SOYBEAN OIL

<table>
<thead>
<tr>
<th>Group of animals</th>
<th>Number of animals</th>
<th>Heart frequency</th>
<th>Probability</th>
</tr>
</thead>
<tbody>
<tr>
<td>Controls</td>
<td>10</td>
<td>314 ± 4.1</td>
<td>-</td>
</tr>
<tr>
<td>2.5 Mrad</td>
<td>10</td>
<td>304 ± 4.1</td>
<td>0.1</td>
</tr>
<tr>
<td>10 Mrad</td>
<td>10</td>
<td>296 ± 4.5</td>
<td>&lt; 0.001</td>
</tr>
<tr>
<td>50 Mrad</td>
<td>10</td>
<td>270 ± 12.5</td>
<td>&lt; 0.001</td>
</tr>
</tbody>
</table>

TABLE X. RECTAL TEMPERATURE OF RATS ON A DIET WITH 20% IRRADIATED SOYBEAN OIL IN 40th WEEK OF THE FEEDING EXPERIMENT

<table>
<thead>
<tr>
<th>Group of animals</th>
<th>Number of animals</th>
<th>Rectal temperature (°C)</th>
<th>Probability</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control</td>
<td>10</td>
<td>38.05 ± 0.08</td>
<td>-</td>
</tr>
<tr>
<td>2.5 Mrad</td>
<td>10</td>
<td>38.16 ± 0.10</td>
<td>-</td>
</tr>
<tr>
<td>10 Mrad</td>
<td>10</td>
<td>37.48 ± 0.16</td>
<td>&lt; 0.001</td>
</tr>
<tr>
<td>50 Mrad</td>
<td>10</td>
<td>36.66 ± 0.30</td>
<td>&lt; 0.001</td>
</tr>
</tbody>
</table>

oils. There was a reduction in liver function after radiation doses of 50 Mrad and more, but not with 10 or 2.5 Mrad.

Data on the fatty-acid composition of the liver of control rats and of rats fed with 100-Mrad-irradiated soybean oil are given in Table XIV. There is no influence on liver weight and total lipid content, but the level of polyunsaturated fatty acids is decreased. This corresponds to the lower uptake of polyunsaturated acids with irradiated oils.

6.4. Blood chemistry

Feeding soybean oil irradiated with 100 Mrad causes hypoproteinaemia, with a striking decrease in the albumin fraction and a relative increase in gamma-globulins, as has been reported earlier [2]. This may be the result of the disturbed liver function and also reflects the decreased protein efficiency. After a feeding period of three weeks there was no influence on total lipids, total cholesterol, and phospholipids in the blood plasma by oils irradiated with 2.5 or 50 Mrad. Oils irradiated with 10 Mrad,
TABLE XI. EFFECT OF FEEDING IRRADIATED SOYBEAN OIL ON THE IRRITABILITY OF THE CENTRAL NERVOUS SYSTEM

<table>
<thead>
<tr>
<th>Rat (No.)</th>
<th>Central chronaxia in the 35th week of the feeding experiment</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Control (μsec)</td>
</tr>
<tr>
<td>1</td>
<td>150</td>
</tr>
<tr>
<td>2</td>
<td>140</td>
</tr>
<tr>
<td>3</td>
<td>170</td>
</tr>
<tr>
<td>4</td>
<td>160</td>
</tr>
<tr>
<td>Mean:</td>
<td>155</td>
</tr>
</tbody>
</table>

TABLE XII. LIVER FUNCTION IN THE 13th WEEK OF FEEDING IRRADIATED SOYBEAN OIL

<table>
<thead>
<tr>
<th>Group of animals</th>
<th>Number of animals</th>
<th>BS-retention in the serum (%)</th>
<th>Probability</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control</td>
<td>12</td>
<td>0.77 ± 0.172</td>
<td>-</td>
</tr>
<tr>
<td>2.5 Mrad</td>
<td>9</td>
<td>1.09 ± 0.210</td>
<td>0.2</td>
</tr>
<tr>
<td>10 Mrad</td>
<td>9</td>
<td>0.71 ± 0.217</td>
<td>0.8</td>
</tr>
<tr>
<td>50 Mrad</td>
<td>13</td>
<td>1.96 ± 0.390</td>
<td>&lt; 0.01</td>
</tr>
<tr>
<td>100 Mrad</td>
<td>10</td>
<td>1.93 ± 0.500</td>
<td>&lt; 0.02</td>
</tr>
</tbody>
</table>

The numbers give the retention of bromsulphthalein as a percentage of the dose (20 mg/kg) 20 min after the intravenous injection.

however, caused an increase in total lipids and phospholipids and a decrease in cholesterol.

7. HISTOLOGICAL EXAMINATIONS

The histological picture of the kidneys, heart, lungs, and brain after 100-Mrad-irradiated oils was quite normal.
TABLE XIII. LIVER FUNCTION IN THE 32nd WEEK OF FEEDING IRRADIATED SOYBEAN OIL

<table>
<thead>
<tr>
<th>Group of animals</th>
<th>Number of animals</th>
<th>BS-retention in the serum (%)</th>
<th>Probability</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control</td>
<td>12</td>
<td>1.01 ± 0.21</td>
<td>-</td>
</tr>
<tr>
<td>50 Mrad</td>
<td>12</td>
<td>6.55 ± 1.19</td>
<td>&lt; 0.001</td>
</tr>
</tbody>
</table>

*The numbers give the retention of bromsulphthalein as a percentage of the dose (20 mg/kg) 20 min after the intravenous injection.*

TABLE XIV. INFLUENCE OF FEEDING IRRADIATED SOYBEAN OIL ON THE POLYUNSATURATED FATTY-ACID CONTENT OF THE LIVER

<table>
<thead>
<tr>
<th></th>
<th>Control</th>
<th>100 Mrad</th>
</tr>
</thead>
<tbody>
<tr>
<td>Liver weight (g)</td>
<td>8.2</td>
<td>8.2</td>
</tr>
<tr>
<td>Total lipids of the liver (%)</td>
<td>5.1</td>
<td>5.2</td>
</tr>
<tr>
<td>Total lipids of the liver (g)</td>
<td>0.42</td>
<td>0.42</td>
</tr>
<tr>
<td>Uptake of dienoic acids (g/d)</td>
<td>1.07</td>
<td>0.65</td>
</tr>
<tr>
<td>Liver, dienoic acids as percentage of total fatty acids</td>
<td>12.5</td>
<td>6.2</td>
</tr>
<tr>
<td>Liver, dienoic acid content (g)</td>
<td>0.052</td>
<td>0.026</td>
</tr>
<tr>
<td>Liver, dienoic acid content (%)</td>
<td>0.63</td>
<td>0.31</td>
</tr>
<tr>
<td>Uptake of trienoic acids (g/d)</td>
<td>0.12</td>
<td>0.034</td>
</tr>
<tr>
<td>Liver, trienoic acids as percentage of total fatty acids</td>
<td>4.0</td>
<td>2.7</td>
</tr>
<tr>
<td>Liver, tetraenoic acids as percentage of total fatty acids</td>
<td>2.4</td>
<td>1.2</td>
</tr>
<tr>
<td>Liver, pentaenoic acids as percentage of total fatty acids</td>
<td>0.4</td>
<td>0.2</td>
</tr>
<tr>
<td>Liver, hexaenoic acids as percentage of total fatty acids</td>
<td>1.8</td>
<td>0.7</td>
</tr>
</tbody>
</table>

*Each number is the mean of 19 male rats which have been fed with a diet containing 20% (wt./wt.) soybean oil.*
In the liver and spleen (100 Mrad, 5½ months) a brown pigment was found, giving reactions for iron. On the basis of further histochemical examinations, this was found to consist of modified fatty acids, with some iron adsorbed.

The testes showed an atrophic picture after 32 weeks of 50-Mrad-irradiated oils or after 12 weeks of 100-Mrad-irradiated oils.

The adrenal cortex showed a progressive transformation after six months of 100-Mrad-irradiated oils, the epithelium being higher than that of controls.

8. TEST FOR TOXICITY ON FERTILE HEN EGGS

Fertile eggs were injected with 0.1, 0.2, or 0.3 ml of different types of soybean oil (untreated, irradiated with 2.5 or 10 Mrad) and placed in an incubator. The number of hatched chicks was determined. The results are summarized in Table XV. Although the number of experiments is not yet high enough for statistical examination, it is not likely, that, by this test, toxicity of irradiation with 2.5 or 10 Mrad can be proved.

9. MECHANISM OF ACTION OF IRRADIATED OILS

The effects of irradiated soybean oils depend very much on the dose of radiation. Higher radiation doses presumably give rise to different products, rather than to larger amounts of the same products as produced by lower doses. Oils irradiated with 2.5 Mrad had no adverse action at all, even after very long feeding periods, and in amounts of 36% of the total calories. Oils irradiated with 10, 50, or 100 Mrad caused a variety of changes, of which only very few (testes atrophy and changes of the fatty-acid composition of liver lipids) are due to the destruction of tocopherol or unsaturated fatty acids by irradiation. The cause of death after highly irradiated oils is still completely unknown. Peroxides are frequently made responsible for the toxic effects of irradiated fats. The author's experiments give strong evidence against this idea. Peroxide formation is just the beginning of changes which lead to further products. Peroxides themselves are quite unstable under the conditions of irradiation, especially with high radiation doses. The peroxide content of the irradiated soybean oils is rather low (Tables I and III) and there is no correlation between the toxicity and peroxide values of irradiated oils. The peroxide values of irradiated oils are, in fact, lower than peroxide values of autooxidized fats, which caused no toxic effects in experiments of other investigators. Moreover, peroxides cause strong local irritation in the gastro-intestinal tract. None of the irradiated soybean oils used by the authors caused any intestinal irritation. The main chemical change of the soybean oils after irradiation is an increase in dimers and polymers. They assume that the toxicity is caused firstly by these products.

Finally, it should be pointed out that the experiments with high doses of radiation (10, 50, and 100 Mrad) have been performed on the basis of a theoretical consideration that critical points should be discovered, on which attention can be focused in experiments with low radiation doses.
TABLE XV. TEST FOR TOXICITY OF IRRADIATED SOYBEAN OIL ON EMBRYONIC CHICKS

<table>
<thead>
<tr>
<th>Doses</th>
<th>Control +80 mg% tocopherol</th>
<th>2.5 Mrad +68 mg% tocopherol</th>
<th>2.5 Mrad +333 mg% tocopherol</th>
<th>10 Mrad +46 mg% tocopherol</th>
<th>10 Mrad +354 mg% tocopherol</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.1 ml</td>
<td>hatched</td>
<td>15</td>
<td>12</td>
<td>13</td>
<td>15</td>
</tr>
<tr>
<td></td>
<td>died</td>
<td>5</td>
<td>6</td>
<td>5</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>poor vitality</td>
<td>0</td>
<td>2</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>0.3 ml</td>
<td>hatched</td>
<td>6</td>
<td>4</td>
<td>5</td>
<td>7</td>
</tr>
<tr>
<td></td>
<td>died</td>
<td>3</td>
<td>2</td>
<td>5</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>poor vitality</td>
<td>1</td>
<td>4</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

These high doses of radiation are of no practical interest in the treatment of food the more changes are caused in taste, flavour and appearance, which make the food disagreeable.

REFERENCES:

DISCUSSION

R.O. SINNHUBER: How were the irradiated oils stored?
K.H. BÄSSLER: In sealed containers at 0°C.
R.O. SINNHUBER: What was the time interval between mixing the oils in the ration and the consumption of the ration?
K.H. BÄSSLER: Three or four days.
R.O. SINNHUBER: What was the tocopheral level of the diet at the time of feeding?
K.H. BÄSSLER: This was not determined.
H. KEPPEL: Have you observed similar effects when oils were treated by other methods, such as heating?
K. H. BÄSSLER: Oils oxidized by heat were found to contain far more peroxides and to cause irritation of the gastrointestinal tract - an effect we did not observe in the case of irradiated oils.

H. KEPPEL: In what kind of atmosphere did you irradiate the oils?
K. H. BÄSSLER: We irradiated them in air.

N. RAICA: Since it is known that vitamins, among other nutrients, are destroyed by autooxidized and irradiated oils, it is difficult to separate nutritional effects and toxic product effects when such fats are incorporated in the diet. Supplementary vitamins and antioxidants should be given orally and, if possible, an active component or components isolated from the fats should also be given as separate supplements.

B. RAJEWSKY: Did you observe any differences between fresh oils and oil that had been stored for some time?
K. H. BÄSSLER: No, we did not.
EFFECT OF DECONTAMINATION OF FEED MIXTURES BY HEAT TREATMENT AND GAMMA RADIATION ON GROWTH AND FEED CONVERSION IN FATTENING PIGS

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RESEARCH INSTITUTE FOR ANIMAL NUTRITION, HOORN, AND NATIONAL INSTITUTE OF PUBLIC HEALTH, UTRECHT, NETHERLANDS

Abstract — Résumé — Аннотация — Resumen

EFFECT OF DECONTAMINATION OF FEED MIXTURES BY HEAT TREATMENT AND GAMMA RADIATION ON GROWTH AND FEED CONVERSION IN FATTENING PIGS. The causal rôle of Salmonella-contaminated foods of animal origin in human Salmonellosis has been demonstrated during recent years on a world-wide scale. Further research has revealed that Salmonella-contaminated feeds are the first link of the chain leading eventually to contaminated foods. Radiation treatment (Salmonella radicidation) has been shown to be a promising mode of decontamination of feeds and feed ingredients. Investigations have now been made as to whether mixed feeds so treated lose any of their nutritional value with regard to pig raising.

In the authors' experiment three groups of eight pigs each were raised on meal that had been irradiated with 1 Mrad of 60Co γ-rays, on heat-decontaminated, and on untreated meal, respectively. The experiments were carried out in two different institutes, to take into account geographical factors, on a total number of 48 pigs. Heat decontamination was carried out at 80-85°C for 30 min. Enterobacteriaceae in the untreated meal averaged 1.0 × 10⁵/g. After both decontamination treatments 30 samples, 50 g each, were taken at random from the decontaminated consignments and examined for Enterobacteriaceae by enrichment. Five of the heat-treated meal samples and two of the irradiated meal samples were found to be not entirely free from these bacteria, but could be considered to be adequately decontaminated as far as Salmonella was concerned.

In one institute the pigs were fattened for about 100 d, reaching a weight of approximately 100 kg. The average growth per animal per day was 767 g for the group fed untreated meal, 770 g for the group receiving heat-treated meal, and 800 g for the irradiated meal group. The feed intake (kg/kg growth) for the above-mentioned groups amounted to 2.85, 2.81 and 2.74 respectively.

In the other institute the pigs were fattened during approximately 155 d, reaching a weight of almost 116 kg. The average growth (grams per animal per day) was 627, 643 and 625 for the groups fed untreated, heat-treated and irradiated meal, respectively. The feed figures, (kg intake/kg growth) were 3.30, 3.23 and 3.24, respectively, for these groups.

From these results the conclusion can be drawn that neither irradiation nor heat decontamination had any adverse effect on the nutritional value of meals in these tests. In all instances the required vitamins were added to the meals subsequent to decontamination treatment.

As a further study of the effect of the bacteriological condition of an animal feed mixture on Salmonella, samples of excretion faeces from each animal were examined twice a week for the presence of Salmonella. In the untreated meal group Salmonellae were isolated in 13 cases. Faeces of pigs fed irradiated or heat-treated meal were free from Salmonellae throughout the whole test period. This demonstrates the efficiency of the decontamination treatments used and, at the same time, the efficacy of such processing methods in the prevention of the occurrence of healthy Salmonella carriers amongst pigs.

EFFET DE LA DECONTAMINATION DE MELANGES ALIMENTAIRES PAR TRAITEMENT THERMIQUE ET IRRADIATION GAMMA SUR LA CROISSANCE ET SUR LA CONVERSION DES ALIMENTS CHEZ LES PORCS D'ELEVAGE. Au cours des dernières années, on a fait dans le monde entier la démonstration du rôle déterminant, dans la salmonellose de l'homme, des produits alimentaires d'origine animale contaminés par Salmonella. De nouvelles recherches ont montré que les nourritures destinées aux animaux et contaminées par Salmonella sont le premier maillon de la chaîne qui peut mener à la contamination des denrées ali-
mentaires. On a constaté que l'irradiation (radication de Salmonella) constituait un moyen prometteur de décontamination des nourritures destinées à la consommation animale et de leurs ingrédients. Les auteurs ont cherché à déterminer si les mélange alimentaires ainsi traités ne perdent rien de leur valeur nutritive pour l'élevage du porc. L'expérience a consisté à élever trois groupes de huit porcs, l'un recevant des aliments irradiés à 1 Mrad de rayons γ de 60Co, l'autre des aliments décontaminés par la chaleur et le troisième des aliments non traités. L'expérience était menée parallèlement dans deux instituts différents, afin de tenir compte des facteurs géographiques, et portait donc sur un nombre total de 48 bêtes. Le traitement thermique a été pratiqué à une température de 80 à 85°C pendant 30 min. Les entérobactériacées contenues dans les nourritures non traitées ont été comptées; on en a trouvé 1,0·10⁵/g. Après les deux traitements de décontamination, on a prélevé au hasard 30 échantillons de 50 g des produits traités et on a recherché les entérobactériacées après enrichissement. On a constaté que cinq des échantillons traités par la chaleur et deux des échantillons irradiés n'étaient pas entièrement exempts de ces bactéries; toutefois, ces échantillons peuvent être considérés comme suffisamment décontaminés en ce qui concerne Salmonella.

Dans l'un des instituts, les porcs ont été engraisés pendant à peu près 100 jours et ont atteint un poids d'environ 100 kg. La croissance moyenne par animal et par jour était de 767 g pour le groupe alimenté avec des nourritures non traitées, de 770 g pour le groupe engraisé avec des nourritures traitées par la chaleur, et de 800 g pour le groupe élevé avec des nourritures irradiées. La quantité de nourriture absorbée par kilogramme de croissance pour ces mêmes groupes était de 2,85, 2,81 et 2,74 respectivement.

Dans l'autre institut, les porcs ont été engraisés pendant 155 jours environ et ont atteint un poids de près de 116 kg. La croissance moyenne par animal et par jour était de 627 g pour le groupe alimenté avec de la nourriture non traitée, de 643 g pour le groupe alimenté avec de la nourriture traitée par la chaleur, et de 625 g pour le groupe engraisé avec des aliments irradiés. La quantité de nourriture absorbée par kilogramme d'accroissement ont été pour ces différents groupes de 3,30, 3,23 et 3,24 kg respectivement.

On peut conclure d'après ces résultats que ni l'irradiation ni le traitement thermique n'ont eu d'effets défavorables sur la valeur nutritive des aliments. Dans tous les cas, on a ajouté les vitamines nécessaires aux aliments, après le traitement.

A titre d'étude complémentaire des effets de la qualité bactériologique d'une nourriture pour animaux sur l'excrétion de Salmonella, les auteurs ont examiné des échantillons de matières fécales de chaque animal deux fois par semaine pour voir si cette bactérie était présente. Dans le groupe nourri avec des aliments non traités, ils ont isolé Salmonellae dans 13 cas. Dans le groupe des porcs nourris avec des aliments irradiés ou traités par la chaleur, les matières ont été exemptes de Salmonellae pendant toute la durée de l'expérience. Ce fait prouve en même temps l'efficacité antibactérienne des traitements et leur utilité pour empêcher l'apparition de porteurs sains parmi les porcs.

**ВЛИЯНИЕ ОБЕЗЗАРАЖИВАНИЯ КОРМОВЫХ СМЕСЕЙ ТЕПЛОВОЙ ОБРАБОТОЙ И ГАММА-ОБЛУЧЕНИЕМ НА РОСТ И КОНВЕРСИЮ ПИЩИ У ОТКЛАРМИВАЕМЫХ СВИНЕЙ.**

За последние годы было доказано в международном масштабе, что пищевые продукты животного происхождения, зараженные сальмонеллой, вызывают у человека сальмонеллез. Дальнейшие исследования показали, что зараженные сальмонеллой корма являются первым звеном этой цепи, которая в конечном счете приводит к заражению пищевых продуктов. Радиационная обработка ("радиацидация сальмонеллы") оказалась перспективным способом обеззараживания кормов и их компонентов. В настоящее время проведены исследования с целью выяснить, не потеряли ли смешанные корма, подвергнутые такой обработке, в какой-либо степени свою питательную ценность при откорме свиней. Три группы свиней, по восемь голов в каждой, откармливали соответственно облученным дозой 1 Мрад ( kobalt-60) кормом, кормом, подвергнутым тепловой обработке, и кормом без обработки. Эксперименты проводили в двух различных институтах, чтобы учесть географические факторы, при этом в общей сложности опыт подверглись 48 свиней. Тепловая обработка проводилась при температуре 80—85°C в течение 30 минут. Количество подсчитанных энтеробактерий в необработанных кормах составляло 1,0·10⁵/g. После обеззараживания обоими способами было произведено выборочное взятие 30 проб весом в 50 г из обеззараженных партий кормов и исследованы на энтеробактерии путем обогащения. Было обнаружено, что 5 проб кормов, подвергнутых тепловой обработке, и 2 пробы облученных кормов не были полностью свободны от этих бактерий, однако можно считать, что они подверглись достаточному обеззараживанию в отношении сальмонеллы. В одном институте свиньи откармливались в течение приблизительно 100 дней, и их вес составлял около 100 кг. Средний прирост одной свиньи в день составлял: 767 г — для группы, получавшей необработанные корма, 770 г — для группы, которая получала корм, подвергнутый тепловой обработке, и 800 г — для группы, получавшей облученные корма. На 1 кг приресса соответственно поняло 2,85, 2,81 и 2,74 кг корма. В другом институте свиньи откармливались в течение приблизительно 155 дней, и их вес достиг почти 116 кг. Средний прирост одной свиньи в сутки составлял для групп, получавших необработанные, подвергнутые тепловой обработке и облученные корма, соответственно 627, 643 и 625 г.
На 1 кг привеса пошло соответственно 3,30, 3,23 и 3,24 кг корма. На основе этих результатов можно сделать вывод о том, что ни облучение, ни тепловая обработка не оказывали никакого отрицательного воздействия на питательную ценность кормов во время проведения этих испытаний. Во всех случаях после обеззараживания в корм добавляли необходимые витамины.

В порядке дальнейшего изучения влияния бактериологического свойства кормов на помет, содержащий сальмонеллу, дважды в неделю у каждой свиньи брали пробу помета и исследовали на сальмонеллу. В отношении группы свиней, получавших необработанные корма, сальмонелла была выделена в 13 случаях. В помете свиней, получавших облученные или подвергшиеся тепловой обработке корма, не было обнаружено сальмонеллы на всем протяжении экспериментов. Вместе с тем это свидетельствует о действенности используемых методов обеззараживания, а также об эффективности таких методов обработки в деле предотвращения распространения среди свиней здоровых носителей сальмонеллы.

INTRODUCTION

Three factors may be important in the incidence of Salmonellae in slaughter-pigs — the possibility of infection in early life ("piglet-infection"), the feed, and the environment [1, 2]. The extent of the influence of the latter factor requires further investigation. In such investigations, possible contamination via the feed is ruled out by complete or partial decontamination of the feed.
Decontamination is currently effected by heat-treatment at 80-85°C for 30 min. [3], by γ-radiation, or by the application of pelleted feeds. Unlike the first two methods, which ensure at least a five-decimal place reduction of the number of Enterobacteriaceae, the third method does not achieve complete decontamination, but ensures a reduction of the order of two to three decimal places. It has, however, been established that the use of pellets for fattening pigs has no adverse effect on growth and feed consumption [4]. There is very little information regarding the possible consequences of the other methods of decontamination. In an attempt to fill this gap, an investigation was carried out into the effects of decontamination by heat-treatment and by radiation of feed mixtures on fattening results in pigs.

DESIGN OF EXPERIMENTS

The effect of the total decontamination of a feed mixture for fattening pigs on the nutritional value of this mixture was studied on the basis of two experiments carried out almost simultaneously. One experiment was carried out in the experimental pig unit of the National Institute of Public Health at Bilthoven, and the other experiment was performed at the Research Institute for Animal Nutrition at Hoorn. Both experiments concerned three groups of eight pigs of the Large White type. In each experiment, optimal comparability of the groups was ensured by dividing the animals by descent, sex, and growth during the preliminary period, and the initial weight.

The three groups in each experiment received: I, non-decontaminated feed (Controls); II, heat-decontaminated feed; III, feed decontaminated by γ-radiation.

As pointed out in the Introduction to this paper, heat decontamination was effected by exposing the mixture to humid heat at 80-85°C for 30 min. Decontamination by radiation was effected as follows: The mixture was packed into cardboard boxes, each containing 12.5 kg of mixture. The boxes were led past the source of radiation (60Co) at a rate ensuring that the radiation dose received was 1 Mrad. This treatment was given at the Package Irradiation Plant in Wantage, Berks., England. Since the feed had to be irradiated in England, it seemed advisable to send the entire batch of feed for both experiments for treatment at the same time. It was consequently impossible to distinguish between the ration for the period up to 50 kg and that for the second part of the experiment. The same feed mixture was therefore used throughout the experiment, made up as follows:

<table>
<thead>
<tr>
<th>Feed mixture</th>
<th>(%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ground maize</td>
<td>25.0</td>
</tr>
<tr>
<td>Ground barley</td>
<td>23.0</td>
</tr>
<tr>
<td>Ground milocorn</td>
<td>15.5</td>
</tr>
<tr>
<td>Ground oats</td>
<td>10.0</td>
</tr>
<tr>
<td>Wheat bran</td>
<td>10.0</td>
</tr>
<tr>
<td>Soybean oil meal</td>
<td>4.0</td>
</tr>
<tr>
<td>Fish meal</td>
<td>7.5</td>
</tr>
<tr>
<td>Alfalfa meal</td>
<td>3.5</td>
</tr>
<tr>
<td>Mineral mixture</td>
<td>1.5</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>100.0</strong></td>
</tr>
</tbody>
</table>
The calculated feed value of this mixture was:

<table>
<thead>
<tr>
<th>Component</th>
<th>Value (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Starch equivalent</td>
<td>68.4</td>
</tr>
<tr>
<td>Digestible crude protein</td>
<td>13.4</td>
</tr>
<tr>
<td>Starch equivalent: digestible crude protein</td>
<td>5.1</td>
</tr>
<tr>
<td>Ca: P</td>
<td>1.3</td>
</tr>
<tr>
<td>Lysine</td>
<td>0.85</td>
</tr>
<tr>
<td>Methionine</td>
<td>0.32</td>
</tr>
<tr>
<td>Cystine</td>
<td>0.28</td>
</tr>
</tbody>
</table>

No vitamin compounds were included in the mixture, because any vitamins added would be partially or wholly lost during decontamination. During feeding, therefore, the mixture per animal was enriched by 30 g of a special vitamin compound providing (per kg feed mixture): 150,000 I. U. vitamin A, 20,000 I. U. vitamin D, 1000 I. U. vitamin E, 100 mg vitamin B₁, 200 mg vitamin B₂, 1000 mg nicotinic acid, 1000 mg pantothenic acid, 6000 mg choline and 50 mg pyridoxine; heat-decontaminated feed was used as carrier. To be on the safe side, it was assumed, when compounding this vitamin preparation, that any vitamins that might have been present in the feed would be made ineffective by decontamination.

The total amount of feed required for both experiments was prepared at the same time so that identical basic substances would be used. The total amount thus obtained was divided into three equal portions, two of which were subjected to the above-mentioned treatment. All feeds were stored at 4°C until used.

To verify the effect of decontamination, the mixture was examined bacteriologically before and after treatment (the untreated mixture was found to average $1.0 \times 10^5$ Enterobacteriaceae per gramme). After treatment by heating, or radiation, thirty 50-gramme samples were obtained at random. Enterobacteriaceae were isolated from 5 of the 30 samples of heat-decontaminated feed and from 2 of the 30 samples of irradiated feed. The results indicate sufficient decontamination.

RESULTS

One pig in the Bilthoven control group died during the experiment. This animal has been excluded from the calculation of the mean results. Otherwise, only a few instances of transient illness occurred, both at Bilthoven and at Hoorn; the course of the experiments can therefore be described as uneventful. The principal average results are presented in Table I.

Before the experiment was begun the animals were twice examined in the pig unit for Salmonellae; none were isolated from them. Throughout the experiment, faeces from the various styes were examined twice a week. Faecal samples from the test styes at Bilthoven originated from 218 animals fattened on heat-decontaminated feeds and from 224 pigs fattened on radiation-decontaminated feeds. None of these samples yielded Salmonellae. However, Salmonellae were isolated from 11 of the 219 faecal samples taken from the group fattened on non-decontaminated feeds (S. give in 10 cases, and S. give and S. dublin in 1 case). In the Hoorn-test styes, faeces from groups fattened with heat-decontaminated and radiation-decontaminated feeds were free from Salmonellae (350 and 344 samples, respectively). S. give was isolated from 2 out of 344 faecal samples obtained in the group fed on untreated feed.
Table 1. Average live weight gain and feed conversion

<table>
<thead>
<tr>
<th></th>
<th>I Control</th>
<th>II Decontaminated by heat treatment</th>
<th>III Decontaminated by γ-radiation</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Bilthoven</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Initial weight</td>
<td>kg</td>
<td>24.4</td>
<td>23.9</td>
</tr>
<tr>
<td>Final weight</td>
<td>kg</td>
<td>101.9</td>
<td>101.4</td>
</tr>
<tr>
<td>Days on experiment</td>
<td></td>
<td>101</td>
<td>100.5</td>
</tr>
<tr>
<td>Mean daily growth</td>
<td>g</td>
<td>767</td>
<td>770</td>
</tr>
<tr>
<td>Standard deviation</td>
<td>g ±</td>
<td>18</td>
<td>± 7</td>
</tr>
<tr>
<td>Feed conversion</td>
<td>kg</td>
<td>2.85</td>
<td>2.81</td>
</tr>
<tr>
<td><strong>Hoorn</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Initial weight</td>
<td>kg</td>
<td>18.6</td>
<td>18.7</td>
</tr>
<tr>
<td>Final weight</td>
<td>kg</td>
<td>115.9</td>
<td>118.3</td>
</tr>
<tr>
<td>Days on experiment</td>
<td></td>
<td>155.5</td>
<td>115.5</td>
</tr>
<tr>
<td>Mean daily growth</td>
<td>g</td>
<td>627</td>
<td>643</td>
</tr>
<tr>
<td>Standard deviation</td>
<td>g ±</td>
<td>14</td>
<td>± 19</td>
</tr>
<tr>
<td>Feed conversion</td>
<td>kg</td>
<td>3.30</td>
<td>3.23</td>
</tr>
</tbody>
</table>

**DISCUSSION**

The fact that Salmonellae were isolated in the two control groups, but not in the test groups, indicates once again that both types of decontamination ensure adequate elimination of Salmonellae.

The better average growth of the Bilthoven pigs must be attributed to the superior quality of the initial material. Although all piglets were bought by the same buyer in the vicinity of Hoorn, the first batch (used for the Bilthoven experiments) was of excellent quality, whereas the second batch (for Hoorn) could only be described as reasonable. This factor also contributed to the higher feed consumption per kilogramme growth in Hoorn (as did the fact that fattening was continued to a higher weight).

In Bilthoven, Group III (irradiated feed) showed the most favourable results in growth and feed conversion; in Hoorn, Group II (heated feed) showed the most favourable results. However, the standard deviations indicate that the differences observed were not significant.

The experiment warrants the conclusion that the methods of decontamination applied had no deleterious effect on the nutritional value of the feed mixture, provided all vitamins required by the pigs were added after decontamination. In addition, it should be noted that the percentage of the very heat-sensitive amino acid, lysine, certainly cannot be regarded as a borderline value. This applies in particular to the second part of the fattening period, when the lysine requirement of the animals is slightly
lower than that in pigs up to 50-kg body weight; since the same feed mixture was used throughout the experiment, however, this fact could not be expressed in the ration.

Earlier experiments [5] have shown that heat decontamination of fish meal has no effect on the composition of protein and crude fat, but does influence digestibility, which is reduced by a few per cent. Availability of basic amino acids also showed a small decrease when this product was used. Heat decontamination proved to have no effect on the digestibility of Argentine meat and bone meal.

Kennedy [6] observed that irradiation of some foods caused a small deterioration in the quality of protein. He assumed that the cause of this phenomenon was to be found in a decrease in methionine availability. Some vitamins of the B complex also proved susceptible to γ-radiation.

The experiences of Dammers and Kennedy, and the results of the experiments described, show that the slightly unfavourable effect of decontamination on the protein quality of certain products has no appreciable influence on the nutritional value of a composite ration which amply meets the animal's requirements.

SUMMARY

Two experiments were carried out with fattening pigs in an attempt to establish whether total decontamination of a feed mixture affects its nutritional value. All animals received the same feed, which was given either untreated (Control, Group I), after heat decontamination (Group II) or after decontamination by irradiation with γ-rays (Group III). In view of the possible destruction of vitamins during decontamination, a complete vitamin mixture was added to the feed immediately before feeding.

The methods of decontamination tested ensured adequate elimination of Salmonellae and had no untoward effect on the nutritional value of the feed mixture.

REFERENCES

N. GETOFF: With regard to the observations concerning radiation-induced changes in the amino acids, I would like to refer to their rate constants and the primary products of the water radiolysis. The ordinary amino acids, such as glycine, alanine, leucine and proline, react with the solvated electrons \( (e^{-}_{aq}) \) with a rate constant of \( 10^6 - 10^8 \text{ M}^{-1}\text{sec}^{-1} \). However, amino acids containing sulphur (cystine, cysteine etc.) possess a rate constant of \( 10^{10} \text{ M}^{-1}\text{sec}^{-1} \). The rate constants of the amino acids with OH radicals are in the range \( 10^7 - 10^9 \text{ M}^{-1}\text{sec}^{-1} \). This would explain their radiolysis by the "indirect effect" of radiation.
NUTRITIONAL VALUE OF IRRADIATED POTATOES

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UNIVERSITY OF MAINZ,
FEDERAL REPUBLIC OF GERMANY

Abstract — Résumé — Аннотация — Resumen

NUTRITIONAL VALUE OF IRRADIATED POTATOES. Rats received dried potatoes, irradiated with 10 krad, in an amount of 72% of the diet. Control groups received the same amount of non-irradiated potatoes. The experiment began on 7 May 1965 and is still running. To date, there is no difference between the groups fed with irradiated potatoes and the controls as far as weight gain and protein efficiency are concerned. Another experiment has been running for 12 weeks under the same conditions, except that the radiation dose was 100 krad. Here, too, no difference to the control groups can be observed.

VALEUR NUTRITIVE DES POMMES DE TERRE IRRADIEES. On a donné à des rats des pommes de terre déshydratées irradiées à 10 krad dans la proportion de 72% du régime alimentaire. Des groupes témoins ont été alimentés avec la même quantité de pommes de terre non irradiées. L'expérience a commencé le 7 mai 1965 et se poursuit. Jusqu'à présent, on n'a observé aucune différence entre les groupes nourris avec des pommes de terre irradiées et les sujets témoins, en ce qui concerne l'accroissement de leur poids et le rendement en protéines. On procède depuis 12 semaines à une autre expérience dans les mêmes conditions, mais avec des pommes de terre irradiées à 100 krad. Là encore, on n'a observé aucune différence par rapport aux groupes témoins.

ПИТАТЕЛЬНАЯ ЦЕННОСТЬ ОБЛУЧЕННОГО КАРТОФЕЛЯ. Крысы получали сушеный картофель, облученный дозой 10 крад. Такой картофель составлял 75% рациона. Контрольные группы получали то же количество необлученного картофеля. Эксперимент начался 7 мая 1965 года и продолжается до сих пор. До настоящего времени различий между группами, получающими облученный картофель, и контрольными группами в прибавлении в весе и эффективности протеина нет. Уже в течение 12 недель продолжается другой эксперимент при тех же условиях, за исключением того, что доза облучения составляет 100 килорад. И в этом случае также не наблюдается никаких различий между подопытными и контрольными группами.

VALOR NUTRITIVO DE LAS PATATAS IRRADIADAS. Se han alimentado ratas administrándoles una dieta constituida en un 72% por patatas desecadas sometidas a una dosis de irradiación de 10 krad. Los grupos testigo recibieron la misma cantidad de patatas no irradiadas. El experimento comenzó el 7 de mayo de 1965 y prosigue aún. Hasta ahora no se ha observado ninguna diferencia entre los grupos alimentados con patatas irradiadas y los grupos testigo, en lo que se refiere al aumento de peso y a la asimilación de proteínas. Hace 12 semanas se ha emprendido otro experimento análogo, con la salvedad de que la dosis de irradiación es de 100 krad. Tampoco en este caso se observan diferencias con los grupos testigo.

Many of the problems generally involved in the sterilization of food by radiation are unimportant with regard to the irradiation of potatoes for sprout inhibition purposes, since only about 7 - 15 krad are required to achieve this [1, 2]. Growth, reproductive performance, mortality, and pathological changes in rats fed with gamma-irradiated potatoes have been investigated by Burns et al.[3]. In these experiments two dose ranges have been used, 13.5 - 20 krad and 27 - 40 krad. The rats received a diet containing 35% irradiated potatoes on a dry-weight basis. No pathological changes have been observed during a period of two years.

Horne and Hickman [4] supplemented the basal diet of pigs with irradiated potatoes (10 krad) ad libitum. This had no adverse effects on weight.
gain, food efficiency, chemical composition of the blood, and the quality of the bacon.

To discover a safety limit the application of higher doses was of interest. In experiments on the toxicity of irradiated food it is often meaningless to just use higher doses of radiation because, as a result of such doses, quite different products may arise. It was therefore decided to use twice the amount of potatoes in the diet as before. This was achieved by feeding dried potatoes as 72% of the diet. In the Institut für Lebensmittelfrischhaltung, in Karlsruhe, it has been shown that rats tolerate dried potatoes very well.

Two feeding experiments are being carried on at present. The first began on 7 May 1965 and is continuing. In this experiment the control group of 60 Spraque-Dawley rats (30 male and 30 female) receives a diet composed of 72% dried potatoes, 15% caseine, 10% "mazola" oil, and 3% salt mixture. The second group, of the same size, receives the same diet, except that the potatoes were irradiated with 10 krad.

To date, there is no difference between the two groups as far as weight gain and protein efficiency are concerned. Data for 4 and 8 weeks are given in Table I.

| TABLE I. GROWTH AND PROTEIN EFFICIENCY ON A DIET CONTAINING IRRADIATED POTATOESa |
|-----------------------------------|-----------------------------------|-----------------------------------|
| Weight gain (g)                  | Protein efficiency               |
| 4 weeks                          | 8 weeks                          | 4 weeks                          | 8 weeks                          |
| Male rats                        |                                  |                                  |                                  |
| Control                          | 121 217                          | 1.72 1.27                        |
| Irradiated                       | 122 211                          | 1.65 1.17                        |
| Female rats                      |                                  |                                  |                                  |
| Control                          | 96 159                           | 1.43 0.97                        |
| Irradiated                       | 96 156                           | 1.35 0.90                        |

a Each group consisted of 30 rats. The numbers in the Table are the mean values of each group. The amount of dried potatoes in the diet was 72%. Irradiation was performed with 10 krad.

A second experiment was started later, under the same conditions, except that the dose of radiation was 100 krad. Here again no difference from the control groups can be observed.

1 Professor Dr. Kuprianoff.
2 Van de Graaf generator, Institut für Lebensmittelfrischhaltung, Karlsruhe.
REFERENCES


CHEMICAL AND PHYSICAL EFFECTS OF IONIZING RADIATION

(Session III)
EFFECTS OF GAMMA RADIATION ON THE CONSTITUENTS OF WHEAT FLOUR. Physical, chemical and biochemical changes occur in the constituents of wheat exposed to gamma radiation. The extent of these changes depends on the origin of the wheat and on the radiation dose.

The carotenoids of the oily fraction of the wheat are reduced by the effects of the radiation, disappearing when the dose reaches 4 Mrad. However, the chemical composition of the lipids, which are the seat of reactions similar to those giving rise to hydroperoxides, remains virtually unchanged even at very high doses.

The substantial degradation of the starch indicates that the polysaccharides of the wheat are the fractions most severely affected by radiation. This leads to an increase in the reducing substances already present and in the maltose index as the dose rises. However, the increase in autolytic production of reducing sugars in the irradiated wheat is due to the greater susceptibility of the starch to hydrolysis by the diastases. The denaturation of the polysaccharides reduces the viscosity of the starch pastes thanks to an increase in the solubility of the amylpectin.

Gamma irradiation generally reduces the proteolytic activity of flour, and, in the case of high doses, causes not only a partial denaturation of the proteins but also their polymerization and/or condensation. This polymerization may be explained by the reaction of free radicals with the gluten proteins having -SH groups and by the interaction of primary radicals in the protein micromolecules (these phenomena occurring during irradiation).

The modifications in the proteins cause variations in the solubility of the albumin, gliadin and glutenin, and also in the percentage distribution of the groups of which they consist.

It was found that low gamma radiation doses (20 000 - 150 000 rad) produce a maximum in the curves of starch viscosity, substances capable of precipitation by electrodialysis, gliadin solubility and the Hagberg index. This anomaly explains the improvement in baking properties which certain authors have noted in the case of wheat receiving small gamma radiation doses.
DESCHREIDER

Les modifications des protéines provoquent des variations de la solubilité des albumine, gliadine et glutéline, ainsi que de la répartition centésimale des groupes qui les constituent.

On a relevé que de faibles doses de rayons gamma, 20 000 à 150 000 rad, font apparaître un maximum dans les courbes: de viscosité de l’amidon, des substances precipitables par électrodialyse, de la solubilité des gliadines et de l’indice Hagberg. Cette anomalie explique l’amélioration des qualités boulangères que certains auteurs ont enregistrée pour des farines irradiées avec de faibles doses de rayonnement gamma.

ДЕЙСТВИЕ ГАММА-ЛУЧЕЙ НА СОСТАВНЫЕ ЭЛЕМЕНТЫ МУКИ. В результате облучения муки гамма-лучами в составных элементах муки наблюдаются физические, химические и биохимические изменения. Они зависят от сорта муки и тем более значительны, чем выше доза облучения.

Под действием излучения уменьшается количество каротиноидов маслянистой фракции муки, которые совсем исчезают, когда доза достигает 4 Мрад. Что касается липидов, то в них происходят реакции, схожие с теми, которые создают гидроперекиси. Тем не менее даже при очень высоких дозах их химический состав практически не меняется.

Значительное уменьшение количества крахмала указывает на то, что полисахариды муки подвергаются наиболее резким изменениям в результате облучения. Это влечет за собой увеличение уже имеющихся редуцирующих веществ и числа мальтозы с возрастанием дозы. Но рост аутолитической продукции редуцирующих сахаров происходит в облученной муке благодаря большой чувствительности крахмала к гидролизу при помощи диастазов. Перерождение полисахаридов вызывает снижение вязкости крахмального клейстера в результате увеличения растворимости амилопектина.

Однако, гамма-облучение снижает протеолитическую активность муки и вызывает при высоких дозах не только частичное перерождение протеинов, но также их полимеризацию и/или конденсацию. Такая полимеризация может быть объяснена реакцией свободных радиоактивных ионов, обладающих соединениями SH с протеинами клейковины, и реакцией первичных радиоактивных ионов между собой в макромолекулах протеинов. Эти явления возникают при облучении.

Изменения протеинов меняют степень растворимости альбумина, глиадина и глутенина, а также меняют сенситивное распределение групп, которые их составляют.

Установлено, что слабые дозы гамма-облучения (от 20 000 до 150 000 рад) вызывают на кривых максимумы: вязкости крахмала, осаждаемых электродиализом веществ, растворимости глиадинов и числа Хагберга. Эта аномалия объясняет улучшение хлебопекарных качеств облученной слабыми дозами гамма-облучения муки, которые установлены некоторыми авторами.

ACCION DE LOS RAYOS GAMMA SOBRE LOS ELEMENTOS CONSTITUTIVOS DE LA HARINA DE TRIGO. Los elementos constitutivos de la harina irradiada con rayos gamma presentan alteraciones físicas, químicas y bioquímicas. Estas alteraciones dependen del origen de la harina y son más importantes cuanto más elevada es la dosis de irradiación.

Los carotinoides de la fracción oleosa de la harina disminuyen bajo la acción de las radiaciones y desaparecen cuando la dosis alcanza 4 Mrad. En los lípidos se producen reacciones análogas a las que engendran los hidroperóxidos, pero su composición química permanece prácticamente invariable, incluso cuando las dosis son muy elevadas.

La importante degradación del almidón indica que los polisacáridos de la harina son las fracciones más fuertemente afectadas por las radiaciones. Esto da lugar a un aumento de las sustancias reductoras preexistentes y del índice de maltosa, paralelo a la elevación de las dosis aplicadas. Pero el incremento de la producción autólítica de los azucares reductores en la harina irradiada se debe a una mayor sensibilidad del almidón a la hidrólisis por las diastasas. La desnaturalización de los polisacáridos provoca pérdida de viscosidad en los engrudos de amiloidón, debida al aumento de solubilidad de la amilopectina.

En general, la irradiación gamma reduce la actividad proteolítica de la harina y, en dosis elevadas, provoca no sólo una desnaturalización parcial de las proteínas, sino también su polimerización y/o condenación. Esta polimerización puede explicarse por la reacción de radicales libres con las proteínas del gluten que poseen grupos -SH, y por la reacción de radicales primarios entre sí dentro de las macromoléculas de proteína; estos fenómenos se producen durante la irradiación.

Las modificaciones de las proteínas provocan variaciones de la solubilidad de la albúmina, la glicina y la glutamina, así como de la distribución porcentual de los grupos que las constituyen.

Se ha observado que pequeñas dosis de rayos gamma -de 20 000 a 150 000 rad- determinan un máximo en las curvas correspondientes a la viscosidad del almidón, las sustancias precipitables por electrodialisis, a la solubilidad de las gliadines y al índice de Hagberg. Esta anomalía explica el mejoramiento de las cualidades de panificación que algunos autores han observado en harinas irradiadas con pequeñas dosis de rayos gamma.
L'autorisation accordée par la FDA \cite{1} des États-Unis d'Amérique d'utiliser les rayons gamma aux doses de 20 000 à 50 000 rad pour la désinsectisation du blé et de ses dérivés, ainsi que la création en Turquie, par la division mixte FAO/AIEA, d'une usine pilote pour la désinsectisation des céréales au moyen de l'irradiation, font franchir une étape décisive à cette technique de lutte contre la dépréciation des grains.

Cette technique de désinsectisation n'est pas strictement limitée aux céréales en général et au blé en particulier, car le traitement par les radiations ionisantes serait intéressant pour la conservation de blé très humide, l'amélioration des qualités boulangères des farines \cite{2-6}, la revalorisation des blés punaisés \cite{7,8}, l'amélioration des qualités technologiques des blés \cite{8,9}, la pasteurisation des pâtes alimentaires aux œufs \cite{10} et l'obtention des amidons spéciaux destinés à l'industrie textile et à celle du papier \cite{11}.

Un tel éventail d'applications éventuelles exige la connaissance des réactions dont les éléments constitutifs de la farine de blé peuvent être le siège sous l'action des rayons gamma, aux doses nécessaires pour obtenir les effets désirés. Cette connaissance est également importante pour l'étude de l'action du rayonnement sur des constituants identiques présents dans d'autres denrées, ainsi que pour les recherches de toxicité et d'innocuité sur animaux nourris avec des aliments irradiés.

C'est dans ce but que l'on passera en revue l'action des rayons gamma sur les principaux éléments constitutifs de la farine de blé, à la lumière des nombreux travaux effectués dans ce domaine tant au Laboratoire central qu'à l'étranger, de façon à en retirer un enseignement quant à leur répercussion sur les propriétés rhéologiques, physiques, chimiques et biochimiques de la farine.

1. LIPIDES ET CAROTÉNOÏDES

On peut suivre l'action des rayons gamma sur les caroténoïdes de la farine par l'évolution de leur spectre d'absorption en lumière visible. Une dose de 0,2 Mrad provoque une perte d'environ 11%; cette perte s'accentue avec des doses croissantes, ce qui entraîne la disparition des caroténoïdes à 5 Mrad \cite{12}.

Dans les lipides on observe une induction des réactions similaires à celles qui engendrent les hydroperoxydes au cours de l'auto-oxydation. Elle se traduit, aux fortes doses, par l'apparition d'une absorption vers 2710 à 2750 Å caractéristique des triènes conjugués \cite{12}, ainsi que par l'augmentation d'un autre dérivé de l'oxydation des lipides qui absorbe vers 2440 Å (fig. 1)\footnote{Source des figures 1 à 5: Ministère des Affaires économiques et de l'énergie, Laboratoire central}.

En irradiant du blé à des doses de 0,5 à 10 Mrad, Tipples et al. \cite{13} ont observé que l'indice des peroxydes des lipides, des farines que l'on extrait de ce blé, augmente avec la dose d'irradiation; mais après six mois de stockage de ces farines, celles qui proviennent de blé traité à fortes doses fournissent des lipides dont l'indice de peroxydes est nettement plus faible que celui des témoins conservés le même temps. Une
telle constatation prouve que les lipides sont le siège de phénomènes de post-exposition. Les mêmes auteurs signalent qu'il y a très peu de différences dans la composition chimique des lipides aux doses très élevées de rayons gamma, et cela malgré l'augmentation des peroxydes.

La figure 1 montre que jusqu'à la dose de 0,2 Mrad le spectre d'absorption des lipides n'est pratiquement pas affecté.

Il faut signaler qu'en ce qui concerne la farine de seigle Wozniak[14] n'a pas davantage trouvé de changements chimiques dans les lipides, pour des doses allant de 10 000 à 160 000 rad.

L'irradiation aux fortes doses se limite donc, pour les lipides de la farine, à une induction des phénomènes d'auto-oxydation.

2. AMIDON ET MALTOSE

L'amidon est un élément constitutif de la farine particulièrement sensible aux rayons gamma, dont la dénaturation influence les substances non protéiques solubles dans l'eau et dans l'alcool [15, 16]. A l'augmentation de produits de dégradation solubles dans l'eau est lié un accroissement de l'acidité titrable et de substances réductrices ainsi que de l'indice maltose [16, 17], ces modifications étant bien souvent fonction des doses appliquées. Comme on ne décèle pas, en même temps, une activation de la bêta-amylase, ainsi que Lee [17] l'a démontré, on peut en conclure que, l'indice maltose augmentant avec l'irradiation, la dépolymérisation de l'amidon rend ce dernier plus sensible aux diastases.

La dénaturation de l'amidon se traduit par l'apparition d'une bande violette (fig. 2) sur les chromatogrammes capillaires de suspensions de farines irradiées. Cette bande est due à l'amylpectine dont la solubilité, dans l'eau à 100°C, augmente avec l'intensité de l'irradiation [18] (fig. 3).
FIG. 2. Chromatographie capillaire de l'amidon - solvant: eau saturée d'iode
A, B - Farine indigène, suspension 1% dans l'eau, temps d'ébullition, 2 min.
C, D - Farine indigène, suspension 1% dans KOH 0,5% après centrifugation.
I: jaune, b: bleu, bf: bleu foncé, v: violet, vb: violet bleu

L'action du rayonnement sur l'amylopectine provoque, selon Saméc [19],
une scission de la molécule au niveau de la liaison α-1,4 ainsi que des
anneaux glucosidiques des chaînes latérales fixées sur les macromolécules,
d'une dose d'environ 2 Mrad libérant à peu près 33% des particules d'un poids
moléculaire inférieur à 5000.

D'après Kertesz et al. [20] la dégradation de l'amidon se situerait vers
60 000 rad, mais on a observé qu'une dose de 25 000 rad pouvait déjà in-
fluencer l'amidon de la farine [18]. Cette différence est due au fait que
les modifications entraînées par les radiations dépendent de l'origine des blés ou des farines.

L'accroissement de la solubilité de l'amyllopectine provoque une chute de la viscosité des empois préparés avec l'amidon de farines irradiées [21], cette chute étant, en général, proportionnelle aux doses d'irradiation lorsqu'on dépasse 0,1 Mrad. Très souvent, entre 25 000 et 100 000 rad on observe un maximum de la viscosité avant la chute de celle-ci (fig. 3). Un tel maximum trouve une confirmation dans le fait que Samec [11] a noté que l'amidon de blé, irradié à environ 50 000 rep, présente une augmentation des composés précipitables par électrodialyse, avant de subir une forte diminution lorsque la dose augmente. Les deux maximums précités pourraient expliquer l'amélioration des qualités boulangères de la farine irradiée, enregistrée par Blinc [3,4] pour des doses de 30 000 à 50 000 rep et par Webb [5] pour le blé irradié à 70 000 rad.

Les rayons gamma influencent également le phosphore de l'amidon [21], phosphore qui s'y trouve sous forme d'acide amylophosphorique et d'estér glycérophosphorique. La teneur en phosphore total de l'amidon décroît avec la dose appliquée, alors que celui qui accompagne l'amyllopectine soluble augmente. Cela indique qu'une partie des liaisons phosphorées de l'amidon a subi un relâchement. Dans les modifications de la répartition du phosphore entre les constituants de l'amidon il existe également, après irradiation, un optimum vers 50 000 à 100 000 rad selon l'origine de la farine.

Les produits libérés par la dégradation de l'amidon peuvent être responsables de réactions de brunissement non enzymatique [22] avec les protéines. C'est ainsi qu'un flocculat jaune-brun apparaît dans un extrait aqueux de farine lorsqu'on irradié celui-ci à une dose de 0,3 Mrad, tandis que la solution acquiert une fluorescence vert-bleu. L'analyse du flocculat indique qu'il contient les acides aminés suivants: acide glutamique, glycocolle, alanine et leucines. Ces réactions expliquent la fluorescence des extraits de blé traité aux rayons gamma et la teinte jaune-brun que prend une farine irradiée à de fortes doses.

3. PROTEOLYSE

Selon la nature de la farine et la dose de rayonnement appliquée, les rayons gamma peuvent jouer un double rôle [23]: soit exercer une action freinante sur la protéolyse, en particulier pour les farines de force, soit favoriser la rupture des protéines par les protéinases – il s'agirait ici d'un effet semblable à celui observé pour l'amidon rendu plus attaquable par les diastases.

La première action peut expliquer une amélioration des qualités boulangères semblable à celle qu'exercent des améliorants à propriétés oxydantes; la seconde pourrait agir favorablement sur l'extensibilité de la pâte.

Une diminution de l'activité protéolytique de la farine provenant de blé irradié de 0,5 à 3 Mrad a été également observée par Romenski et al. [7] et Cmyr et al. [8].
4. GLUTEN

Lorsque du gluten lyophilisé, ayant 7 à 8% d'humidité, est irradié à des doses de 1,6 à 5 Mrad, les protéines qui le constituent peuvent non seulement être dénaturées mais également subir des réarrangements moléculaires conduisant à une condensation et/ou une polymérisation de certaines d'entre elles [24-26]. La gluténine est dénaturée partiellement et libère des protéines apparentées aux gliadines; les albumines subissent une condensation se traduisant par un recul de leur solubilité dans l'eau, de leur mobilité électrophorétique et par l'apparition d'une bande de protéines à faible mobilité. Dans les phénomènes observés, l'origine de la farine dont provient le gluten joue un rôle important.

Les réarrangements moléculaires se traduisent par l'augmentation générale de l'absorption en lumière ultra-violette, en particulier dans la région des acides aminés aromatiques. Cette augmentation est sensiblement proportionnelle aux doses reçues, comme on peut le constater à la figure 4 où sont représentées les variations de l'absorption spécifique 1% protéines 1 cm 290 nm, par un recul de la solubilité dans l'eau; et par une modification des rapports entre les acides aminés soufrés et leurs dérivés (tableau I).

Le rôle joué par ces acides aminés est important, car ils interviennent dans la formation des liaisons -S-S-. Ces ponts peuvent à leur tour être scindés pour reformer de la cystéine ou l'un de ses dérivés. Le mécanisme de la polymérisation des molécules de protéines sous l'action des radiations ionisantes peut s'expliquer:

a) Par un effet indirect du rayonnement qui forme des radicaux libres actifs dus aux molécules d'eau présentes dans le milieu, par exemple: 2R-SH + 2OH → R-S-S-R + 2H₂O; à ce sujet, Lee et al. [27], étudiant la disparition des radicaux emprisonnés dans le glutén, à 6,5% d'humidité et soumis à 1 Mrad de rayons gamma, ont trouvé qu'une petite concentration résiduelle de radicaux persiste pendant une période assez longue; cette stabilité relative s'explique par le fait que dans le glutén déshydraté il n'y a pas une grande prépondérance de groupements donneurs d'hydrogène, comme c'est le cas dans l'amidon, susceptibles de provoquer la disparition totale des radicaux, certains de ceux-ci pouvant être produits dans les parties internes inaccessibles des macromolécules de protéines;
<table>
<thead>
<tr>
<th>Echantillon</th>
<th>Acides aminés</th>
<th>Variations observées</th>
<th>Rapport cystéine + cystine</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Mesure spectrophotométrique</td>
<td>Planimétrie</td>
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<td>Témoin</td>
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<td></td>
<td></td>
<td></td>
<td>5000 krad</td>
</tr>
<tr>
<td>Indigène n°1</td>
<td>Dérivé de l'acide cystéique</td>
<td>Inchangé</td>
<td>3,2</td>
</tr>
<tr>
<td></td>
<td>Acide aspartique</td>
<td>21%</td>
<td>3,9</td>
</tr>
<tr>
<td></td>
<td>Cystéine + cystine</td>
<td>28%</td>
<td></td>
</tr>
<tr>
<td>Français</td>
<td>Dérivé de l'acide cystéique</td>
<td>120%</td>
<td>16,0</td>
</tr>
<tr>
<td></td>
<td>Acide aspartique</td>
<td>6%</td>
<td>3,7</td>
</tr>
<tr>
<td></td>
<td>Cystéine + cystine</td>
<td>-47%</td>
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</tr>
<tr>
<td>Indigène n°3</td>
<td>Dérivé de l'acide cystéique</td>
<td>-42,8%</td>
<td>2,1</td>
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<tr>
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<td>Acide aspartique</td>
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<td>2,6</td>
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<tr>
<td></td>
<td>Cystéine + cystine</td>
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<td>Manitoba</td>
<td>Dérivé de l'acide cystéique</td>
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<tr>
<td></td>
<td>Acide aspartique</td>
<td>+11%</td>
<td>12</td>
</tr>
<tr>
<td></td>
<td>Cystéine + cystine</td>
<td>+23,5%</td>
<td></td>
</tr>
</tbody>
</table>

Note: Ministère des Affaires économiques et de l'énergie, Laboratoire central.
b) Par un effet direct du rayonnement produisant des particules ionisées ou des radicaux primaires, entraînant une modification immédiate des molécules: \( RS^+ + RS^- \rightarrow RS-SR^- \). Dans la formation de radicaux primaires, Singh et al. [28] ont démontré l'importance des acides aminés soufrés; plus la teneur en soufre est élevée, plus la production d'ions -S + -S- ou -S -S- est grande; le soufre des résidus cystine et cystéine peut interférer avec certaines des réactions ioniques qui apparaissent, pour conduire à la formation de radicaux primaires. Les variations enregistrées pour l'acide aspartique au tableau I impliquent des changements au niveau des acides aminés terminaux des molécules de protéines, en particulier celles du type gliadine.

On a également constaté des indices de polymérisation et/ou de condensation des protéines du gluten lorsque ce dernier provient de farines irradiées à des doses de 0,5 à 5 Mrad [15]. La figure 4 montre qu'il y a aussi une augmentation de l'absorption spécifique à 290 µm lorsque les doses croissent.

5. PROTEINES

Si le traitement des farines par des doses élevées de rayons ionisants ne modifie pas leur teneur en protéines, celles-ci accusent, par contre, des variations de solubilité dans les divers solvants utilisés pour leur extraction progressive [12, 29]. À 5 Mrad la gluténine est partiellement dénaturée, libérant des composés possédant les caractères des gliadines solubles dans l'acide lactique. Les taux d'albúmines solubles dans l'eau et de gliadines solubles dans l'alcool propylénique ne varient que dans une mesure relativement faible. Mais les différences de solubilité sont beaucoup plus importantes lorsque les protéines ont été préalablement isolées du gluten extrait des farines irradiées; cela signifie que in situ les protéines ont une réponse différente vis-à-vis des solvants. Comme pour le gluten irradié après sa lyophilisation, l'origine de la farine joue un rôle important en ce qui concerne l'amplitude et le signe des changements qui se sont produits.

Parallèlement aux variations de solubilité des divers types de protéines présents dans la farine, il y a des modifications dans leur fractionnement par chromatographie sur colonne de carboxyméthylcellulose, donc dans leur composition centésimale. Pour une dose de 5 Mrad, les albúmines à caractère anionique augmentent fortement ainsi que celles passant en tête de colonne. En outre, on y voit apparaître une absorption dans l'ultra-violet à 2670 Å et, en ce qui concerne les gliadines solubles dans l'alcool propylénique, on observe un glissement des fractions éluables par les tampons alcalins vers les tampons acides. Les changements dans les diagrammes d'élation et dans la solubilité des gliadines supposent une modification de leur structure également mise en évidence par l'augmentation de l'absorption des fractions à 2840 Å et 2900 Å.

En irradiant des blés à 10,25 et 26% d'humidité, avec des doses allant de 10 à 20 Mrad, Resnichenko et al. [30], qui étudiaient les modifications de structure de la gliadine extraites, ont trouvé que dans les échantillons irradiés la quantité d'acides aminés terminaux, acide glutamique, acide aspartique et sérine, diminue, cette diminution étant indirectement proportionnelle aux doses appliquées. De plus, lorsque l'humidité du blé irradié augmente, le poids moléculaire de la gliadine extrait diminue.
6. PROTEINE ADHERENTE ET PROTEINE INTERSTITIELLE

Lorsqu'on agite la farine avec un solvant organique de densité 1,45, on obtient, après centrifugation, une fraction légère contenant une grande partie de la protéine interstitielle (Zwickelprotein, wedgeprotein) et une fraction lourde contenant la majorité de la protéine adhérant aux grains d'amidon (Haftprotein, adheringprotein).

Le Laboratoire central\(^2\) a étudié l'action des rayons gamma sur ces protéines. Celles-ci furent isolées d'une farine irradiée à des doses allant de 0,15 à 4 Mrad; les modifications de leurs indices physico-chimiques sont présentées à la figure 5. Alors que l'indice de Hagberg ne descend en dessous de celui du témoin qu'entre 1 et 2 Mrad pour la protéine interstitielle, il le fait déjà à partir de 0,5 Mrad pour la protéine adhérente. On observe que cet indice passe par un maximum à 0,15 Mrad avant de diminuer; il monte de 191 à 251 pour la première protéine et de 201 à 218 pour la seconde, à cette dose de radiations. L'indice de Pelshenke modifié croît régulièrement avec les doses appliquées pour la protéine interstitielle, alors qu'il accuse une chute brutale entre 2 et 4 Mrad pour la protéine adhérente. Quant à l'indice de Zeleny, il diminue régulièrement à partir de 0,15 Mrad pour la première protéine, mais reste inchangé au-delà de 0,5 Mrad pour la seconde.

Le maximum accentué de l'indice de Hagberg à 0,15 Mrad pour la protéine interstitielle, ainsi que l'accroissement de l'indice de Pelshenke modifié, vont de pair avec un maximum, à cette même dose, des fractions solubles dans l'alcool propylique et dans l'acide lactique, c'est-à-dire des protéines du type gliadine. Dans l'alcool propylique, les protéines augmentent de 5%, et dans l'acide lactique, de 27,5%, alors que celles du type gluténine diminuent de 18%.

Ces facteurs favorables, du point de vue de la qualité boulangerie, sont à l'origine des améliorations de la farine observées dans certains cas après une irradiation modérée : ils démontrent également qu'ils agissent en particulier sur la protéine interstitielle.

\(^2\) Travail non publié.
Des travaux qui viennent d'être passés en revue dans le domaine de l'irradiation de la farine de blé par les rayons gamma, ainsi que de ceux signalés dans le rapport de Brownell et al. [31], il ressort que le traitement de la farine entraîne des changements physiques, chimiques et biochimiques dans ses éléments constitutifs. Leur nature et leur amplitude sont fonction des doses appliquées.

L'amidon est le constituant particulièrement sensible, dont la dépolymerisation s'amorce déjà à la dose de 25 000 rad. L'action de doses élevées sur les protéines est complexe car, à côté de phénomènes de dénatisation, il en est qui provoquent ou amorcent leur polymérisation et/ou condensation.

Pour les protéines comme pour l'amidon, on remarque que, dans le tracé des courbes modifications/doses appliquées, un maximum apparaît entre 20 000 et 150 000 rad. Cette anomalie permet d'expliquer l'action favorable sur les qualités boulangères que certains auteurs signalent lorsque des farines sont irradiées à ces doses.

Dès lors, on peut se rallier aux conclusions du rapport de Brownell et al. [31] disant que des doses de 20 000 à 50 000 rad utilisées pour la désinsectisation n'ont pas d'effets défavorables sur les caractères organoleptiques, nutritionnels et rhéologiques des produits provenant de blés ou farines de blé irradiés. Dans certains cas ces doses ne pourront qu'influencer favorablement les qualités boulangères de la farine.

On peut conclure également que, des travaux cités par Brownell et al. [31] concernant l'alimentation, la reproduction et la croissance d'animaux, il ressort que le blé irradié ou ses dérivés irradiés présentent les mêmes caractères d'innocuité que les blés et dérivés non irradiés.

En dehors de l'emploi des rayons gamma pour la désinsectisation du blé ou de la farine de blé, on pourra les utiliser dans le futur, à des doses allant jusqu'à 150 000 rad, pour améliorer les qualités boulangères des farines faibles ou pour conserver des blés très humides; des doses comprises entre 0,5 et 3 Mrad permettront d'améliorer les qualités technologiques des blés ou de revaloriser ceux qui sont punaisés. Mais à ces doses élevées il faudra trouver le moyen de combattre certains facteurs indésirables, notamment l'altération de la couleur et de l'odeur de la farine obtenue. De nombreuses recherches doivent encore être effectuées en vue de ces applications éventuelles.

En terminant, il convient de signaler un fait qui est souvent perdu de vue au cours des recherches sur l'irradiation du blé ou de ses dérivé le type ou l'origine du blé et de la farine conditionnent fortement les changements qui apparaissent dans les éléments constitutifs, et par conséquent la nature de l'amélioration éventuelle apportée par les rayons gamma.

REFERENCES

DISCUSSION

J. C. CAUSERET: You said in your presentation that the irradiation of wheat or flour may lead to structural changes in the proteins and the formation, from starch, of substances capable of causing non-enzymatic browning reactions with the proteins. The question therefore arises as to whether the digestive utilization and the biological value of the proteins are affected.

A. R. DESCHREIDER: The non-enzymatic browning reaction between the starch degradation products and the proteins do not affect either the biological value of the proteins or their digestive utilization.

J. C. CAUSERET: Did you consider the long-term effects of irradiation on the composition and the various characteristics of the flour? We have studied one aspect of this question, although no account of our work has been published. In flour irradiated to above 50,000 rad the amount of vitamin B₁ during storage depends on the humidity of the product. If the humidity is 15%, the amount of vitamin B₁ declines slowly during the first month and then becomes stable; in a non-irradiated control sample, on the other hand, the vitamin content remains constant.

This limited example suggests that it is not enough simply to determine the immediate effects of irradiation.

A. R. DESCHREIDER: This is an important aspect of the treatment of flour by ionizing radiation; post-exposure phenomena are observed at fairly high doses. For example, when flour is irradiated to 5 Mrad in a nitrogen atmosphere some of the carotenoids are still present immediately after irradiation. However, after a few weeks they have completely disappeared.

N. GETOFF: We are studying the radiolysis of amino acids as well as their radiation-induced formation by carboxylation of amines in aqueous solutions. The primary products of water radiolysis, such as H, e⁻<sub>aq</sub>, OH, act preferentially on a carbon atom in the α-position, thereby removing hydrogen. The radicals thus formed can react in various ways. Moreover, groups such as CH₃, COOH, NH₂ and SH can also be split up. In acid solutions there is competition between H⁺<sub>aq</sub> and the -NH₃⁺ group for the e⁻<sub>aq</sub>.

Using the ESR (Electron Spin Resonance) method we have also investigated the reaction mechanisms of amino acids and amines at low temperatures. The e⁻<sub>aq</sub> reacts with amino acids at below -160 °C, and the hydrogen atoms and the OH radicals at below -100 °C, leading to the formation of the corresponding radicals. In the presence of CO₂ an electron transfer can also occur.

N. GRECZ: You mentioned that the absorption of the proteins underwent a change. I wonder whether this change was due to changes in amino acids containing resonant ring structures. In other words, could the change in the absorption spectrum be correlated with a specific action spectrum? Was this a shift in the absorption spectrum or a reduction in absorption intensity?

A. R. DESCHREIDER: The observed changes in the absorption spectrum are of two types: a shift in the absorption spectrum and an increase in absorption intensity.
EFFETS CHIMIQUES DES RAYONNEMENTS DU COBALT-60 SUR LES ELEMENTS CONSTITUTIFS DES ALIMENTS:
ACTION SUR LES GLUCIDES*

G. THIEULIN, D. BASILLE, J. MORRE ET G. CUMONT
SERVICE VETERINAIRE SANITAIRE DE PARIS ET DU DEPARTEMENT DE LA SEINE, PARIS, FRANCE

Abstract — Résumé — Аннотация — Resumen

CHEMICAL EFFECTS OF COBALT-60 GAMMA RADIATION ON THE CONSTITUENT ELEMENTS OF FOODSTUFFS: ACTION ON GLUCIDES. The experimental study of the changes undergone by a food commodity, such as meat, under the action of cobalt-60 radiation, poses difficult problems in view of the chemical complexity of the material treated. For this reason the authors considered it necessary to begin their study by attempting to show the effects of the action of these radiations on the elementary components of muscular tissue, and turned their attention to the glucides.

Sixteen simple glucides, monosaccharides and their derivatives, diholosides, dialcohols, ketoses, etc., were investigated. In view of its biological importance, particular attention was given to galactose.

A particular feature of the work was the addition of sodium borate to the sugars before exposure to radiation.

Degradation of the glucides was assessed by qualitative and quantitative investigation of the malonic aldehyde produced. The thiobarbituric acid reaction was used; spectrophotometric measurement was carried out at 268 and 535 nm, and differentiation with glyoxal was performed.

The work showed that at pH 9.5 and dilution 0.001 M borated sugars are from 2 to 12 times more sensitive to radiation than pure sugars and maximum sensitivity is obtained for equimolecular mixtures.

EFFETS CHIMIQUES DES RAYONNEMENTS DU COBALT-60 SUR LES ELEMENTS CONSTITUTIFS DES ALIMENTS: ACTION SUR LES GLUCIDES. L'étude expérimentale des transformations subies par un aliment tel que la viande sous l'action des rayonnements du cobalt-60 pose des problèmes difficiles en raison de la complexité chimique du matériel traité. C'est pourquoi il est apparu nécessaire de commencer cette étude en cherchant à mettre en évidence les effets de ces rayonnements sur les composants simples du tissu musculaire, et on a étudié les glucides.

Les recherches ont porté sur 16 glucides simples, oses et leurs dérivés: diholosides, dialcools, cétoses, etc. Les auteurs ont consacré une attention particulière au galactose à cause de son importance biologique.

Un aspect particulier de ce travail réside dans l'adjonction de borate de sodium aux sucrés avant l'exposition aux rayonnements.

La dégradation des glucides a été évaluée par la recherche qualitative et quantitative de l'aldéhyde malonique produit. On a utilisé la réaction à l'acide thiobarbiturique; la mesure spectrophotométrique était effectuée à 268 et 535 nm; la différenciation avec le glyoxal a été faite.

Il ressort de ce travail qu'à pH 9,5 et à la dilution 0,001M les sucrés boratés sont de 2 à 12 fois plus sensibles aux rayonnements que les sucrés purs, et le maximum de sensibilité est obtenu pour des mélanges équimoléculaires.

ХИМИЧЕСКИЕ ЭФФЕКТЫ ГАММА-ОБЛУЧЕНИЯ ПИЩЕВЫХ ПРОДУКТОВ И ИХ СО- СТАВНЫХ ЭЛЕМЕНТОВ: ДЕЙСТВИЕ НА УГЛЕВОДЫ. В связи с экспериментальным изу- чением превращений, которым подвергается такой продукт, как мясо, под действием излуче- ний кобальта-60, возникают трудные проблемы, ввиду химической сложности обрабатываемого материала. Вот почему оказалось необходимым сначала определить влияние этих излучений на простые компоненты мускульной ткани и прибегнуть к углеводам.

* Travail effectué au Laboratoire de radiobiologie du Service vétérinaire sanitaire de Paris et du Département de la Seine, 99, rue de Dantzig, Paris 15e.
Проводились исследования с 16 простыми углеродами, сахаридами и их производными: диполиозами, двухатомными спиртами, кетозами и т.д. Особое внимание уделялось галактозе ввиду ее биологического значения.

Особый аспект в работе составляет присоединение бората натрия к сахарам перед облучением.

Уменьшение количества углеродов определялось количественным и качественным исследованием полученного малонового альдегида. Использовалась реакция тиobarбитуровой кислоты, проводилось спектрофотометрическое измерение на 268 и 535 ммк, была осуществлена дифференциация с глиоксалом.

Из этой работы следует, что при pH 9,5 и растворе 0,001 М: боратовые сахары в 2—12 раз более чувствительны к излучению, чем чистый сахар; максимальная чувствительность получена для эквимолекулярных смесей.

В результате проведённых исследований можно сделать вывод, что при pH 9,5 и растворе 0,001 М: боратовые сахары в 2—12 раз более чувствительны к излучению, чем чистый сахар; максимальная чувствительность получена для эквимолекулярных смесей.

INTRODUCTION

Le laboratoire de radiobiologie du Service vétérinaire du département de la Seine, qui s'intéresse principalement au contrôle des aliments contaminés par les retombées radioactives, s'est en outre proposé d'étudier les incidences possibles de l'emploi des rayonnements ionisants en technologie alimentaire. En qualité d'hygiénistes, nous nous sommes particulièrement attachés aux problèmes de toxicologie découlant de la mise en œuvre de ce procédé.

Deux voies s'ouvraient à nous: la première, essentiellement empirique et globale, consistait à faire consommer à l'animal les aliments traités; la seconde, plus spéculative et analytique, était fondée sur la mise en évidence des nouveaux composés apparus dans l'aliment comme résultat du traitement.

La méthode globale est simple, mais coûteuse et lente. Elle requiert une grande circonspection. Le changement d'un seul paramètre risquerait de remettre en question tous les résultats. La deuxième est certainement beaucoup plus difficile; elle est longue aussi, mais permet d'obtenir des informations plus détaillées et d'aboutir à des conclusions de portée générale.

En réalité, nous avons appliqué ces deux modes de recherche simultanément et nous nourrissons depuis deux ans déjà une population de rats avec des biscuits fabriqués à partir d'œufs congelés irradiés aux rayons gamma du 60Co. L'irradiation est l'une des méthodes efficaces
permettant de détruire les germes des toxi-infections alimentaires et spécialement les Salmonellae qui, très fréquemment, contaminent les ovoproduits. L'expérience en cours comporte des pesées, des examens hématologiques, l'étude de la reproduction, etc. Il en sera rendu compte lorsqu'elle sera achevée.

A l'origine de nos recherches biochimiques sur les aliments irradiés, nous avions attaqué de front l'étude des changements chimiques provoqués par l'irradiation dans la viande et dans l'œuf. Mais nous nous sommes bien vite aperçus que notre propos était démesurément ambitieux en raison de l'extraordinaire complexité biochimique du muscle et du vitellus. Aussi nous sommes-nous bornés, dans cette phase initiale de nos recherches, à étudier l'action des radiations sur les éléments constitutifs de nos aliments: glucides, protides, lipides. Nous avons commencé par les glucides, et c'est des résultats de ces travaux qu'il sera question ici. Nous nous proposons d'étudier ultérieurement les acides aminés et les acides gras.

TECHNIQUES D'ÉTUDE

Plusieurs techniques s'offraient à nous pour étudier la dégradation des glucides sous l'action des rayonnements: chromatographie, mesure du pouvoir diélectrique et résonance paramagnétique. Nous avons choisi de nous en remettre à la polarimétrie et à l'étude du pouvoir réducteur en association avec le dosage de l'aldéhyde malonique.

Les mesures polarimétriques des solutions étaient effectuées avant et après irradiation. Le polarimètre classique étant trop peu sensible pour apprécier le taux de sucre détruit, nous avons eu recours au polarimètre électronique Roussel-Jouan fondé sur l'effet Faraday (loi de Verdet). Cet appareil permet de mesurer une teneur en sucre de l'ordre de 0,002 à 0,001 mole avec une précision de 1% suivant le pouvoir rotatoire du sucre étudié. Toutes les mesures ont été faites à 20°C ± 0,05. L'emploi de la polarimétrie est limité: la méthode convient pour de grosses doses d'irradiation qui détruisent en totalité la molécule; mais les doses faibles de l'ordre de 0,3 à 0,5 Mrad couramment employées pour la radiopasteurisation des aliments donnent souvent naissance à des permutations, à des coupures qui font que tel sucre dextrogyre est remplacé par un sucre lévogyre, ce qui fausse totalement le calcul du sucre détruit.

Nous avons, en conséquence, complété cette méthode d'analyse par des déterminations colorimétriques au ferroferricyanure du pouvoir réducteur de sucres, au moyen de l'appareil automatique auto-analyseur Technicon. La précision de la mesure est satisfaisante, à condition de passer des échantillons témoins avant et après chaque analyse. La manipulation est simple et rapide. En combinant les résultats des deux méthodes, nous avons obtenu une appréciation correcte de la dégradation des sucres après irradiation.

Mais nous avons utilisé principalement, pour juger de l'attaque des oses, le dosage de l'aldéhyde malonique (AM) produit au cours de l'irradiation. En effet, ce composé est un témoin fidèle de toute irradiation de produit biologique: que l'on irradiie glucide, lipide ou protide, on le retrouve dans les produits de dégradation.

Certains chercheurs [1] ont signalé que les jus de fruits irradiés présentaient une absorption dans l'ultra-violet à 268 nm. Nous croyons que l'aldéhyde malonique est responsable de ce phénomène.
Enfin, on ne peut manquer d'être frappé par la similitude qui existe entre l'aldéhyde malonique et le corps non identifié que des auteurs anglais ont signalé avoir rencontré dans des produits soumis à l'irradiation et qui serait un inhibiteur cellulaire. Les deux composés ont trois atomes de carbone et absorbent à 268 nm [2].

Détection de l'aldéhyde malonique

Celle-ci est aisée par spectrophotométrie d'absorption, par la réaction avec l'acide thiobarbiturique à pH 2, comme l'ont montré Yu et al. [3]. Il y a production d'un composé coloré avec absorption à 535 nm.

Le glyoxal donne aussi cette réaction, mais son coefficient d'extinction molaire est de 130 contre 156 000 pour l'aldéhyde malonique [4]; le glyoxal n'intervient donc que peu dans la mesure. D'autre part, le fait que l'aldéhyde malonique possède une forme énolique nous a incité à rechercher son pouvoir d'absorption en ultra-violet: nous avons trouvé un pic bien défini à 268 nm.

\[
\begin{align*}
\text{CHO} & \quad \text{CHO} \\
\text{CH}_2 & \quad \text{CH} \\
\text{CHO} & \quad \text{CH} \\
& \quad \text{OH}
\end{align*}
\]

Comme le glyoxal n'absorbe pas pour ces longueurs d'onde, la distinction est facile. La sensibilité de la méthode permet de déceler jusqu'à $10^{-5}$ mole, aussi bien à 535 nm qu'à 268 nm. Les mesures ont été faites au spectrophotomètre Beckmann DB.

Pour étalonner nos courbes, nous avons produit de l'aldéhyde malonique par la technique suivante: hydrolyse du 1, 1, 3, 3, tétraéthoxypropane par l'acide phosphorique, blocage de l'alcool éthyllique produit par le dihydro- pyrane, distillation, production de la dinitrophénylhydrazone de l'aldéhyde malonique que nous extrayons par l'hexane et dosage spectrophotométrique de la dinitrophénylhdyazaine restant en excès.

Technique d'irradiation

L'irradiation du matériel d'étude a été exécutée au service d'applications physico-chimiques du CEN de Saclay au moyen d'une source au cobalt-60 de 10 000 Ci répartie en 10 crayons.

Le matériel à irradier était placé dans des flacons en quartz ou en verre préalablement irradiés, remplis de solutions de carbonate acide de sodium 0,1M, puis rincés et passés au mélange sulfochromique et enfin stérilisés à l'étuve à 100°C pendant une heure. L'eau utilisée pour préparer les solutions était de l'eau tridistillée sur quartz.
Préparation des solutions de glucides

La présence d'un sel indifférent est indispensable pour avoir une force ionique constante et un pH stable que, pour nos expériences, nous avons fixé à 9,5.

Les glucides irradiés acidifient le milieu, ce qui a pour effet de diminuer la production d'aldéhyde malonique. Le sel indifférent devait donc avoir un pouvoir tampon élevé au pH considéré (9,5); il devait également être stable sous irradiation afin que ne soient pas introduits de facteurs d'oxydation ou de réduction. Ce sel ajouté à nos solutions de glucides était destiné à jouer le rôle régulateur de force ionique et de pH que remplissent, dans les produits biologiques que sont nos aliments, les sels dissous du «milieu intérieur»: NaCl, KCl, NaHCO₃, Na₂HPO₄.

Nous avons essayé divers sels: le nitrate de sodium, sous l'effet du rayonnement, donne du nitrite, ce qui perturbe toute la réaction. Le sulfate bipotassique résiste parfaitement aux radiations aux doses utilisées, mais son pouvoir tampon est pratiquement nul. Les phosphates sont de bons tampons mais ils forment des complexes avec les sucres.

Finalement, nous avons employé la solution de carbonate de sodium NaHCO₃ 0,1M amenée à pH 9,5 par adjonction de soude: nous avons donc obtenu en définitive une solution mixte carbonate-bicarbonate, dont la résistance aux radiations était satisfaisante et le pouvoir tampon excellent, ce qui a été attesté par le fait que nous n'avons pas enregistré de variation dépassant ± 0,05 unité de pH après une irradiation à 3 Mrad d'une solution de sucre 0,01M.

La mesure des pH était exécutée avec une précision de 0,01 unité. Les solutions préparées ont été, avant irradiation, filtrées sur un filtre Millipore 0,8 μm, afin qu'elles soient exemptes de toute impureté en suspension.

IRRADIATION DU GALACTOSE

Appliquant les techniques ainsi définies, nous avons étudié un certain nombre d'oses à 5 et 6 atomes de carbone, des cétoses, des di- et des triholosides ainsi que des dialcools que nous avons soumis aux rayons gamma du cobalt-60 dans une solution de NaHCO₃ 0,1M à pH 9,5.

Pour étudier l'action des rayonnements sur les divers glucides tout en les protégeant contre une oxydation éventuelle, nous avons pensé qu'il pouvait être profitable de bloquer certaines fonctions par le borate de sodium.


Il convenait, en premier lieu, de reconnaître l'existence et la formule du complexe prenant naissance entre galactose et borate de soude à pH 9,5. Nous avons employé la méthode de Job ou des « variations continues » [6,7] en polarimétrie. La formation du complexe s'accompagne d'une variation du pouvoir rotatoire. Considérons des solutions de NaHCO₃ 0,1M dont le pH est maintenu constant (pH = 9,5) et contenant x ml de borate 0,01M et
(1 - x)ml de galactose de même concentration. Nous obtenons une série de solutions en faisant varier la valeur de x. La solution de borate n’ayant pas de pouvoir rotatoire, on désigne par $\alpha$ la déviation de la lumière polarisée en fonction de x: $\alpha = f(x)$.

Nous avons préparé des mélanges de x ml d’eau et (1-x) ml de galactose 0,01M en présence de NaHCO$_3$ 0,1M et mesuré la déviation $\alpha_0$ de la lumière polarisée en fonction de x. Nous avons tracé ensuite la courbe $|\alpha - \alpha_0| = f(x)$ pour la raie bleue du mercure (436 nm). Nous avons obtenu un maximum pour x $= 0,5$.

Job a montré que, dans ces conditions, on était en présence d’un complexe 1-1, soit une molécule d’ose pour une molécule de borate. Le même résultat a été obtenu par la méthode de Moore et Anderson [8] (fig. 1).

Le complexe ayant été ainsi défini, nous avons vérifié, en polarimétrie, que l’aldéhyde malonique en présence de borate et le galactose en présence de NaHCO$_3$ ne donnaient pas de complexes. Nous avons alors entrepris l’irradiation de diverses solutions de galactose avec du borate de soude à pH 9,5 dans le carbonate acide de sodium 0,1M.

Dans une première série d’expériences pour deux doses déterminées (0,5 et 3 Mrad) - la concentration en galactose restant constante (0,01M) - nous avons fait varier celle du borate de sodium de 0 à 0,1M; la production d’aldéhyde malonique diminue alors avec la concentration en borate (fig. 2). Par mesure du pouvoir réducteur, on constate la présence d’un minimum de sucre détruit pour les concentrations voisines de celles correspondant au complexe.

Nous avons vérifié, en faisant l’expérience inverse, que la quantité d’aldéhyde malonique formé croît avec la concentration en galactose (borate 0,01M).

Enfin, pour un mélange équimoléculaire 0,1M, c’est-à-dire correspondant à la formation du complexe galactose-borate, et pour des doses croissantes de rayonnement, la courbe représentant la production d’aldéhyde malonique à partir d’un sucre pur s’élève bien plus rapidement que la courbe correspondant à un sucre boraté (fig. 3).

Le brunissement de la solution de sucre dû aux fortes doses d’irradiation apparaît plus tardivement sur le sucre boraté que sur le sucre pur.

IRRADIATION DE DIVERS SUCRES

Après ces recherches préalables sur le galactose, nous avons soumis à l’irradiation divers glucides purs ou boratés à la concentration de 0,01M, à pH 9,5 en solution dans NaHCO$_3$ 0,1M.

Nous avons ajouté aux sucres boratés une molécule de borate par molécule d’ose, par exemple une molécule de saccharose pour deux molécules de borate.

On trouvera le résultat de cette étude au tableau I. A part certains résultats dus à la configuration particulière des sucres (xylose: position des oxydriles; fructose: sucre cétonique; raffinose: triholoside; désoxyribose: absence d’O) le rapport (production AM sucre boraté/production AM sucre pur) se situe autour de 0,8 pour les oses simples et les dialcools et de 0,90 pour les diholosides. Il y a donc un effet de protection qui semble général et constant d’un sucre à l’autre.
De cette étude sur l'irradiation des glucides, il ressort que:
- La technique de recherche, par mesure de AM et emploi du borate,
TABLEAU I. RAPPORT DE LA PRODUCTION D'ALDEHYDE MALONIQUE D'UN SUCRE BORATE A UN SUCRE PUR APRES IRRADIATION A 0,5 MR

<table>
<thead>
<tr>
<th>Nature chimique</th>
<th>Glucose 0,01M</th>
<th>Borate 0,01M ajouté</th>
<th>Rapports</th>
</tr>
</thead>
<tbody>
<tr>
<td>Alcool-aldéhyde à 3 C</td>
<td>Aldéhyde glycérique</td>
<td>1</td>
<td>0,83</td>
</tr>
<tr>
<td>Oses à 5 C</td>
<td>D + xylose</td>
<td>1</td>
<td>0,46</td>
</tr>
<tr>
<td></td>
<td>L - arabinose</td>
<td>1</td>
<td>0,80</td>
</tr>
<tr>
<td></td>
<td>D - ribose</td>
<td>1</td>
<td>0,78</td>
</tr>
<tr>
<td>Oses à 6 C</td>
<td>L + rhamnose</td>
<td>1</td>
<td>0,80</td>
</tr>
<tr>
<td></td>
<td>Glucose</td>
<td>1</td>
<td>0,74</td>
</tr>
<tr>
<td></td>
<td>Galactose</td>
<td>1</td>
<td>0,77</td>
</tr>
<tr>
<td></td>
<td>Mannose</td>
<td>1</td>
<td>0,76</td>
</tr>
<tr>
<td></td>
<td>Fructose ou levulose</td>
<td>1</td>
<td>1,14</td>
</tr>
<tr>
<td>Diholosides</td>
<td>Cellobiose</td>
<td>2</td>
<td>0,93</td>
</tr>
<tr>
<td></td>
<td>Maltose</td>
<td>2</td>
<td>1,00</td>
</tr>
<tr>
<td></td>
<td>Lactose</td>
<td>2</td>
<td>0,88</td>
</tr>
<tr>
<td></td>
<td>Saccharose</td>
<td>2</td>
<td>0,94</td>
</tr>
<tr>
<td>Triholoside</td>
<td>Raffinose</td>
<td>3</td>
<td>1,20</td>
</tr>
<tr>
<td>Dialcools</td>
<td>Dulcite</td>
<td>1</td>
<td>0,83</td>
</tr>
<tr>
<td></td>
<td>Mannite</td>
<td>1</td>
<td>0,94</td>
</tr>
<tr>
<td>Divers</td>
<td>2-désoxyribose</td>
<td>1</td>
<td>1,47</td>
</tr>
<tr>
<td></td>
<td>Glycérol</td>
<td>1</td>
<td>0,01</td>
</tr>
</tbody>
</table>

offre des possibilités certaines; la détection de AM, très sensible, permet une étude très fine des phénomènes.

- Le rôle du pH est primordial; des résultats d'irradiation d'un sucre qui ne se référeraient pas à un pH donné seraient sans signification; une variation d'une unité de pH peut inverser les réactions.

- Le pouvoir tampon du milieu joue un grand rôle car il conditionne la stabilité du pH.

- La présence de composés (borates) susceptibles de bloquer certaines fonctions peut, suivant le pH, modifier les phénomènes dus à l'irradiation.
FIG. 3. Variation de la production d'aldéhyde malonique en fonction de la dose d'irradiation

Nous avons entrepris une étude toxicologique de l'aldéhyde malonique dont il sera rendu compte en temps opportun.

REFERENCES


DISCUSSION

G. MOCQUOT: Could the result indicated in Fig. 2 be due to the fact that the borate accelerates the destruction of the malonic aldehyde?

J. MORRE: When we irradiated malonic aldehyde solutions containing sodium borate in varying concentrations, partial destruction of the malonic aldehyde occurred, but quite independently of the borate
concentration. We believe the result is due to a decline in the destruction of galactose.

R. O. SINNHUBER: After the irradiation of sugars, were you able to isolate or form a crystalline derivative that would confirm the formation of malonaldehyde other than by the 2-thiobarbituric acid test?

J. MORRE: The amount of malonaldehyde is very small, and we should like to obtain a crystalline derivative. However, we have not yet done so.

W. K. G. KÜHN: You mentioned that the browning of the sugar solution took place much later in the case of pure sugar than in that of borated sugar. Have you carried out studies to determine whether this effect is dependent on the dose-rate for a given dose?

J. MORRE: There is a dependence on dose-rate. Administering a dose of 500,000 rad over periods of 33 min and 16 h in the same apparatus, we found that browning was greater and the protective effect of the borate more pronounced for the shorter period.
CHEMICAL CHANGES INDUCED BY IRRADIATION IN MEATS AND MEAT COMPONENTS

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Abstract — Résumé — Аннотация — Resumen

CHEMICAL CHANGES INDUCED BY IRRADIATION IN MEATS AND MEAT COMPONENTS. The acceptability of meats preserved by irradiation has been hampered by the formation of an irradiation flavour and odour. This flavour and odour is believed to be due to the volatile chemical compounds produced by radiation impact on the protein and lipid molecules.

The analysis of the volatile compounds has been accomplished, employing programmed cryogenic temperature gas chromatography for separation of the complex mixtures obtained, and rapid scanning mass spectrometry for identification of the individually separated components. Comprehensive analyses of the volatiles from irradiated ground beef, pork, mutton, lamb, and veal, as well as the volatile irradiation degradation products of several amino acids and proteins, animal fats, methyl esters of fatty acids, and triglycerides have been made.

The results of the analysis of the irradiated component meat substances are compared with those obtained from the irradiation of meat itself, and of separate meat fractions, thus establishing the contribution of each fraction to the total. Mechanisms are postulated for the formation of the volatile components from each fraction and for interactions among intermediates from different fractions.

TRANSFORMATIONS CHIMIQUES PROVOQUEES PAR LES RAYONNEMENTS DANS LES VIandes ET LEURS CONSTITUANTS. La comestibilité des viandes conservées par les rayonnements s'est trouvée diminuée à la suite de l'apparition dans celles-ci d'un goût et d'une odeur engendrés par l'irradiation. On pense que ces derniers sont dus aux composés chimiques volatils qui sont formés par l'action des rayonnements sur les molécules des protéines et des lipides.

Il a été procédé à l'analyse des composés volatils à l'aide d'un programme de chromatographie en phase gazeuse à température cryogénique visant à séparer les constituants des mélanges complexes obtenus, et par spectrométrie de masse à balayage rapide destinée à identifier les constituants séparés. L'auteur a effectué des analyses complètes des composés volatils émanant de viande hachée de bœuf, de porc, de mouton, d'agneau et de veau; il a également analysé les produits volatils de la dégradation, par les rayonnements de plusieurs acides aminés et protéines, de graisses animales, d'esters méthyliques d'acide gras et de triglycérides.

L'auteur compare les résultats de l'analyse des substances constitutives de la viande soumises à l'irradiation avec ceux obtenus par l'irradiation de la viande elle-même et de fractions distinctes de viande, ce qui permet de déterminer l'apport de chaque fraction à l'ensemble. Il postule des mécanismes expliquant la formation des éléments volatils dans chacune de ces fractions ainsi que les interactions entre les substances intermédiaires des différentes fractions.

ХИМИЧЕСКИЕ ПРЕВРАЩЕНИЯ В МЯСНЫХ ПРОДУКТАХ И ИХ СОСТАВНЫХ ЧАСТЯХ ПОД ВОЗДЕЙСТВИЕМ ОБЛУЧЕНИЯ. Облучение различных сортов мяса с целью консервации отражается на вкусовых качествах, вызывая появление специфического привкуса и запаха. Полагают, что это объясняется образованием летучих химических соединений при действии радиации на белки и липидные молекулы.

Анализ летучих соединений осуществляется на газовом хроматографе с криогенным охлаждением до заданной температуры, где происходит разделение сложных смесей. Идентификация выделенных компонентов проводится с помощью масс-спектрометрии с быстрым сканированием. Проведен исчерпывающий анализ летучих соединений, выделяющихся из говядины, свинины, баранины и телятины, которые были облучены, а также анализ летучих соединений, образующихся при разложении под действием облучения некоторых аминокислот, белков, животного жира, метиловых эфиров жирных кислот и триглицеридов.

Результаты анализа облученных компонентов мясных продуктов сравниваются с результатами, полученными при облучении самого мяса и его отдельных фракций, что дает возможность установить роль каждой фракции в целом. Постулируются механизмы образования
Alteraciones Químicas Producidas por Irradiación de las Carnes y de Sus Componentes. El mal sabor y el mal olor originados por la irradiación de la carne conservada son un obstáculo para su aceptación. Se cree que este sabor y este olor desagradables se deben a los compuestos químicos volátiles producidos por las radiaciones en las moléculas de proteínas y lípidos.

Se han analizado los compuestos volátiles por cromatografía en fase gaseosa a temperaturas sumamente bajas y con arreglo a un programa, para determinar las mezclas complejas obtenidas, y por espectrometría de masas con exploración rápida, para identificar los componentes separados. Se han efectuado análisis minuciosos de las sustancias volátiles formadas por irradiación en carne picada de vaca, cerdo, camello, cordero y ternera, así como de los productos volátiles de degradación originados por las radiaciones en varios aminoácidos y proteínas, grasas animales, ésteres metílicos de ácidos grasos y triglicéridos.

Los resultados del análisis de los componentes de la carne irradiados se comparan con los obtenidos irradiando la carne misma y distintas fracciones de ella. Se postulan los mecanismos de formación de los componentes volátiles de cada fracción y los de las interacciones de las fases intermedias correspondientes a distintas fracciones.

The acceptability of meats preserved by irradiation has been hampered by the formation of an irradiation flavour and odour. Studies of this problem have been in progress in many laboratories for several years in order to discover the nature of the irradiation flavour and how to prevent it. This flavour and odour is believed to be due to the volatile chemical compounds produced by radiation impact on the protein and lipid molecules, and it has been a basic assumption that chemical analysis would show by comparison of irradiated with unirradiated meat that certain compounds might be responsible for the undesirable effects. The objective of the studies of chemical changes induced by irradiation is to discover the precursors of the volatile compounds and the mechanisms by which they are formed.

There are three sensory observations related to the production of irradiation odour which have influenced the choice of irradiation conditions and technique, and which all serve to delineate the problem more clearly. Firstly, irradiation odour in raw meat is a characteristic property, is the same for beef, pork, lamb, and the other meats, and does not vary in type but only in intensity. Secondly, the odour is reproducible, and given radiation doses can produce approximately the same odour. Thirdly, irradiation odour is the direct result of changes due to irradiation impact, and does not depend on the type of irradiation employed, nor on the presence of such variables as water or oxygen in the surrounding environment.

In this paper the author describes the principal facts relating to the analytical composition of volatile compounds produced in irradiated meat, and of a number of model systems, in the hope that this information will provide some understanding of the mechanism of the formation of such compounds.

During the past decade several groups of investigators [1-10] have contributed to the identification of some of the volatile compounds isolated from irradiated meats. They have established the presence of several types of compounds, including carbonyls, alcohols, thiols, thioalkanes and esters, and have demonstrated a quantitative relationship between the presence of these compounds and the irradiation dose. They have shown that, as the dose increases, the amounts of the various oxygenated
and sulphurated compounds increase. However, all the compounds have been found to be present in unirradiated meat, and their presence in greater amount in the irradiated product may contribute to the overall flavour, but their presence from the viewpoint of chemical composition is not peculiar to irradiated meat. Recent work [11-13] has shown, through the use of new analytical techniques, that homologous series of n-alkanes and n-alk-1-enes can be found in irradiated ground beef, and that these hydrocarbons are not found in appreciable amounts in an unirradiated control sample. These results are discussed in detail below.

EXPERIMENTAL

The preparation of the samples of irradiated ground beef and the isolation and collection of the volatile components were accomplished by procedures already described [5, 12, 14]. The total condensate was collected by high vacuum distillation at room temperature and then further separated into a "water fraction" and a "carbon dioxide" fraction by vacuum distillation at -80°C. The components of the carbon dioxide fraction were separated by a cryogenically-programmed temperature gas chromatograph and identified in the eluate by means of a rapid-scanning mass spectrometer. The components of the water fraction were also identified by means of the combined gas chromatograph-mass spectrometer after extraction with ether. The details of the analytical procedures are described in previous publications [5, 12, 14-17].

Table I summarizes the various meats, meat constituents and other related substances that were analysed. The substances chosen were intended to provide a cross-section of the type of inherently related material from which volatile odour and flavour compounds might be expected to form. Thus, in addition to several whole meats, the volatile irradiation products from a number of protein and lipid substances were also analysed. Among the lipid substances were included typical whole fats and separate moieties, such as triglycerides, fatty acid esters, and cholesterol, as an example of a steroid. Among the proteinaceous substances were included a protein, a polypeptide and some individual amino acids. Finally, beef itself was separated into a protein, a lipid and a lipoprotein fraction and these were irradiated and analysed.

RESULTS AND DISCUSSIONS

The formation of volatile compounds in beef is a reproducible phenomenon. Figure 1 shows two cryogenically-programmed gas chromatograms of a carbon dioxide fraction of irradiated ground beef volatiles isolated from two separate samples of meat, one irradiated in February 1960, the other in November 1960. The amount of sample and temperature programme rates were slightly different in each case, but the overall similarity of the sample composition is readily apparent.

Although beef has been studied extensively, very few, if any, significant analyses of other meats have been performed until recently [12]. A comprehensive analysis of the volatiles from irradiated ground beef, pork, mutton, lamb and veal showed that the compounds formed are
TABLE 1. SUBSTANCES EMPLOYED FOR IRRADIATION STUDIES

<table>
<thead>
<tr>
<th>Whole Meats</th>
<th>Lipid</th>
<th>Protein</th>
</tr>
</thead>
<tbody>
<tr>
<td>Beef</td>
<td>Beef fat</td>
<td>Haddock (0.3% fat)</td>
</tr>
<tr>
<td>Veal</td>
<td>Butterfat</td>
<td>Beef protein</td>
</tr>
<tr>
<td>Mutton</td>
<td>Triglycerides</td>
<td>Oxytocin</td>
</tr>
<tr>
<td>Lamb</td>
<td>Fatty acid esters</td>
<td>Amino acids</td>
</tr>
<tr>
<td>Pork</td>
<td>Cholesterol</td>
<td>Beef lipoprotein</td>
</tr>
</tbody>
</table>

essentially the same in all the meats. All the samples were irradiated at a dose of 6 Mrad and the complete analyses of the volatiles produced show the presence of more than 80 compounds, many in appreciable quantity. The controls, or unirradiated samples, showed the presence of only trace quantities of compounds, except for expected components, such as ethanol, acetaldehyde or acetone. The compounds identified are too numerous to tabulate here, but complete tabulations may be readily found in the literature [12, 17, 18].

The most abundant components were the hydrocarbons. Figure 2 shows the distribution of n-alkanes found in a sample of irradiated beef.
Alkanes are usually regarded by chemists as nearly odourless. Alkenes, on the other hand, and more particularly, alkynes, are definitely odorous. The unsaturated compounds cannot be disregarded as potential sources of odour and the saturated compounds may also contribute, notwithstanding previous opinions about their odour.

For the present, however, it is more important to regard the formation of these compounds from the point of view of mechanisms rather than as odorants.

It now seems well-established that the hydrocarbons, except possibly those having three or four carbon atoms, found in irradiated meats, must come mainly from the lipid. This hypothesis was previously verified in earlier studies [11], when the volatiles from irradiated methyl oleate were found to contain appreciable quantities of alkanes and alkenes, and recently in more detail from studies of both triglycerides and fatty-acid esters [12, 13].

Comparison of the volatiles produced in irradiated and oxidized butterfat has also helped understanding of the mechanisms involved [19-21]. Figure 3 shows the relative abundances of n-alkanes and n-alkanals found in a sample of butterfat irradiated at 6 Mrad, and an aliquot of the same

volatiles compared with a control. The small amounts of the hydrocarbons found in the unirradiated control are probably due to oxidation of the meat fat during storage. A similar distribution of n-alkanes was found in the volatiles from mutton, lamb, pork and veal. There were essentially no hydrocarbons in the controls. A distribution of normal alk-1-enes, corresponding to the normal alkanes but in smaller quantity, was found to exist uniformly in all the irradiated meat samples. The olefin compounds, together with the alkanes, constitute approximately 90 to 95% of the total composition of the total volatile constituents isolated. Alkanes constitute about 60% and alkenes about 40% of the total hydrocarbon content. Trace amounts of n-alkynes are also found among the hydrocarbons isolated from the various meats.
butterfat autooxidized for one week in the presence of a copper catalyst. In accordance with the generally accepted mechanism for fat oxidation, the usual high concentration of carbonyl compounds is found in the oxidized sample. Small amounts of hydrocarbons are also found, however, probably due to the occasional recombination, or hydrogen termination, of alkyl-free radicals.

However, the presence of large amounts of hydrocarbons, and the relative lack of carbonyl compounds, even in the presence of air, shows that the mechanism for the irradiation production of volatiles is obviously different. The sensory response is likewise different. Whereas the oxidized fat is typically rancid, the irradiated fat is not, but has what has come to be recognized as a characteristic fat irradiation 'dour'. In view of this, the attempts of many workers to correlate irradiation odour with tests, such as iodine number or TBA values, etc., are not likely to succeed.

The mechanism of irradiation damage in lipids now seems quite clear, and is relatively simple. It appears that radiation-induced, direct-bond cleavage to form primarily alkyl-free radicals can account for nearly all of the components detected upon analysis.

If, as an example, the glycerol stearate depicted in Figure 4 is considered scission of the bonds at all points of the chain with recombination or hydrogen termination of the resulting alkyl-free radicals, all the n-alkanes from methane to heptadecane could be formed. All alkanes from methane to hexadecane have been found in good yield. Moreover, if secondary collisions extracting a second electron occur, a similar homologous series of alkenes is predicted, and these also are detected in quantity. If the fatty acid were oleic or linoleic, increased quantities of olefins might be expected; and this, in fact, proves to be the case.

Study of the radiation products induced in methyl oleate, methyl stearate, trioleate and tristearin also supports the argument for a direct cleavage mechanism. Data are given in Table II and a representation of the process is given in Fig. 5. Bond cleavage would be expected to lead to an homologous series of alkanes, alkenes and esters to C10 if the fatty
acid is oleate but would give higher homologues if the fatty acid were stearate. The principal products are, in fact, alkanes, alkenes and an homologous series of methyl esters. The highest member of the alkane series found in irradiated methyl oleate is n-nonane and the highest methyl ester is methyl pelargonate (i.e., the C₉ acid) whereas hexadecane is found in methyl stearate and tridecane in tristearin. No methyl esters are found, however, among the radiation products in tristearin or triolein.

Most of the other products found in irradiated meat volatiles, except those containing sulphur or aromatic rings, may also be accounted for by mechanisms associated with alkyl-free radical formation in the fat. Oxygenated compounds are far less abundant than hydrocarbons, but appreciable amounts of the members of an homologous series of n-aliphatic alcohols up to hexanol are found. Of these, only ethanol is detected in the unirradiated controls. Since the water content of meat averages nearly
60%, the formation of alcohols may be thought to occur by direct reaction of the alkyl-free radical with water. Such a mechanism is supported by the fact that only traces of alcohols are found in irradiated dry butterfat and were undetected in irradiated triglycerides or methyl esters of fatty acids.

The aldehydes and ketones are least abundant of all the compounds found which may be considered as derived from the fat. Carbonyl compounds, on the other hand, are probably produced by an indirect route which is probably similar to that involved in autooxidation of a fat. The alkyl-free radical can absorb oxygen, form a hydroperoxide, and then follow the many decomposition paths which are familiar in the oxidation chemistry of fats. The more abundant aldehydes found are unsaturated, which is in further agreement with the hypothesis that they are derived from the decomposition of hydroperoxides.

There does not seem to be much evidence that carbonyl compounds are related to irradiation odour. Chemical evidence shows them to be absent, or in low concentration, in samples which are irradiated in the absence of air; yet the irradiation odour of these samples is very definite and unmistakable. There is undoubtedly a superimposed oxidative type of rancidity which is present in meats and lipids which are irradiated in the presence of oxygen, but in oxygen-free material, uniquely radiation-induced compounds are still present. From lipids these substances are primarily only hydrocarbons.

Although minor, the contribution from steroid substances has been generally neglected. Figure 6 shows the compounds isolated from a sample of cholesterol irradiated at 6 Mrad. The principal products were a series of normal alkanes form C_1 to C_7 and a series of isoalkanes from C_4 to C_8. The relative abundance of the iso compounds compared to the normal compounds is shown by dashed lines. The origin of these series of compounds is readily deduced to be the result of cleavage of the alkyl side chain of the cholesterol molecule.

In meats, of course, there are components which arise from the protein, which cannot be present in the products from pure fat. Table III shows some of the sulphur compounds and aromatic compounds which are also found in irradiated meats. Many of these can be postulated as arising from direct bond cleavage of amino acid moieties. Benzene and toluene may come from phenyl alanine and phenol and p-cresol from tyrosine. Recent studies have been directed to a consideration of the origin of some of the compounds from proteinaceous substances. Some of the sulphides, disulphides and mercaptans can derive directly from cysteine or methionine, but those containing more than two carbon atoms in a chain require more than a superficial explanation. To evaluate the contribution of the volatiles from the protein, as well as the lipid constituents of meat, volatile components produced in various protein substances have also been analysed.

A summary of the principal components found in haddock flesh irradiated at 6 Mrad is given in Table IV. Haddock was chosen because it was a convenient source of animal protein which is relatively fat free.

The major components identified among the volatiles produced in haddock upon irradiation are seen to be benzene and toluene, and the sulphur compounds. These compounds may be expected from the radiation-induced degradation of protein. The only carbonyl compounds found
are acetone and methyl ethyl ketone, and these are present in only moderate amount. Trace quantities of low molecular weight (C₁-C₄) hydrocarbons were also found. The detection of hydrocarbons, even in trace amounts, however, led to the question of whether their origin was in the protein or in the small amount of fat present in the haddock.

It thus seemed that the origin of the various components in meat volatiles could best be established by carrying out analyses of irradiation-induced compounds in meat protein and meat fat separately. Accordingly, a 500 g sample of meat, the same size sample as normally used in irradiation studies of whole meat, was separated into a protein, a lipid and a lipoprotein fraction by means of a methanol-chloroform extraction of the fat. The dry, air-free fractions were then irradiated separately with 6 Mrad gamma radiation in the same manner as that used for whole meat. The results are summarized in Table V.

The analytical results show clearly that mainly sulphur compounds and aromatic hydrocarbons are formed in the protein fraction, whereas mainly aliphatic hydrocarbons are formed from the lipid. The lipoprotein fraction produced, as expected, both aliphatic hydrocarbons and sulphur compounds. It was extremely interesting to observe that only the lipoprotein fraction had a characteristic irradiation odour.

To acquire further insight into the mechanism of the formation of these compounds, particularly of the protein-derived components, a study of the radiolysis of several amino acids was undertaken. The results of these analyses are shown in Table VI.

The major and universal product of amino-acid irradiation is carbon dioxide, which is produced in large quantities. Decarboxylation is apparently the major effect induced by the radiation. The other products, if any, are the expected decomposition products which may arise from cleavage of the side chain moieties.

Thus, hydrogen sulphide is a likely derivative of cystine and dimethyl disulphide is a likely derivative of cysteine. The formation of dimethyl
TABLE III. SOME MISCELLANEOUS COMPOUNDS IN IRRADIATED MEAT VOLATILES

<table>
<thead>
<tr>
<th>Compound</th>
<th>Compound</th>
<th>Compound</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sulphur dioxide</td>
<td>Dimethyl sulphide</td>
<td>Benzene</td>
</tr>
<tr>
<td>Carbonyl sulphide</td>
<td>Methyl ethyl sulphide</td>
<td>Toluene</td>
</tr>
<tr>
<td>Hydrogen sulphide</td>
<td>Dimethyl disulphide</td>
<td>Phenol(^a)</td>
</tr>
<tr>
<td>(C_4-C_6) thiols</td>
<td>Diethyldisulphide</td>
<td>(p)-cresol(^a)</td>
</tr>
<tr>
<td></td>
<td>Methional(^a)</td>
<td></td>
</tr>
</tbody>
</table>

\(^a\) Radiation dose — 18 Mr.

TABLE IV. VOLATILE COMPUNDS ISOLATED FROM IRRADIATED HADDOCK FLESH\(^a\)

<table>
<thead>
<tr>
<th>Compound</th>
<th>Compound</th>
<th>Compound</th>
</tr>
</thead>
<tbody>
<tr>
<td>Methane</td>
<td>Methyl mercaptan</td>
<td>Dimethyl sulphide</td>
</tr>
<tr>
<td>Propane</td>
<td>Dimethyl disulphide</td>
<td>Acetone</td>
</tr>
<tr>
<td>Butane</td>
<td>Ethanol</td>
<td>Methyl ethyl ketone</td>
</tr>
<tr>
<td>Butene</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Benzene</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Toluene</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

\(^a\) Sample size — 500 g

Fat content ~ 0.3%

sulphide and dimethyl disulphide from methionine is readily deduced from expected combinations of thiomethyl and methyl-free radicals. Dimethyl disulphide is the major product.

Other amino acids were chosen to typify an aromatic, a basic, a neutral and an acidic amino acid. Of these, only phenylalanine proved to be radio-sensitive at the doses and concentration used in this study. In all the amino-acid studies, solutions or slurries of the acid were used in amounts corresponding to the average amount present in 500 g of meat, which is the usual size sample of meat. The results are in good agreement with the actual observations for meat protein, i.e., sulphur and aromatic moieties seem to be most subject to radiation cleavage.

The volatile products from the irradiation of oxytocin were examined to see if any indication of destruction of peptide bonds could be observed. The products found were mainly short chain hydrocarbons and were readily explained by cleavage of the side chains from the leucyl and isoleucyl
### TABLE V. VOLATILE COMPOUNDS ISOLATED FROM MEAT SUBSTANCES

<table>
<thead>
<tr>
<th>Protein</th>
<th>Lipid</th>
<th>Lipoprotein</th>
</tr>
</thead>
<tbody>
<tr>
<td>Methyl mercaptan (1)</td>
<td>$C_1-C_{12}$ $n$-alkanes (1)</td>
<td>$C_1-C_{14}$ $n$-alkanes (1)</td>
</tr>
<tr>
<td>Ethyl mercaptan (s)</td>
<td>$C_2-C_{15}$ $n$-alkenes (1)</td>
<td>$C_2-C_{14}$ $n$-alkenes (1)</td>
</tr>
<tr>
<td>Dimethyl disulphide (m)</td>
<td>$C_4-C_8$ $i$-alkanes (s)</td>
<td>Dimethyl sulphide (s)</td>
</tr>
<tr>
<td>Benzene (m)</td>
<td>Acetone (m)</td>
<td>Acetone (m)</td>
</tr>
<tr>
<td>Toluene (m)</td>
<td>Methyl acetate (t)</td>
<td></td>
</tr>
<tr>
<td>Ethylbenzene (s)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Methane (s)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Carbonyl sulphide (s)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
| Hydrogen sulphide (s) | | | *(1) = large; (m) = moderate; (s) = small; (t) = trace.*

### TABLE VI. VOLATILE COMPOUNDS PRODUCED IN IRRADIATED AMINO ACIDS

<table>
<thead>
<tr>
<th>Amino Acid</th>
<th>Major Components$^a$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cysteine</td>
<td>Sulphur dioxide (1)</td>
</tr>
<tr>
<td></td>
<td>Hydrogen sulphide (m)</td>
</tr>
<tr>
<td>Cystine</td>
<td>Sulphur dioxide (s)</td>
</tr>
<tr>
<td></td>
<td>Carbonyl sulphide (m)</td>
</tr>
<tr>
<td></td>
<td>Carbon disulphide (m)</td>
</tr>
<tr>
<td>Methionine</td>
<td>Methyl mercaptan (s)</td>
</tr>
<tr>
<td></td>
<td>Dimethyl sulphide (m)</td>
</tr>
<tr>
<td></td>
<td>Dimethyl disulphide (t)</td>
</tr>
<tr>
<td>Phenylalanine</td>
<td>Toluene (l)</td>
</tr>
</tbody>
</table>

$^a$) Carbon dioxide present in large amount in all samples.
constituents. No evidence for rupture of peptide bonds is seen. In all amino-acid and peptide radiolysis sulphur dioxide and carbonyl sulphide were found to be present in varying amounts, but at present no explanation for the formation of these compounds can be offered.

To summarize, the data thus far obtained support the simple hypothesis that radiation products are primarily the result of direct bond cleavage. The main products of irradiation of dry oxygen free lipid substances are the homologous series of n-alkanes, n-alkenes and traces of n-alkynes. Sterols give mainly normal and iso alkanes from the cleavage of the alkyl side chain. Proteins and peptides show little evidence of rupture of the peptide bond and the main products are from cleavage of the side chains on end groups. The amino acids with aromatic rings or with sulphur groups tend to be most radio-sensitive.

There is evidence that some compounds found in meat are produced by an interaction between phases. Methional, when found, is perhaps formed by interaction of a thiomethyl free radical from protein and an oxygenated free radical from the fat. Also, hexyl mercaptan or ethyl butyl disulphide would seem to come perhaps from free radicals originating in part in the protein and in part in the lipid portions of the meat. Although the current work has seemingly provided greater insight into the mechanisms of irradiation damage in meat, it has also raised more questions. Further studies will be directed toward relating the effects of irradiation on model systems of fat and protein substances in mixtures to clear up some of the questions of phase interactions.

ACKNOWLEDGEMENTS

The author is indebted to his colleagues, P. Angelini and M. L. Bazinet, for their contributions to the experimental work, and to D. A. Forss, of CSIRO, Melbourne, Australia, for his participation in the work on butter-fat.

REFERENCES

DISCUSSION

E. DENTI: You have developed a remarkably sensitive analytical technique. Have you used it to study the effects of temperature (especially low temperatures) on the spectra of volatile products obtained during irradiation?

C. MERRITT: We have studied the effects of irradiation at temperatures down to that of liquid nitrogen, and find that the amount of the various components is correspondingly decreased.

E. KAMELMACHER: You mentioned in your paper only doses of 6 Mrad. What is the lowest dose at which these odours occur?

C. MERRITT: We used other dose levels down to about 1 Mrad, and the main components were still found. We have no data for doses below 1 Mrad, so I cannot give you the threshold dose.

A. R. DESCHREIDER: Have you studied the radiolysis of an aromatic amino acid such as tryptophane?

C. MERRITT: Yes, but at the dose level and with the amount used in these experiments no product except carbon dioxide was found.

R. O. SNNUBER: Have you attempted to reproduce the radiation flavour or odour found in irradiated lipids by preparing mixtures of the compounds characterized and subjecting them to taste panels?

C. MERRITT: We have not yet done so in a systematic manner, but this is obviously a step which must now be taken.

H. KEPPEL: Have you found that the amounts of substances estimated by you are quantitatively the same for pure solutions as for meat after irradiation, or do you believe that the energy transfer in a combination of substances, such as meat, is higher than in pure solutions?
C. MERRITT: We have no data that might serve as a basis for speculating on the relative energy transfer within the two systems.

M. INGRAM: I find it difficult to accept the suggestion that irradiation flavour is independent of the presence of oxygen. It is well known that the off-flavour is different for meat irradiated in air or in nitrogen and that, for example, different sulphur compounds are produced in the two cases. Further, if we accept that there is in either case a characteristic "irradiation note" in the off-flavours, it seems probable that, if it were due for example to alkanes or alkenes as proposed, the course of the relevant chemical changes would be influenced by oxygen. May I therefore ask how the concentration of oxygen in the system was controlled during irradiation?

C. MERRITT: One may expect to find an increased concentration of oxygenated components if the meat is irradiated in air. Nevertheless, the formation of hydrocarbon compounds is found to be independent of the presence of air, the same compounds being formed in about the same abundance whether air is present or not. The oxygen content of the flask is controlled during irradiation by removing the air under high vacuum. The final pressure in the flask is about $10^{-6}$ Torr and the oxygen content about one-fifth of that.

N. GETOFF: The behaviour of molecular oxygen under the influence of radiation is well known in principle; most of it is scavenged by the hydrogen atoms, as follows:

$$
H + O_2 \rightarrow HO_2
$$

$$
HO_2 + HO_2 \rightarrow H_2O_2 + O_2.
$$

In addition to $H_2O_2$ formation, the HO$_2$ radicals are very reactive and act on different organic substances in the same way as the OH radicals.

G. MOCQUOT: I should like to raise a point of terminology. In your experiment on butter you say that one of the oxidized butter samples was typically rancid. A distinction is usually made between the oxidized flavour and the rancid flavour. The rancid flavour results from the liberation of short-chain fatty acids by the lipases, while the oxidized flavour results from the oxidation of long-chain, non-saturated fatty acids.

C. MERRITT: If one wished to distinguish between "rancidity" induced by microbial deterioration or by enzymes and "oxidation" odours, one would have to say, of course, that the oxidized samples had a typical "oxidation" odour. The fact remains that the odour of irradiated samples is unmistakably different and characteristic.

F. J. LEY: In view of the fact that the irradiation odours and flavours which develop in meats at certain doses are objectionable, does the knowledge of the nature of the chemical changes which occur give an indication as to how they might be prevented and the quality of the meat thereby improved?

C. MERRITT: Yes, the knowledge of chemical changes provides a great deal of information, and studies of such phenomena as the effects on these changes of dose, dose-rate, temperature, or additives to the system can yield suggestions as to how the changes may be prevented or minimized.
EVALUACION DEL ESTADO DE CONSERVACION DE PESCADO POR MEDIO DE ALGUNOS PARAMETROS ELECTRICOS

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COMISION NACIONAL DE ENERGIA ATOMICA, BUENOS AIRES, ARGENTINA

Abstract — Résumé — Аннотация — Resumen

ELECTRICAL PARAMETERS FOR EVALUATING THE STATE OF PRESERVATION OF FISH. In fish irradiation experiments it is important to have a simple method of obtaining quantitative data for evaluating the state of preservation of the irradiated material. With this object in view, the authors studied certain electrical parameters of fish species that are of local importance as a source of food. Measurements were made, on non-irradiated fish, with electrode-carrying pincers and a tester as commonly used in electronics.

The results are presented of capacitance and resistance measurements carried out either with naked electrodes in contact with the exterior of the fish or with an electrolytic paste interposed for better conductivity. The experiments were then repeated with irradiated fish. A comparative analysis is made of the results, and the authors discuss their possible usefulness as a parameter in irradiation experiments.

EVALUATION DE L'ETAT DE CONSERVATION DES POISSONS A L'AIDE DE CERTAINS PARAMETRES ELECTRIQUES. Dans les expériences sur l'irradiation du poisson, il importe de disposer d'une méthode qui permette d'obtenir aisément des données quantitatives pour l'évaluation de l'état de conservation de cette denrée. Tenant compte de cet objectif, les auteurs étudient certains paramètres électriques sur différentes espèces de poissons présentant un intérêt alimentaire sur le plan local. Les mesures ont été effectuées à l'aide d'une pince porte-électrodes et d'un dispositif de mesure couramment utilisé en électronique.

Le mémoire expose les résultats obtenus à la suite de la mesure de la capacité et de la résistance, soit en appliquant les électrodes directement sur les poissons, soit en interposant une pâte électrolytique assurant une meilleure conductivité. Les expériences ont été répétées avec du poisson irradié. Les auteurs font une analyse comparative des résultats et examinent l'utilité de la capacité comme paramètre pouvant servir dans les expériences d'irradiation.

ЭЛЕКТРИЧЕСКИЕ ПАРАМЕТРЫ ДЛЯ ОЦЕНКИ СТЕПЕНИ СОХРАННОСТИ РЫБЫ. В экспериментах по облучению рыбы важно располагать простым методом получения количественных данных для оценки степени сохранности облученного продукта. Имея в виду эту цель, авторы изучили определенные электрические параметры видов рыб, которые представляют ценность в местном масштабе как источник питания. Были сделаны измерения на необлученной рыбе с помощью несущей электроды пинцета и обычно используемого в электронике шупа.

Представлены результаты измерений емкости и сопротивляемости, проведенных или при наличии контакта оголенных электродов с внешними частями рыбы, или с помощью электролитной активной среды, введенной для создания лучшей проводимости. Эксперименты были затем повторены на облученной рыбе. Сделана сравнительный анализ результатов, и авторы обсуждают их возможную полезность в качестве параметра в экспериментах по облучению.

EVALUACION DEL ESTADO DE CONSERVACION DE PESCADO POR MEDIO DE ALGUNOS PARAMETROS ELECTRICOS. En las experiencias sobre irradiación de pescado es importante disponer de un método que, en forma sencilla, permita obtener datos cuantitativos para la evaluación del estado de conservación del alimento. Teniendo en cuenta ese objetivo en el presente trabajo se encareció el estudio, en especies de pescado de interés alimenticio local, de ciertos parámetros eléctricos. La medición de los mismos fue efectuada con una pinza portaelectrodos y un tester común usado en electrónica.

En la memoria se relatan los resultados obtenidos midiendo capacitancia y resistencia, utilizando ya sea electrodos desnudos en contacto con el exterior de los peces o interponiendo una pasta electrolítica para mejor conducción. Se repitieron las experiencias con pescado irradiado. Se analizaron comparativamente los resultados y se discute su posible utilidad como parámetro a utilizarse en las experiencias de irradiación.
Por sus características geográficas la República Argentina es un país con capacidad para una explotación pesquera considerable. La enorme extensión de sus costas marítimas, sus importantes cuencas fluviales y sus lagos interiores albergan una población ictícola muy variada, que comprende desde la de climas cálidos hasta la de climas fríos.

Sin embargo, debido a la gran distancia en que se encuentran ubicadas del litoral fluvial y marítimo, la mayoría de las poblaciones del interior del país completan su alimentación casi exclusivamente con proteínas de origen bovino y farínaceo.

A pesar de ello, el consumo de pescado ha incrementado en forma considerable en los últimos años, debido fundamentalmente a la aparición de una industria fileteadora y congeladora de algunas especies férticas.

Resulta, en consecuencia, que una mejor técnica de conservación permitirá extender el mercado consumidor a zonas lejanas de los centros pesqueros.

Con el objeto de contribuir a una mejor solución de este problema en la Comisión Nacional de Energía Atómica se han iniciado estudios tendientes a evaluar la posibilidad de aplicar técnicas de conservación mediante irradiación de especies autóctonas.

Con este fin se ha elaborado un plan de trabajo que incluye sucesivamente estudios de especies de agua dulce y de agua de mar, para establecer los tipos de tratamientos necesarios de acuerdo a las variedades locales.

Para la valoración del tratamiento por irradiación, tiene obvia importancia la evaluación cuantitativa del estado de conservación del material tratado. En el caso del pescado, diversos métodos se utilizan con tal finalidad, desde la simple estimación de las características organolépticas hasta complicadas determinaciones bioquímicas.

Entre estos límites existen diversos métodos cuya precisión generalmente varía en razón de su complejidad. El método de determinación más conveniente sería aquel que resulte independiente de la apreciación subjetiva del operador, rápido, sencillo y, en lo posible, no destructivo.

El intento de establecer una correlación entre el estado de conservación y características eléctricas del pescado mediante el uso del Electrón, equipo desarrollado en Alemania, y evaluado últimamente por Carver [1] en Gloucester, Massachusetts, para las especies locales, configura un método que reúne las características anteriormente enunciadas.

Adoptando el criterio de utilizar parámetros eléctricos, se decidió realizar, en el Departamento Fuentes Intensas de Radiación, de la CNEA, un estudio sobre nuestras especies locales. Los resultados preliminares de este estudio serán expuestos en el presente trabajo.

El material utilizado consistió en un primer tiempo y por motivos de ubicación geográfica en las siguientes especies de agua dulce de importancia culinaria:

Sábalo (Prochilodus Platensis)
Pejerrey (Atherinidae Odonthestes Bonariensis)
Dorado (Caracinidae Salminus)

La pesca de estas especies se realiza en el Río de la Plata mediante embarcaciones menores, por lo que resultó fácil obtenerlas al poco tiempo de extraídas del agua. No obstante, no pudieron evitarse variaciones dependientes de las fluctuaciones climáticas y forma de pesca, hecho que será tenido en cuenta más adelante al discutir los resultados.
Los parámetros analizados fueron la resistencia eléctrica y la impedancia. Se utilizó para medir un tester común usado en electrónica. Los valores de resistencia se obtuvieron en forma inmediata por medición directa en las escalas correspondientes. La impedancia fue medida acondicionando el equipo como para medición de capacitancia, es decir, intercalando en serie una fuente de corriente alterna de 6 V y en paralelo una resistencia de 3000 ohms (fig. 1), leyéndose los valores en ohms en las escalas correspondientes, previa calibración con resistencias de valores conocidos. Los contactos fueron establecidos por medio de una pinza con electrodos de bronce montados en lucite de 2,5 cm de diámetro (fig. 2).

Teniendo en cuenta que en el trabajo de Carver se describen variaciones en los valores obtenidos de acuerdo con la presión ejercida sobre la muestra, se trató de resolver este inconveniente mediante dos artificios. Por un lado, se dotó a la pinza portaelectrodos de un simple mecanismo de modo que la presión ejercida fuese amortiguada por un resorte con el fin de obtener una mayor constancia y, por otro lado, se hicieron también experiencias intercalando entre electrodos y pescado una pasta conductora con el objeto de homogeneizar además la superficie de contacto, al regularizar las diferencias por convexidad. En todos los casos, se midieron los pescados sin eliminar las escamas.

La pasta conductora estaba constituida por kaolín y solución concentrada de cloruro de calcio, similar a la utilizada en medicina cuando se realizan registros de actividades bioeléctricas. Como parámetro de referencia se utilizó el dato correspondiente a los días transcurridos desde la captura hasta el momento de la medición. En general se trataron de realizar en las experiencias mediciones en serie sobre los mismos ejemplares. El pescado se conservó en refrigeradora a una temperatura que oscilaba entre 5 y 8°C.

Cada serie estaba constituida por un número variable de ejemplares, siendo la cantidad promedio de los lotes de alrededor de 15 pescados. En cada caso, sea cual fuere el parámetro registrado, se efectuaron tres mediciones sobre cada muestra y el dato obtenido fue el promedio de ellas. Se trató de que el sitio de contacto de los electrodos fuese relativamente constante; así, para la primera medición se emplazaban los electrodos inmediatamente por detrás de los orificios branquiales y por
encima de la línea blanca lateral, y para las siguientes se desplazaban los electrodos a una distancia igual al diámetro de los mismos.

En un primer ensayo se midieron ejemplares sin irradiar; posteriormente se hizo lo mismo con pescados que habían sido irradiados con una dosis de 0,5 Mrad con el objeto de intentar una correlación.

El análisis de los resultados se efectuó de la siguiente manera: cuando la serie era numerosa y había sufrido reiteradas mediciones se analizó la serie completa. Cuando, por el contrario, la cantidad de ejemplares era escasa o el número de mediciones pobre, se integraron en un gráfico común sólo aquellos en que el tiempo de conservación hasta el momento de la putrefacción era similar. Esto último no ocurrió siempre y la causa probable de ello radica en los factores que se enunciaron anteriormente.

De acuerdo a la especie estudiada, los resultados fueron los siguientes:

1. **SABALO**


2. **PEJERREY**

   Se midió la resistencia con y sin pasta. Comprendieron tres series de 11, 16 y 9 ejemplares, respectivamente, y sus pesos oscilaron entre 100 y 150 gr. Los resultados están expresados en las figuras 4 y 5.
De los gráficos anteriores surge que los valores de resistencia, tanto para sábalos como para pejerreyes, muestran una tendencia a disminuir a medida que transcurre el tiempo de almacenamiento. En esta última especie, cuando se utilizó pasta electrolítica, la tendencia a la disminución fue más manifiesta aunque con una pronunciada dispersión. Con estos valores se trazó el gráfico de dispersiones máximas (fig. 6), y se ubicaron en el mismo algunos valores de otras mediciones aisladas que comprendieron, además, pescados que habían sido irradiados con las dosis descritas. Aunque escasos, los puntos se ubican alrededor del gráfico de dispersión, no habiendo aparentemente diferencias entre pescados irradiados y sin irradiar.

La impedancia de los pejerreyes fue medida sin interposición de pasta, y se representaron sus resultados como promedio de las determi-
naciones correspondientes a los respectivos días de distintas experiencias (fig. 7).

Con el objeto de establecer si existía alguna relación entre los valores correspondientes de resistencia e impedancia, se efectuó el cociente entre estas magnitudes, y sus resultados se pueden observar en la figura 8.

3. DORADOS

En dos experiencias con dorados constituidas por grupos de escaso número de ejemplares y de peso de alrededor de 500 gr, los resultados de impedancia y resistencia aislados no mostraron una correlación definida. Sin embargo, al efectuarse los cocientes descriptos se insinuó una tendencia según puede verse en la figura 9, en la que se han agregado además los datos correspondientes a ejemplares irradiados que no muestran aparente diferencia con los no irradiados.
CONCLUSIONES

De los resultados anteriores puede inferirse que en las especies de pescado estudiadas, existe una sugestiva correlación entre los parámetros eléctricos medidos y el tiempo transcurrido desde el momento de la captura de los mismos. La gran dispersión hallada; en concordancia con lo descrito por Carver, tiene su origen en distintos factores cuya influencia respectiva tratará de aclararse en estudios futuros.

Es interesante destacar que con la interposición de pasta, sobre todo en la especie pejerrey, se han mejorado los valores. Esta especie se caracteriza por su cuerpo de forma cilíndrica y su tamaño reducido, y por lo tanto resulta obvio que la pasta interpuesta permite un mejor contacto entre electrodos y pescado. Por otra parte, el uso de la misma hace que las características de humedad del tegumento del pescado tengan menor influencia en las mediciones.

La existencia de una probable correlación entre los cocientes y los valores medidos, sugiere la posibilidad de disponer de un parámetro con menor probabilidad de variación al independizar las determinaciones de los factores que influyen en ambas.

Un hecho importante que debe tenerse en cuenta es la falta de un parámetro absoluto de referencia. Así, son posibles variaciones entre lotes, que dependerán del sistema de captura utilizado, de la temperatura ambiente del día de la pesca o de variaciones estacionales. En este sentido, se planea continuar las experiencias utilizando como parámetro de referencia determinaciones bioquímicas, habiéndose evaluado como satisfactoria la medición del contenido de bases volátiles libres [2]. Esto tendría particular interés para establecer si la correlación ocurre entre parámetros eléctricos y estado de conservación o sólo entre aquéllos y el tiempo de almacenamiento transcurrido.

La aparente similaridad en el comportamiento de pescados irradiados y no irradiados parecería abonar en favor de esta última hipótesis. La dilucidación de este aspecto es de capital importancia para la evaluación de la utilidad del método.

REFERENCIAS


DISCUSSION

A. S. KOVACS: What was your reason for using a conducting paste?

H. A. MUGLIAROLI: We used a conducting paste to keep the skin humidity of the fish constant and to improve the contact between electrodes and sample. We were not aware of the possibility of using cold electrodes with the Intelectron since we did not know, in spite of corresponding with a number of centres in the United States of America, all the design characteristics of the equipment.
ANALYSIS OF THE VOLATILE CONSTITUENTS OF IRRADIATED APPLE JUICE. The organoleptic studies and wholesomeness tests that are being carried out as part of the International Programme on the Irradiation of Fruit and Fruit Juices (Seibersdorf Project) entail analysis of the aromatic substances present in irradiated and non-irradiated juice.

The volatile substances present in irradiated fruit juices were analysed by gas chromatography, with direct injection of the emitted vapours at ambient temperature and at 60°C (Weurman’s Head Space Technique).

The volatile constituents were identified by comparing the amounts retained in the column with those for pure substances and by removing certain constituents from the vapour with the help of chemical reagents. To simplify the analyses, the first tests were carried out on concentrated apple juice from which the volatile substances had been removed before irradiation.

Irradiation gave rise to five aldehydes in the normal apple juice (acetaldehyde, isobutyraldehyde, butyraldehyde, isovaleraldehyde and capronaldehyde), but only three in the concentrated juice (acetaldehyde, isobutyraldehyde and isovaleraldehyde).

In addition, 2-butanone appeared in the concentrated juice; however, the peak corresponding to it on the chromatogram was completely masked by the ethanol peak in the case of non-concentrated juice.

Furan was also detected, together with traces of two compounds that have not yet been identified.

Similar results have been obtained by pasteurization, such as in bottling by heat.

ANALYSE DES CONSTITUANTS VOLATILS DES JUS DE POMMES IRRADIES. Dans le cadre du projet international de recherches sur la conservation des fruits et jus de fruits par irradiation (Seibersdorf), les études organoleptiques, de même que les tests d’innocuité, rendent indispensable l’analyse des substances aromatiques des jus irradiés et non irradiés.

Les substances volatiles des jus de pommes irradiés ont été analysées par chromatographie en phase gazeuse, par injection directe des vapeurs qu’ils émettent, soit à la température du laboratoire, soit à 60°C (Head Space Technique de Weurman).

Les identifications ont été faites par comparaison des volumes de rétention avec ceux de substances pures, et à l’aide de réactifs chimiques permettant d’éliminer certains constituants de la vapeur. Pour simplifier les analyses, les premiers essais ont porté sur des concentrés de jus de pommes ne contenant plus de substances volatiles avant irradiation.

Par irradiation, cinq aldéhydes prennent naissance dans les jus de pommes: acétaldéhyde, isobutyraldéhyde, butyraldéhyde, isovaléraldéhyde et capronaldéhyde; mais trois seulement dans les jus concentrés: acétaldéhyde, isobutyraldéhyde et isovaléraldéhyde.

De plus, la 2-butane apparaît dans les jus concentrés, mais le pic qui lui correspond sur les chromatogrammes est entièrement masqué par celui de l’éthanol dans le cas des jus non concentrés.

Par ailleurs on a mis en évidence les formations de furane et de deux composés qui n’apparaissent qu’à l’état de traces et qui n’ont pas pu être identifiés à ce jour.

Des résultats analogues ont été obtenus par pasteurisation, telle qu’elle est réalisée par embouteillage à chaud.

МЕЖДУНАРОДНЫЙ ПРОЕКТ ПО ОБЛУЧЕНИЮ ФРУКТОВ И ФРУКТОВЫХ СОКОВ. В рамках Международного исследовательского проекта по консервированию фруктов и фруктовых соков методом облучения (Зайберсдорф) органолептические исследования, а также испытания на безопасность делают необходимым проведение анализа ароматических веществ, облученных и необлученных соков.

Анализировались летучие вещества облученных яблочных соков методом хроматографии в газовой фазе путем непосредственного введения паров, испускаемых соками, либо при рабочей температуре либо при 60° – 100° (Head Space Technique de Weurman).

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Идентификация производилась путем сравнения объемов удержания с объемами чистых веществ и при помощи химических реактивов, которые позволяли устранить некоторые компоненты пара.

Для упрощения анализов первые исследования проводились с концентратами яблочных соков, не содержащих перед облучением летучих веществ.

При облучении в яблочном соке появляются пять альдегидов: ацетальдегид, изомасляный альдегид, масляный альдегид, изовалерьяновый альдегид и капроновый альдегид. В концентрированных соках появляются только три альдегида: ацетальдегид, изомасляный альдегид и изовалерьяновый альдегид.

Кроме того, в концентрированных соках появляется 2-бутанон, но соответствующий ему пик полностью покрывается пиком этанола, когда речь идет о неконцентрированных соках.

Были обнаружены к тому же образования фурана и двух соединений, которые появляются только в виде следов и которые не были определены до настоящего времени.

Полученные результаты были аналогичны тем, что и при пастеризации путем нагревания.

ANALISIS DE LOS COMPONENTES VOLATILES DE LOS ZUMOS DE MANZANA IRRADIADOS. Los estudios organolépticos y los ensayos de inocuidad que se realizan dentro del marco del proyecto internacional de investigaciones sobre la conservación de frutas y zumos de fruta por irradiación (Seibersdorf) hacen indispensable el análisis de las sustancias aromáticas de los zumos irradiados y no irradiados.

Las sustancias volátiles de los zumos de manzana irradiados han sido analizados por cromatografía en fase gaseosa, introduciendo directamente los vapores que emiten a la temperatura ambiente y a 60°C (técnicas «Head Space», de Weurman).

Las identificaciones se han efectuado comparando los volúmenes de retención con los de sustancias puras y eliminando ciertos constituyentes del vapor con reactivos químicos.

Para simplificar los análisis, los primeros ensayos se han efectuado con concentrados de zumos de manzana que no contenían ya sustancias volátiles antes de la irradiación.

En los zumos de manzana, la irradiación hace aparecer cinco aldehídos: acético, isobutírico, butírico, isovalérico y caprónico; en los zumos concentrados sólo se han observado tres: acético, isobutírico e isovalérico.

En estos zumos concentrados aparece, además, 2-butanona pero en los no concentrados el máximo que le corresponde en los cromatogramas queda enteramente cubierto por el del etanol.

Se ha comprobado la formación de furano y de dos compuestos que sólo aparecen como vestigios y que no han podido ser aún identificados.

Se han obtenido resultados análogos mediante pasterización realizada por embotellamiento en caliente.

Dans le cadre du projet international de recherche sur la conservation des fruits et jus de fruits par irradiation, l'analyse des composés volatils prenant naissance dans les jus de pommes a été envisagée en vue d'une étude des modifications de composition qui interviennent lors du traitement, et qui subsistent après une conservation plus ou moins longue.

Ces modifications de composition ont une incidence sur les propriétés organoépítiques des jus, et sont susceptibles d'en avoir sur son innocuité.

Il ressort des premiers essais effectués et de diverses publications (1 à 4), que les arômes de jus de pommes sont constitués par des alcools, et par des quantités comparativement très faibles d'autres composés, tels qu'aldéhydes et esters. Les alcools gênent d'autant plus les analyses par chromatographie en phase gazeuse qu'ils sont prédominants et qu'ils donnent des pics dont les traîtées viennent masquer les autres composés volatils.
Il n'existe pas, à notre connaissance, de technique simple permettant d'éliminer totalement les alcools sans que d'autres modifications importantes interviennent dans l'échantillon. Mais il est possible de les éliminer en grande partie, en mettant à profit leurs faibles constantes de volatilité en solution aqueuse, et c'est ainsi que nous avons essentiellement utilisé la technique de Weurman (5) qui consiste à injecter dans le chromatographe en phase gazeuse l'atmosphère confinée en équilibre avec le liquide à analyser.

Opérant comme l'indiquent Bassette, Süheyl Ozeris et Whitnah (6) qui s'inspirent du travail de Weurman, nous avons pu obtenir des résultats préliminaires. On a rapidement constaté que, dans bien des cas, on se trouvait à la limite de sensibilité de cette méthode. Il fallait donc opérer de la même façon sur ce qu'il est convenu d'appeler un concentré d'arôme.

Nous inspirant alors du travail de Nawar et Fagerson (7), les composés volatils des jus ont été entraînés vers un piège plongé dans l'azote liquide par pompage en circuit fermé de l'air contenu dans l'appareil car une purge par de l'azote entraîne les composés à très fortes constantes de volatilité.

Comme les composés volatils prenant naissance au cours de l'irradiation se trouvent mêlés aux composés naturels, les premiers essais ont été effectués sur des jus de pommes dont les composés volatils avaient été éliminés avant irradiation par concentration. De la sorte, seuls apparaissent sur les chromatogrammes les composés volatils qui se forment lors de l'irradiation des constituants non volatils des jus.

**MATERIEL**

Le jus de pommes provient de HBL u. VA für Wein- und Obstbau Klosterneuburg. Ce jus a été obtenu après lavage, broyage et pressurage de pommes à cidre de diverses variétés. Après addition de 2 ml par litre de Pectinol (Rohm et Hass) et repos de 12 heures, le jus a été stérilisé par filtration et a été congelé à la température de -27°C. Ce jus présente une acidité totale de 110 meq/l, une densité de 1,049 et un pH de 3,29.

Les jus concentrés ont été obtenus par évaporation sous le vide de la trompe à eau et chauffage dans un bain-marie maintenu à 60°C, jusqu'à obtention d'un volume égal à la moitié du volume initial. Les dernières traces de constituants volatils ont été éliminées par entraînement à la vapeur d'eau dans un appareil classique.
1. Modalités d'irradiation

250 ml de jus sont introduits dans un flacon de capacité légèrement supérieure. Le flacon est fermé à l'aide d'un bouchon en matière plastique, maintenu par une capsule en aluminium dont la partie centrale peut être évidée. Ce mode de fermeture permet des prises d'échantillons à l'aide de seringues hypodermiques sans ouverture du flacon. Des fragments de ces bouchons ont été irradiés dans de l'eau distillée, mais aucun produit volatile n'a pu être détecté.

L'irradiation a lieu dans des appareils du type gamma cell, dont les débits de doses sont respectivement 50 et 750 krad/h; l'élément radioactif est dans les deux cas le cobalt-60. Aucune différence n'est apparue du fait du débit de dose.

Enfin les jus conservés à 18°C pendant 2 mois ont été irradiés à la dose de 500 krad (débit de dose 750 krad/h) immédiatement après chauffage, 10 min à 50°C.

2. Chromatographie en phase gazeuse

Le chromatographe en phase gazeuse est le modèle Fractometer 116 E Perkin-Elmer. Cet appareil est muni d'un détecteur à ionisation de flamme et ne peut être utilisé qu'à température constante. Les colonnes ont été également fournies par les Etablissements Perkin-Elmer. Il s'agit de 2 colonnes de type Macro-Golay de 100 m de long et de 1 mm de diamètre. Pour l'une, la phase liquide est le polypropylène glycol, pour l'autre, le squalane. Dans tous les cas, le gaz vecteur est l'hélium utilisé à un débit de 10 ml par minute. Les débits d'hydrogène et d'air, alimentant le détecteur, sont réglés de telle sorte que l'air qui est injecté en même temps que l'échantillon donne un pic légèrement positif.

METHODES

Analyse de l'atmosphère confinée

L'analyse de l'atmosphère confinée, selon Weurman, a été envisagée de 5 façons différentes qui correspondent à diverses modalités de préparation.

1. Analyse de l'atmosphère confinée des flacons

Comme il a été indiqué, il est possible de prélever l'atmosphère confinée des flacons irradiés ou non, et d'injecter ainsi 2 à 4 ml de vapeur dans l'appareil d'analyse.
2. Atmosphère confinée des jus

Dans un flacon de 12 ml, on pèse 3 g de sulfate de sodium anhydre et on ferme le flacon de la même façon que précédemment. A l'aide d'une seringue hypodermique, on extrait 5 ml de jus que l'on injecte dans le flacon. On agite 15 min à la température du laboratoire, on prélève 4 ml de vapeur que l'on injecte dans l'appareil d'analyse.

3. Atmosphère confinée d'un concentré d'arôme

Les composés volatils de 250 ml de jus sont entraînés dans un circuit fermé comprenant une pompe à gaz (0,5 l/min), un ballon de 1 litre dans lequel on place l'échantillon et un piège dont la partie inférieure est plongée dans de l'azote liquide. L'opération dure 2 heures. Après réchauffement du piège, on le rince par quelques ml d'eau distillée, et le concentré d'arôme ainsi obtenu est versé dans un flacon de 12 ml qui est fermé comme précédemment. Un ml d'extrait est alors injecté dans un flacon de 12 ml dans lequel on a préalablement pesé 0,5 g de sulfate de sodium anhydre. Après 15 min d'agitation à la température du laboratoire, on prélève 2 ml de vapeur qui sont injectés dans l'appareil d'analyse.

4. Atmosphère confinée à 60°C

La préparation de l'échantillon est celle indiquée en 2, mais l'équilibre entre phase liquide et phase vapeur est obtenu à 60°C par immersion dans un bain-marie. La seringue d'analyse est, elle aussi, chauffée à la même température de façon à éviter toute condensation.

5. Autre analyse du concentré d'arôme

Deux ml de concentré, obtenu comme il a été indiqué en 3, sont injectés dans un flacon contenant 2 g de sulfate de sodium anhydre. Cette fois 4 ml sont utilisés pour l'analyse.

Dans les trois premiers cas l'analyse est faite sur colonne de polyéthylène glycol à 40°C, ou sur colonne de squalane à 26°C. Dans les deux derniers cas l'analyse est faite sur ces mêmes colonnes maintenues respectivement aux températures de 54° et 40°C.

Utilisation des réactifs chimiques

Il est toujours possible d'ajouter au jus des réactifs tels que le chlorure mercureux ou le chlorure d'hydroxylamine qui permettent d'éliminer de la vapeur les sulfures volatils ou les composés carbonylés. Par contre d'autres réactifs, tels que l'hydroxyde
de sodium ou le permanganate de potassium, qui ne peuvent être utilisés directement sur les jus, ont été employés sur les concentrés d'arôme.

C'est à l'aide de ces réactifs que les identifications ont été faites en constatant la disparition des pics. Deux colonnes de polarités différentes ont été utilisées, en vue d'obtenir des séparations meilleures pour certains composés.

RESULTATS

Du fait de l'irradiation sont apparus, d'une part des composés carbonylés, d'autre part des composés plus difficiles à identifier, et qui ont été désignés par des lettres.

1. Composés carbonylés volatils

Deux méthyl cétones se forment dans les jus concentrés, par irradiation, il s'agit de l'acétone et de la butanone. Ces deux cétones se forment également lors de l'irradiation des jus de pommes, et subsistent après 2 mois de conservation à 18°C.

Trois aldéhydes apparaissent dans les jus concentrés : l'acétaldéhyde et des traces d'isobutyraldéhyde et de 3-méthyl butanal. La formation de propanaldéhyde et de 2-méthyl butanal est incertaine. Il n'apparaît ni butyraldéhyde, ni capronaldéhyde.

Tous ces composés, y compris le butyraldéhyde et le capronaldéhyde, se forment, du fait de l'irradiation, dans les jus de pommes non concentrés. Les aldéhydes sont toujours à l'état de traces, sauf l'acétaldéhyde, dont la teneur semble d'ailleurs augmenter lors de la conservation à 18°C.

Ces composés ont été signalés dans les jus de pommes non irradiés, mais les analyses du jus témoin, faites dans les mêmes conditions, n'ont révélé la présence que de traces d'acétone et d'acétaldéhyde.

On peut donc affirmer que prennent naissance, du fait de l'irradiation, les 2 cétones et les 7 aldéhydes dont il a été question, et que ces composés subsistent après 2 mois de conservation à 18°C.

Enfin la technique n°2, appliquée à une solution de butanone à 0,1 ppm, a permis d'obtenir un pic équivalent à celui obtenu par la même méthode appliquée à un jus concentré irradié à 1 Mrad. Or la butanone est, des composés carbonylés trouvés, celui qui après l'acétaldéhyde donne le pic le plus important. Cette teneur
de 0,1 ppm est l'ordre de grandeur de la limite de sensibilité de la méthode, comme l'indiquent Bassette, Süheylâ Ozeris et Whitnah (6).

2. Autres composés volatils

Le composé "A" apparaît à l'état de trace dans les jus concentrés irradiés. Il est élué dans la traînée du pic d'acétaldéhyde sur colonne de polypropylène glycol, et sa présence dans l'atmosphère confinée des bouteilles irradiées montre qu'il est peu polaire. Son volume de rétention est celui de l'éther diéthylique sur colonne de polypropylène glycol. Ce composé, qui ne se trouve pas dans la préparation des concentrés d'arôme, n'a pu être identifié.

Le composé "B" apparaît en quantités relativement importantes, aussi bien dans l'atmosphère confinée des bouteilles irradiées, que dans les jus irradiés. Il se forme dans les jus et dans leurs concentrés, mais sa teneur semble décroître lors de la conservation à 18°C. Ce composé réagit avec le permanganate de potassium et avec l'eau de brome, et ses volumes de rétention sur l'une et l'autre phase liquide sont ceux du furane.

Le composé "C", élué sur colonne de polypropylène glycol et le composé "D", élué sur colonne de squalane, semblent correspondre à un seul et même composé qui n'apparaît pas immédiatement après irradiation mais dans les jours qui suivent. Ce composé se forme aussi bien dans les jus que dans leurs concentrés, et il apparaît dans les concentrés d'arôme des jus non irradiés. Il ne réagit avec aucun des réactifs utilisés, et il a été impossible de l'identifier. Son indice de Kowats sur polypropylène glycol à 40°C est 750, et ce même indice, mesuré sur squalane à 40°C, est 670. Ces indices sont proches l'un de l'autre, ce composé est donc peu polaire et pourrait être un éther.

DISCUSSION

Les analyses que nous avons faites sont limitées aux composés les plus volatils, c'est-à-dire ceux qui sont décelables par la technique de l'atmosphère confinée. Nos résultats sont donc encore partiels et ils ne tiennent pas compte de la formation possible d'autres composés qui, à cause de leur tension de vapeur plus faible, échappent à la technique utilisée.

Le tableau I montre que l'irradiation provoque des modifications assez semblables à celles de la pasteurisation, telle qu'elle est réalisée dans l'embouteillage à chaud. La présence de certains composés est vraisemblable (\( ^\)\textsuperscript{2} ) mais n'a pu être mise en évidence par l'apparition de pics individualisés sur les chromatogrammes. Ceci est dû à ce que ces composés sont élués au voisinage d'autres
<table>
<thead>
<tr>
<th>Produits formés</th>
<th>Jus congelé</th>
<th>Jus pasteurisé</th>
<th>Concentré</th>
<th>Concentré irradié 1 Mrad</th>
<th>Jus irradié 0,5 Mrad</th>
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<td>Butanone</td>
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<td>Acétaldéhyde</td>
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<td>Isobutyraldéhyde</td>
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<td>2-méthyl butanal</td>
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<td>3-méthyl butanal</td>
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<tr>
<td>Capronaldéhyde</td>
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<td>Furane</td>
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<tr>
<td>Composé A</td>
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<td>Composés C\text{et}^{\text{et}}_{\text{D}}</td>
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corps présents en quantité bien supérieure. C'est en particulier le cas du propanaldéhyde.

On peut aussi se demander d'où proviennent ces composés volatils. Ceux qui apparaissent par irradiation de concentrés sont nécessairement formés à partir de composés non volatils. Sur les 12 composés décelés, 10 doivent avoir cette origine. Au contraire, le butyraldéhyde et le capronaldéhyde n'apparaissent après irradiation que dans des jus qui n'ont pas été privés de leur fraction volatile. On est donc amené à penser qu'ils proviennent de l'oxydation des alcools correspondants. Cette constatation est aussi valable dans le cas de jus simplement chauffés.

Il n'a pas été possible de mettre en évidence des sulfures volatils dans les jus de pommes irradiés, et nous pensons que cela est dû à leur très faible teneur en protéines. Dans les jus de raisins, qui sont plus riches en protéines, l'irradiation produit la formation d'un disulfure volatile qui peut être piégé dans une solution d'acétate mercure. Ceci nous amène à penser qu'une teneur élevée en protéines risque de provoquer dans les jus de fruits irradiés des modifications organoleptiques défavorables.

Le furane apparaît comme un produit typique des jus irradiés, alors qu'on ne le trouve pas dans les jus chauffés. La présence de furane pourrait donc servir, dans les jus de fruits, comme indicateur d'un traitement par irradiation, de la même façon que la présence d'hydroxy méthyl furfural indique un traitement par chauffage. Cependant, il faut indiquer que la stabilité du furane dans le jus n'est pas parfaite et qu'il conviendrait de préciser ce point. On a remarqué que le furane se forme en quantité plus faible lorsqu'on irradite des jus traités aux enzymes pectolytiques. Cela suggère qu'il pourrait provenir de la radiolyse des pectines. Or jusqu'ici, le furane n'a été signalé, à notre connaissance, que dans les produits de pyrolyse formés lors de la combustion du tabac (8) et de la torréfaction du café (9).

REFERENCES

DISCUSSION

F. DE LA CRUZ: The Division of Chemistry and Isotopes of the Spanish Nuclear Energy Board is engaged in investigations connected with the radiolysis of volatile fruit juice components in collaboration with the Seibersdorf Project. Perhaps I may say a few words here about the progress of this work.

One of our lines of approach (see Fig. D) is the chromatographic study, by a "head space" method similar to that described by Dr. Dubois, of irradiated and non-irradiated fruit (apple and grape) juice after concentration of the volatile products by flash distillation at low temperature (8-10 °C) and in a nitrogen atmosphere.

The other approach is to obtain an aroma concentrate by flash distillation and a residue from which the aromatic compounds have been removed; the concentrate and residue are then irradiated in our NAYADE 60Co apparatus.

The volatile products resulting from irradiation are separated from the residue by flash distillation.

The three preparations (non-irradiated aroma concentrate, irradiated aroma concentrate, and concentrate of new volatile products occurring in the residue as a result of irradiation) are analysed by the "head space" technique or, in order to increase the sensitivity of the chromatographic method, by the extraction of the volatile components from the concentrates by means of organic solvents possessing a high boiling point (paramethylcresol, diethyl phthalate, etc.). The extract is analysed by preparative gas chromatography. The results obtained by this method are extremely satisfactory and make possible the use of preparative gas chromatography to separate fractions that are then used, in conjunction with analytical gas chromatography, in complementary identification techniques (mass spectrometry and infrared spectrophotometry).

Among the results obtained I would mention the finding of an approximately linear relationship when apple and grape juices are irradiated, between the amount of acetaldehyde of radiolytic origin and the total dose.
In the case of grape juice irradiation, 2-methyl-2-butanol is produced in quantities proportional to the radiation dose.
ANALISIS FISICOQUIMICO DE TRIGO IRRADIADO:
ESTUDIO DE SUS CARACTERISTICAS GERMINATIVAS Y NUTRICIONALES

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Abstract — Résumé — Аннотация — Resumen

PHYSICAL AND CHEMICAL ANALYSIS OF THE GERMINATING AND NUTRITIONAL PROPERTIES OF IRRADIATED WHEAT. The authors exposed wheat to radiation at various dose levels for the purpose of determining the physical and chemical effects on whole grain (its behaviour as seed) and flour (nutritional value). They used the Sureña M. A.G. variety of wheat, which is cultivated in Argentina and was supplied by the National Wheat Board. A Canadian Gammacell 220 apparatus was employed, equipped with a 13 000-Ci 60Co source and capable of delivering a dose of approximately 1 Mrad/h. Irradiation was carried out at the following dose levels: 10, 15, 20, 50, 100, 150, 200, 300, 500, 1000, 1500 and 2000 krad.

The following analytical values were determined: (a) whole wheat — hectolitric weight, moisture content, percentage of proteins (nitrogen content ×13.5), Zeleny figure, ash content, ability to germinate (two and three days); (b) flour — moisture content, percentage of proteins (nitrogen content ×13.5), Zeleny figure, ash content, alcoholic acidity, maltose content, wet gluten content, dry gluten content, farinograph values (absorption of water, development time, degree of sponginess, Brabender moisture tester), alveograph values (stretch-resistance, stretch, degree and rate of deformation, ratio of stretch-resistance to stretch), extensometer values (work required to stretch dough, stretch-resistance, stretch, ratio of stretch-resistance to stretch), bread-making characteristics (weight of bread, volume of bread and specific volume). The same values were also determined for non-irradiated wheat. Sufficient quantities of wheat were irradiated to permit analyses of samples after different periods of time had elapsed.

The analytical values were found to vary with dose, marked differences (with respect to the control sample) being noted in the texture, odour, colour and taste of bread made with wheat that had received the highest doses.

To determine changes in nutritional value the irradiated wheat was included in the diet of rats, both immediately following irradiation and after various periods of time had elapsed. The development of the rats, in particular that of their blood picture and bone marrow, was then closely followed.

ANALYSE PHYSICO-CHIMIQUE DES CARACTERISTIQUES GERMINATIVES ET NUTRITIVES DU BLE IRRADIE. Dans leur plan de travail, les auteurs ont prévu l'irradiation de blé à des doses diverses en vue de déterminer les effets physiques et chimiques sur les grains et la farine, le comportement du blé en tant que semence et sa valeur alimentaire. Ils ont utilisé la variété Sureña M. A.G., qui est cultivée en Argentine et dont des échantillons avaient été fournis par l'Office national de céréales. Pour l'irradiation, ils se sont servi d'un appareil canadien Gammacell 220, de 13 000 Ci de cobalt-60, fournissant une dose d'environ 1 Mrad/h. Des irradiations ont été effectuées aux doses suivantes: 10, 15, 20, 50, 100, 150, 200, 300, 500, 1000, 1500 et 2000 krad.

On a analysé les échantillons irradiés pour déterminer les valeurs suivantes: a) pour le blé entier: poids d'hectolitre, humidité, protéines en pour cent (base azote multipliée par 13.5), Zeleny, cendres, pouvoir germinatif (deux et trois jours); b) pour la farine: humidité, protéines (base azote multipliée par 13.5), Zeleny, cendres, acido-alcoolique, maltose, gluten humide, gluten sec; procédés utilisés: farinographie (absorption d'eau, temps de formation de la pâte, degré d'élasticité, valorimètre de Brabender), alvéographie (ténacité, extensibilité, travail de déformation, rapport ténacité/extensibilité), extensimétrie (force, résistance, extensibilité, rapport résistance/extensibilité), panification (poids du pain, volume du pain et volume spécifique). Parallèlement, il a été procédé aux mêmes mesures sur du blé non
irradié. Etant donné les quantités irradiées, on a pu conserver des échantillons en vue de procéder à l'analyse des mêmes paramètres après divers laps de temps.

Les diverses valeurs analysées ont accusé des variations en fonction de la dose. En ce qui concerne la texture, l'odeur et le goût du pain, les doses les plus fortes ont engendré des différences très sensibles par rapport à l'échantillon témoin.

Pour déterminer la valeur alimentaire du grain irradié, les auteurs en ont inclus dans la ration alimentaire de rats, aussi bien après l'irradiation et, par la suite, à divers intervalles. On a suivi l'évolution des animaux et plus particulièrement celle de leur système sanguin et de leur moelle osseuse.

**ФИЗИЧЕСКИЕ И ХИМИЧЕСКИЕ АНАЛИЗЫ СВОЙСТВ РОСТА И ПИТАТЕЛЬНЫХ КАЧЕСТВ ОБЛУЧЕННОЙ ПШЕНИЦЫ.** Пшеницу облучали различными дозами с целью определить химическое и физическое влияние облучения на целое зерно (его поведение как семени) и муку (пищевая ценность).

В опыте использовали разновидность пшеницы Sureña M. A. G., культивируемой в Аргентине, она была поставлена Национальной организацией по пшенице. Был применен прибор канадская гамма-камера 220 с источником кобальт-60, мощностью 13 000 кюри, способным давать дозу приблизительно 1 мрад/час.

Пшеницу облучали дозами 10, 15, 20, 50, 100, 150, 200, 300, 500, 1000, 1500 и 2000 килорад.

Были определены следующие аналитические величины: a) по зерну — вес 1 гектолитра, влажность, процент протеина (содержание азота х 13,5), цифра Zeleny, содержание золы, способность к прорастанию (2 и 3 дня); b) по муке — влажность, процент протеина (содержание азота х 13,5), цифра Zeleny, содержание золы, алкогольная кислотность, содержание соледоватого сахара, содержание жидкой клейковины, фаринографические величины (поглощение воды, время развития, степень пористости, шуп для измерения влажности). Для определения изменений в питательных свойствах, пшеницу облученную в варианте максимальной дозы, было облучено с тем, чтобы можно было осуществить анализ образцов по истечении различных периодов времени.

**ANALÍSIS FISICOQUÍMICO DE TRIGO IRRADIADO: ESTUDIO DE SUS CARACTERÍSTICAS GERMINATIVAS Y NUTRICIONALES.** El plan de trabajo contempló la irradiación de trigo a distintos niveles de dosis, a fin de determinar los efectos físicos y químicos sobre grano entero y harina, su comportamiento como semilla y su valor alimenticio. Se utilizó la variedad Sureña M. A. G., que se cultiva en la República Argentina, suministrada por la Junta Nacional de Granos. Se empleó para irradiar un GammaCell 220 (Canadiense) provisto de 13 000 Ci de cobalto-60 y que provee una dosis aproximada de 1 Mrad/h. Se han realizado irradiaciones a los siguientes niveles de dosis: 10, 15, 20, 50, 100, 150, 200, 300, 500, 1000, 1500 y 2000 kradi.

Se determinaron los siguientes valores analíticos de las muestras irradiadas: a) Sobre trigo entero: peso hectolitrico, humedad, proteínas por ciento (base nitrógeno por 13,5), Zeleny, cenizas, energía germinativa (2 y 3 días), b) Sobre harina: humedad, proteínas (base nitrógeno por 13,5), Zeleny, cenizas, acidez alcohólica, maltosa, gluten húmedo, gluten seco, farinógrafo (comprende: absorción de agua, tiempo de desarrollo de la masa, grado de aflojamiento, valorímetro Brabender), alveógrafo (comprende: tenacidad, extensibilidad, trabajo de deformación, relación tenacidad/extensibilidad), extensógrafo (comprende: energía, resistencia, extensibilidad, relación resistencia/extensibilidad), panificación (comprende: peso del pan, volumen del pan, y volumen específico). Paralelamente se realizaron las mismas determinaciones con trigo sin irradiar. Las cantidades irradiadas permitieron conservar muestras para realizar los análisis de los mismos parámetros luego de transcurrido el lapso determinado.

Se apreciaron distintas variaciones en los valores analíticos determinados, variaciones que dependían de la dosis. En cuanto a la textura, color y sabor del pan, se observaron diferencias sumamente marcadas respecto al testigo, para las dosis más elevadas. Para evaluar el valor alimenticio del grano irradiado, se emplearon ratas a las cuales se les incluyó en la dieta dicho material. La incorporación se
realizó inmediatamente después de la irradiación, y con posterioridad a lapsos variables. Se controló la evolución de los animales y fundamentalmente el cuadro hemático y médula ósea.

Hace aproximadamente un año y medio llegó a nuestro país una misión conjunta FAO-OIEA con el objeto de analizar las posibilidades de instalar en la República Argentina una planta experimental de desinfección de granos por irradiación, para poder estudiar, entre otros puntos, los aspectos económicos de estos procesos.

Como consecuencia del arribo de esta misión surgió la necesidad de determinar el comportamiento de nuestras variedades de granos frente a las radiaciones ionizantes, motivo por el cual se llevó a cabo este plan de trabajo.

Dicho plan de trabajo, con respecto a los granos irradiados, se ha dividido en tres puntos fundamentales.

a) el conocimiento de las propiedades fisicoquímicas;

b) el estudio de las características germinativas;

c) su valor alimenticio y comestibilidad.

En un plan de largo alcance se ha previsto trabajar con los cereales que se cultivan en nuestro país. De todos ellos se decidió comenzar con el trigo, dada su importancia por la extensión del área sembrada y el volumen de producción, considerándose necesario estudiar por lo menos tres de sus variedades tipo: trigo blando, semiduro y duro.

Para el punto a) se han planeado las siguientes determinaciones, contando con la colaboración de los Laboratorios especializados de la Junta Nacional de Granos:

Para trigo: peso hectolítrico; humedad; proteínas totales; Zeleny; cenizas.

Para harina: humedad; proteínas totales; Zeleny; cenizas; acidez alcohólica; maltosa (azúcares reductores); gluten (húmedo y seco): farinógrafo (absorción de agua, tiempo de desarrollo, grado de aflojamiento y valorímetro Brabender); alveógrafo (tenacidad, extensibilidad, trabajo de deformación); panificación (peso del pan, volumen y volumen específico del mismo).

Para desarrollar el punto b) se investigó el comportamiento del grano irradiado como semilla, evaluando la energía y poder germinativos. En otro aspecto se observó la evolución de la planta propiamente dicha.

Para el punto c), contando con la colaboración del Instituto de Hematología y del Centro de Radioisótopos de los Institutos Nacionales de la Salud, se estudió el valor alimenticio de los granos irradiados sobre ratas de la raza Wistar, reemplazando en su alimentación habitual los hidratos de carbono por harina y detritus provenientes de trigo irradiado, y manteniendo un adecuado equilibrio proteico, mineral, vitamínico e hídrico, en el resto de la alimentación.

Para los animales en estudio se ha dispuesto una serie de análisis físicos, hemáticos, orgánicos e histológicos. Se investigó además su capacidad de reproducción y desarrollo de las crías.

Se comparó su evolución con animales testigos en los que se mantuvieron las mismas características alimenticias, pero con granos sin irradiar.

Se trató también de profundizar el conocimiento del problema citado
por varios autores sobre la llamada energía residual o remanente y su posible acción sobre las propiedades de los alimentos irradiados.

A tales efectos se proyecta realizar todas las determinaciones citadas en este plan con granos recién irradiados y, a continuación, con sucesivos lotes sometidos a diferentes períodos de almacenamiento.

Se requiere una suma de valores para establecer, respecto de cada parámetro, no sólo el umbral de dosis en el cual algunos cambios comienzan a manifestarse, sino también cuál sería el tiempo óptimo de almacenamiento, para la desaparición de posibles efectos desfavorables.

Para desarrollar este plan la CNEA cuenta, desde el año pasado, con un irradiador Gammacel 220 canadiense, cargado con una fuente de cobalto-60 de aproximadamente 13 000 Ci, de geometría cilíndrica y que suministra una dosis cercana de 1 Mrad/h. El aparato dispone de una cámara de irradiación de las siguientes dimensiones: 20 cm de alto y 15 cm de diámetro, o sea un volumen útil de aproximadamente 3400 cm³, permitiendo una distribución de dosis que varía entre 80 y 120%.

Con el fin de lograr una dosis uniforme, se acondicionaron los granos de cada carga en dos bolsas de polietileno, cuya capacidad es aproximadamente el doble del correspondiente al volumen de los granos propiamente dicho.

Al transcurrir la primera mitad del tiempo total de irradiación se interrumpió y se procedió a la agitación del cereal dentro de dicha bolsa, aprovechando el exceso de volumen disponible y reanudando luego la irradiación, hasta completar el tiempo necesario para cada dosis.

Para efectuar una comprobación de la homogeneidad de la dosis suministrada se ubicaron en diversas bolsas de prueba, junto con los granos, pequeños dosímetros de Fricke, entre los cuales, una vez concluida la irradiación, no se encontraron diferencias mayores que 5%.

En la primera parte de este trabajo, se llevó a cabo la irradiación de cinco series, abarcando las siguientes dosis: 10, 15, 20, 50, 100, 150, 200, 300 y 500 krad.

Se empleó trigo de la variedad Sureña MAG, seleccionado por los expertos de la Junta Nacional de Granos, que constituye un tipo de trigo semiduro.

La cantidad de trigo irradiado en los diferentes niveles de dosis fue suficiente para realizar los ensayos fisicoquímicos y germinativos (aproximadamente 4,5 kg) correspondientes a los puntos a) y b). En cada caso se realizaron simultáneamente las determinaciones con un trigo testigo sin irradiar.

Además, la cantidad irradiada para cada dosis y en cada una de las cinco series, permitía el duplicado de las evaluaciones, transcurrido cierto lapso.

Posteriormente, ante ciertas tendencias que parecían manifestarse en los resultados inicialmente obtenidos se resolvió efectuar otras cinco series con dosis más elevadas. En esta oportunidad se suministraron las siguientes dosis: 200, 500, 1000, 1500 y 2000 krad, trabajando en condiciones y cantidades similares a las experiencias anteriores.

Aunque todavía no se pueden extraer conclusiones definitivas, del análisis de los resultados obtenidos, pueden observarse ciertas tendencias en algunos de los parámetros estudiados, tal como se indica a continuación:

**Zeleny:** Se puede observar en la figura 1 que entre 0 y 2000 krad los valores de este parámetro disminuyen hasta un 50% del valor del testigo. La reproducibilidad de este método es bastante bueno dado que, como se
observa, la desviación tipo prácticamente no supera el 5% de los valores parciales. El hecho de que los valores para harina sean paralelamente menores que para trigo se debe a que en la molienda del grano para harina la extracción es mayor y, por lo tanto, la cantidad de gluten presente, proporcionalmente por unidad de peso, es menor. Estos valores de Zeleny se expresan en ml de una probeta tipo.

Maltosa: Coincidiendo con otros autores, se nota en los valores de maltosa una tendencia al aumento con la dosis. Esto indicaría un incremento de los azúcares reductores en el trigo irradiado, que justificaría entre otras cosas el aspecto exterior de los panes preparados con estas harinas. Si bien puede hablarse de una tendencia, como se observa en la figura 2, no se pueden sacar conclusiones muy firmes puesto que se cuenta con un grado apreciable de dispersión en los valores obtenidos.

Farinógrafo: a) Absorción de agua: prácticamente no hay variación definida. Las oscilaciones que se observan en la figura 3 pueden englobarse dentro del error experimental. b) Tiempo de desarrollo: este parámetro, vinculado al gluten, disminuye notablemente con la dosis, obteniéndose para 2000 krads aproximadamente la tercera parte del valor testigo, como se observa en la figura 4. El acortamiento del tiempo de desarrollo indicaría una disminución de la calidad del trigo; se podría decir, coincidiendo con otros autores, que la irradiación, sobre todo a altas dosis, llevaría un trigo del tipo semiduro, como es el tratado, a las características de un trigo blando. c) Grado de aflojamiento: se han tomado valores a los 10 y 12 min, ambos con neta tendencia a aumentar, hasta que, a altas dosis, sus valores prácticamente coinciden, como se observa en la figura 5. Relacionado con el tiempo de desarrollo, indica el castigo sufrido por el grano a dosis elevadas. d) Valorímetro Brabender: también este parámetro, índice de calidad, disminuye con la dosis a un valor prácticamente del 50% del testigo entre 0 y 2000 krads, como se observa en la figura 6.

Alveógrafo: De los parámetros determinados con el alveógrafo se observa lo siguiente: a) La figura 7 indica que la tenacidad (P) disminuye, aunque sin una tendencia definida. b) La extensibilidad (G) también disminuye, aunque en forma irregular, puesto que entre 0 y 1000 krads su variación está dentro de los límites del error del método, y a partir de ese valor muestra una caída brusca (figura 8). La representación de la relación P/G en función de la dosis (figura 9) no presenta mayores cambios debido a la compensación de los parámetros anteriores. c) El trabajo de deformación (W) muestra una disminución definida a partir de 300 krads, alcanzando valores del 50% del testigo para 2000 krads (figura 10).

Panificación: La figura 11 muestra lo siguiente: el peso del pan, como es lógico, no presenta variación, mientras que el volumen del mismo y por ende el volumen específico, prácticamente no varían hasta los 500 krads; a partir de esta dosis comienzan a disminuir gradualmente. En el aspecto cualitativo se nota, con el aumento de la dosis, una disminución de la calidad del pan y los ojos en las migas tienden a disminuir de tamaño. Miga y costra se oscurecen, sobre todo por encima de 500 krads y aunque el sabor, hasta esta dosis, no acusa variaciones apreciables, por encima de ella se notan cambios desfavorables.

Los demás parámetros citados no presentan variaciones de consideración. Como se dijo, aún no se pueden obtener conclusiones definitivas, puesto que todavía no se tienen suficientes datos de peso estadístico,
FIG. 1. Variación de la determinación de Zeleny (para trigo y harina) en función de la dosis

FIG. 2. Aumento de maltosa (azúcares reductores) en función de la dosis
así como tampoco se han analizado, por falta material de tiempo, otras variedades de trigo.

Sin embargo, en general, se observa un efecto perjudicial en las propiedades del trigo y especialmente de la harina. Estos efectos parecen materializarse principalmente en las características fisicoquímicas y coloidales del gluten y del almidón. Por debajo de 200 krad no parecen notarse estos cambios, aunque está previsto un análisis más exhaustivo en dicha zona puesto que, como se observa en las figuras indicadas, existen fluctuaciones notables de los parámetros analizados en bajas dosis.

Si bien los valores totales de gluten y proteínas no sufren modificaciones, diversas determinaciones parecen demostrar, sobre todo por encima de 200 krad, una cierta degradación en las propiedades tensioelásticas del gluten. Esto se afirma en las disminuciones que sufre el Zeleny, el tiempo de desarrollo, los valores Brabender, la extensibilidad y el trabajo de deformación, y en el aumento del grado de aflojamiento.

Todo este conjunto de acciones sobre el gluten, sumadas a efectos similares sobre el almidón, conducen a una harina que a medida que aumenta la dosis recibida va adquiriendo caracteres desfavorables. Tales efectos se manifiestan, organolépticamente, en su color oscuro y su olor desagradable, y especialmente en sus características panaderiles, tal como se muestra en las figuras 3, 4, 5 y 6.
FIG. 7, 8, 9 y 10. Variación de los parámetros deducidos del alveograma en función de la dosis.
como se observa por ejemplo en la disminución del volumen específico y el aspecto de los panes elaborados.

Por otra parte, cabe señalar que el fuerte y desagradable olor de la harina se atenúa bastante en el pan elaborado. Este último presenta un notable oscurecimiento en su costura, sobre todo por encima de 500 krad, que presumiblemente puede estar vinculado al aumento de azúcares reductores.

En lo que respecta al punto b), la energía germinativa se determinó colocando las semillas en las condiciones de humedad y temperatura habituales. Se evaluó al cabo de dos, tres y cinco días el porcentaje de semillas germinadas.

En la figura 12 se observa una notable disminución a partir de los 200 krad, anulándose la germinación, para las observaciones a los dos días, a partir de los 1000 krad, y para las observaciones a los tres y cinco días, prácticamente a partir de los 1500 krad.

Para conocer el desarrollo de la planta a partir de estas semillas irradiadas, se las sembró en arena. Pudo observarse que las plantas originadas de las semillas que recibieron 10 y 15 krad adquirían un mayor desarrollo que el correspondiente al testigo, pero a partir de este valor la evolución fue disminuyendo, hasta anularse el crecimiento de las plantas provenientes de semillas irradiadas por encima de 200 krad. Las semillas obtenidas de estas plantas serán sembradas para estudiar su evolución, repitiéndose esta operación a través de varias generaciones. Se proyecta efectuar estudios genéticos en cada una de estas etapas en nuevas series a irradiar.

Para el estudio del punto c) se utilizaron ratas de la variedad Wistar de una edad promedio de ciento treinta días, cuyo peso promedio era de 320 g para las hembras y 350 g para los machos. El lote en observación ha sido dividido en dos subgrupos, cada uno de los cuales estaba integrado por igual número de machos y hembras.

Se hace notar que el total de los animales utilizados para este trabajo formaba parte de un lote mayor, que fue previamente estudiado de modo exhaustivo, incluso órganos y funciones hematopoyéticas, además de su evolución ponderal; durante este período, fueron alimentados con los mismos pellets que luego recibirían, pero elaborados con harina y detritus sin irradiar.

Para la preparación de dichos pellets se obtuvo, por gentileza de la compañía que elabora los que se utilizaban en su alimentación habitual, el suministro de la misma mezcla, a la que se le introdujeron pequeñas variaciones, desprovista de la fracción hidrocarbonada. Esta mezcla, que representa el 60% del total, contiene harina de avena, harina de pescado, minerales y vitaminas A, D y E en proporciones adecuadas para proveer un balance dietético útil. Se completó el 40% restante con harina de trigo en estudio, más detritus de ese trigo, en la proporción adecuada para asegurar el aporte de glúcidos y de vitaminas del llamado grupo B, para complementar el equilibrio metabólico total. Tras un período con esta dieta y verificada la normal evolución de los animales, se comenzó entonces a administrarles los pellets preparados con harina proveniente de granos irradiados.

En las primeras experiencias se han utilizado granos que han recibido una dosis de 2 krad, con un intervalo entre la irradiación y la ingestión de 48 h.
FIG. 11. Peso y volumen del pan en función de la dosis

FIG. 12. Porcentaje de semillas germinadas a diferentes tiempos en función de la dosis
Al cabo de cinco días de alimentación con grano irradiado, se tomó para su estudio el primer sublote. Para obtener la muestra de sangre, siempre luego de 3 h de ayuno, se los anestesió con éter bajo campana, tomando el material de la cola. Con la muestra de sangre obtenida, se efectuaron frotis para determinar la fórmula leucocitaria, previa tinción con Wright; posteriormente se realizó el recuento de leucocitos y de plaquetas, como así también un hematocrito y dosaje de hemoglobina. Transcurridos 14 d de comenzada la experiencia, se llevó a cabo el mismo conjunto de operaciones con el segundo sublote. A los 30 d, en idénticas condiciones, se obtiene una tercera muestra con el primer sublote y a los 45 días, la cuarta muestra con el segundo sublote. Las tomas de muestras se hacen sobre sublotes alternados, para dejar transcurrir un tiempo suficiente, a fin de que el animal se reponga del proceso inflamatorio que supone la cicatrización de la cola y evitar que esto modifique los resultados obtenidos.

Una vez cumplidos los 3 meses se sacrifica el total de animales. Llegados a esta etapa, además del pasaje y los análisis ya mencionados, se estudian hígado, bazo, médula ósea y ganglios, se aprecian el peso y aspecto de los mismos, y se realizan estudios histológicos de todos ellos. Para complementar los datos anteriores, se lleva a cabo un fraccionamiento protéico por electroforesis y finalmente un estudio histocqumico de la serie blanca.

Todas estas series de parámetros se repetirán a diferentes dosis mayores y menores a la dosis inicial y con distintos intervalos entre la irradiación y la ingestión.

En cuanto a esta parte del plan presentado, no se tiene aún un número suficiente de animales estudiados, por lo que no se pueden obtener conclusiones que permitan aseverar o negar modificaciones que potencialmente pudieran producirse, pero que de comprobarse serán comunicadas oportunamente.

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BIBLIOGRAFÍA

DISCUSSION

A. R. DESCHREIDER: I was interested to hear that you found some improvement in the baking properties of wheat receiving low radiation doses. Did you carry out these studies on soft, semi-hard and hard wheat?

J. PAHISSA-CAMPA: No, only on semi-hard wheat.

J. C. SOMOGYI: Did you observe any change in the organoleptic properties of the bread made from irradiated wheat? If so, at what dose?

J. PAHISSA-CAMPA: Changes in colour were noted at above 300 krad, but virtually no changes in aroma or taste occurred until 500 krad. Above this dose level conditions changed abruptly and we noted strong, disagreeable aromas and tastes.

J. C. CAUSERET: Your programme of research on animals seems very ambitious. Will this work be carried on with rats that are initially 130 days old and weigh 300-350 g? Normally, younger rats are used for this kind of study; if possible, they are taken immediately after being weaned in order to allow for the particular sensitivity of the growing organism to possible toxic factors.

J. PAHISSA-CAMPA: We began our investigations on adult rats with a view to working out suitable techniques and analysing the possible effects on animals of this type. We intend to work with younger animals in the future and to evaluate their growth curves. We also intend to follow the development, over at least four generations, of the offspring of the experimental animals.
PROBLEM OF INDUCED RADIOACTIVITY IN FOOD PRODUCTS. Radioactivity induced by irradiation of foods is caused by the interaction of high-energy radiation with nuclei of food elements. The induced activity is a function of the applied energy, the dose, the sample thickness and the chemical composition of the food. A prime condition for a prediction of the radioactivity induced by irradiation is therefore the knowledge of the chemical composition of the sample. Suitable experimental methods of food analysis are described.

Electron and gamma rays are equivalent in the production of induced radioactivity. In the energy range of 0.05 to 10 MeV induced radioactivity is due to stimulation of isomers in \((y, y')\)-reactions. In this range the \(^{107}\)Ag\((y, y')^{107m}\)Ag-reaction is responsible for the greatest part of the induced activity. Using a new simplified method of calculation the expected induced radioactivity is estimated, and it is concluded that the activity of these isomers presents no health hazard.

By the same method the induced radioactivity in the energy range above 10 MeV, where besides \((y, y')\) reactions the possibility of \((y, n)\) reactions exists, is calculated for the principal foodstuffs. Methods for experimental verification of calculated activities are discussed. The magnitude of induced radioactivity due to single elements is compared with the total maximal permissible concentration (MPC) of nuclides in foods \((10^{-7} \mu\text{Ci/g food})\). Factors which determine the maximum permissible radiation energy and dose are discussed.
Научная работа посвящена исследованию наведенной радиоактивности в пищевых продуктах. Описываются соответствующие экспериментальные методы анализа образцов пищевых продуктов.

Электроны и гамма-лучи играют одинаковую роль в образовании наведенной радиоактивности. В диапазоне энергий от 0,05 до 10 МэВ наведенная радиоактивность вызывается стимулирующей изомериями в \((\gamma, \gamma')\) - реакциях. В данном энергетическом диапазоне большая часть наведенной активности приходится на дочерний реакция серебро-107 \((\gamma, \gamma')\) серебро-107. С помощью нового упрощенного метода вычисляется ожидаемая наведенная радиоактивность, причем делается вывод, что активность этих изомеров не представляет опасности для здоровья.

Таким же методом вычисляется наведенная радиоактивность в основных пищевых продуктах в энергетическом диапазоне выше 10 МэВ, где помимо \((\gamma, \gamma')\) - реакций, имеется возможность прохождения \((\gamma, n)\) реакции. Обсуждаются методы экспериментальной проверки полученных таким образом величин активности. Величина наведенной активности, вызванной отдельными элементами, сравнивается с общей максимально допустимой концентрацией (МДК) изотопов в пищевых продуктах (10^-7 кюри/г). Обсуждаются факторы, определяющие максимально допустимую энергию излучений и дозу.

При облучении пищевых продуктов электронами или гаммаЛучами в продуктах возникает наведенная радиоактивность. Она возникает при взаимодействии радиации с ядрами элементов в пищевых продуктах. Действия гамма-излучения и электронов при вызывании наведенной радиоактивности одинаковы: действие электронов определено главным образом возникающими в продукте тормозным спектром. Процессы в ядрах похожи на процессы возбуждения и ионизации в электронных оболочках. При возбуждении нуклонов может возникнуть радиоактивное изомерное состояние; при превращении ядра в большинстве случаев возникает радиоактивное дочернее ядро.

Методы определения наведенной радиоактивности были описаны в последних годах рядом авторов, главным образом Глассом и Рочерсом. Экспериментальное определение наведенной радиоактивности в большинстве случаев очень трудно, так как результирующий спектр излучения очень сложный. Порядок наведенной радиоактивности в зависимости от примененной энергии облучения, как правило, определяется путем математического расчета. Число активации определено следующим уравнением:

\[
A = \sum_{Mx} N_M \int_{\nu M}^{\nu 0} \sigma_M (\nu) F(\nu) d(\nu)
\]
с следующими обозначениями:
\[ N_M \] — число атомов элемента \( M \);
\[ \sigma_M(\nu) \] — сечение реакции радиации на элементе \( M \);
\[ F(\nu) \] — тормозной спектр;
\[ \nu_M \] — частота;
\[ \nu_1, \nu_0 \] — предельные частоты.

Решение этого главного уравнения можно облегчить обсуждением отдельных выражений. Сперва можно ограничить число рассмотренных реакций. Как видно на табл. 1, возникают при энергиях облучения

<table>
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<tr>
<th>Область энергии [МэВ]</th>
<th>Возможные ядерные процессы</th>
<th>Обсужденный процесс</th>
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<tr>
<td>( 1 \leq E \leq 5 )</td>
<td>( (\gamma, \gamma') ), ( (\gamma, p) ), ( (\gamma, \alpha) ), ( (\gamma, n) )</td>
<td>( (\gamma, \gamma') )</td>
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<tr>
<td>( 5 &lt; E &lt; 25 )</td>
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\( E < 1 \text{МэВ} \) только \( (\gamma, \gamma') \)-реакции. И в пределе энергии \( 1 < E < 5 \text{МэВ} \) порядок радиоактивности можно определить при обсуждении \( (\gamma, \gamma') \)-реакции. При энергиях облучения \( E > 5 \text{МэВ} \) достаточно обсуждение \( (\gamma, \gamma') \) и \( (\gamma, n) \)-реакций. При применении этих реакций для отдельных элементов пищевых продуктов возникают радиоизотопы (табл. 2). Обсуждением отдельных временных полураспада можно также ограничить число рассмотренных элементов. Как видно на рисунке, все-таки большинство элементов необходимо рассмотреть. Главное предположение для предсказания наведенной радиоактивности в зависимости от энергии облучения таким образом является элементарное составление продукта. Концентрации всех элементов с порядковым числом \( Z \geq 12 \) легко всего определяются при помощи метода рентгеновской флуоресценции. Концентрации всех других элементов можно определить с хорошей точностью при помощи горения продуктов в определенных газовых потоках и применением методов впитывания (макро-Деннстедт). Дальнейшее упрощение уравнения активации невозможно. Рассмотрим сперва проблему наведенной радиоактивности в пределе энергии \( E < 10 \text{МэВ} \). Как показано выше, радиоактивность в этой области можно определить по вероятностям изомерных процессов. Так как радиоактивность изомеров очень мала, достаточно для принципиальной оценки наведенной радиоактивности в этой области энергии определение самой большой возможной активности.

В табл. 3 сопоставлены все изотопы, в которых могут возникнуть изомерные состояния с временами полураспада \( \tau > 10 \text{сек} \). Пищевые продукты большинство этих элементов не содержат. Концентрация всех других элементов в пищевых продуктах почти одинаковы в порядке
ТАБЛИЦА 2. ГЛАВНЫЕ СВОЙСТВА ИНТЕРЕСУЮЩИХ ЭЛЕМЕНТОВ В ПИЩЕВЫХ ПРОДУКАХ

<table>
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<th>Реакция</th>
<th>Концентрация изотопа</th>
<th>Уровень энергии [МэВ]</th>
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<td>H</td>
<td>8 г</td>
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<td>20,4 мин</td>
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<td>N14(γ, n) N13</td>
<td>99,6</td>
<td>10,5</td>
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<td>O16(γ, n) O15</td>
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<td>15,6</td>
<td>2 мин</td>
</tr>
<tr>
<td>O</td>
<td>80 г</td>
<td>K38(γ, n) K38</td>
<td>93,1</td>
<td>13,1</td>
<td>7,7 мин</td>
</tr>
<tr>
<td>K</td>
<td>300 мг</td>
<td>Na23(γ, n) Na22</td>
<td>100</td>
<td>12,1</td>
<td>2,6 г</td>
</tr>
<tr>
<td>Na</td>
<td>100 мг</td>
<td>Ca46(γ, n) Ca39</td>
<td>97</td>
<td>15,1</td>
<td>1 сек</td>
</tr>
<tr>
<td>Ca</td>
<td>100 мг</td>
<td>P32(γ, n) P30</td>
<td>100</td>
<td>12,1</td>
<td>2,5 мин</td>
</tr>
<tr>
<td>P</td>
<td>100 мг</td>
<td>S32(γ, n) S31</td>
<td>95</td>
<td>14,7</td>
<td>3 сек</td>
</tr>
<tr>
<td>S</td>
<td>100 мг</td>
<td>Cl35(γ, n) Cl34m</td>
<td>75,5</td>
<td>12,8</td>
<td>33 сек</td>
</tr>
<tr>
<td>Cl</td>
<td>100 мг</td>
<td>Mg24(γ, n) Mg23</td>
<td>78</td>
<td>16,5</td>
<td>12 сек</td>
</tr>
<tr>
<td>Mg</td>
<td>50 мг</td>
<td>Fe54(γ, n) Fe53</td>
<td>5,84</td>
<td>13,8</td>
<td>8,9 мин</td>
</tr>
<tr>
<td>Fe</td>
<td>50 мг</td>
<td>Zn64(γ, n) Zn63</td>
<td>48,9</td>
<td>11,6</td>
<td>38,3 мин</td>
</tr>
<tr>
<td>Zn</td>
<td>10 мг</td>
<td>Cu65(γ, n) Cu62</td>
<td>69,1</td>
<td>10,9</td>
<td>10 мин</td>
</tr>
<tr>
<td>Cu</td>
<td>0,1 мг</td>
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<td>30,9</td>
<td>9,8</td>
<td>12,8 час</td>
</tr>
<tr>
<td>Mn</td>
<td>0,2 мг</td>
<td>Mn58(γ, n) Mn54</td>
<td>100</td>
<td>10</td>
<td>290 дн</td>
</tr>
<tr>
<td>Co</td>
<td>0,001 мг</td>
<td>Co59(γ, n) Co58</td>
<td>100</td>
<td>10,2</td>
<td>71,3 дн</td>
</tr>
<tr>
<td>Al</td>
<td>0,4 мг</td>
<td>Al27(γ, n) Al26</td>
<td>100</td>
<td>12,8</td>
<td>8 105 г</td>
</tr>
<tr>
<td>As</td>
<td>0,01 мг</td>
<td>As75(γ, n) As74</td>
<td>100</td>
<td>10,1</td>
<td>17,5 дн</td>
</tr>
<tr>
<td>J</td>
<td>0,005 мг</td>
<td>J127(γ, n) J126</td>
<td>100</td>
<td>9,1</td>
<td>13,3 дн</td>
</tr>
<tr>
<td>F</td>
<td>0,1 мг</td>
<td>F19(γ, n) F18</td>
<td>100</td>
<td>10,4</td>
<td>112 мин</td>
</tr>
<tr>
<td>Si</td>
<td>1,0 мг</td>
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<td>12,5</td>
<td>4,5 сек</td>
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<tr>
<td>Ag</td>
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<td>Ag109(γ, γ') Ag109m</td>
<td>51,35</td>
<td>0,094</td>
<td>44 сек</td>
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<tr>
<td>Sr</td>
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<td>48,65</td>
<td>0,087</td>
<td>39 сек</td>
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<tr>
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<td>Sr87(γ, γ') Sr87m</td>
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<td>Ba133(γ, γ') Ba133m</td>
<td>6,6</td>
<td>0,269</td>
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<tr>
<td>Sn</td>
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<td>Ba137(γ, γ') Ba137m</td>
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<td>0,662</td>
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<tr>
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<tr>
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<td>Sn119(γ, γ') Sn119m</td>
<td>8,62</td>
<td>0,089</td>
<td>250 дн</td>
</tr>
</tbody>
</table>

1 мг/кг. Так как все пищевые продукты похожи на чистую воду, то и F(ν)-распределение для всех продуктов приблизительно одинаковое. Самое большое число активаций найдем поэтому у того элемента, для которого вероятность активации самая большая. Вероятность возбуждения изомерного состояния зависит от разности квантовых чисел интересующих уровней. Для определения вероятности активации изо-
Таблица 3. Изомеры с временами полураспада τ > 10 сек

| Изотоп   | $E_m$ (МэВ) | $\tau$ (с)  | Квантовые числа $|l_m|$, $|l_n|$ |
|----------|-------------|-------------|------------------|
| 34 Sc$^{77m}$ | 0,162       | 17,5 сек    | $7/2^+$, $1/2^-$ |
| 39 Y$^{89m}$  | 0,913       | 14 сек      | $9/2^+$, $1/2^-$ |
| 45 Rh$^{106m}$ | 0,040       | 57 сек      | $7/2^+$, $1/2^-$ |
| 47 Ag$^{107m}$ | 0,094       | 44 сек      | $7/2^+$, $1/2^-$ |
| 47 Ag$^{109m}$ | 0,087       | 39 сек      | $7/2^+$, $1/2^-$ |
| 38 Sr$^{87m}$   | 0,390       | 2,8 час     | $1/2^-$, $9/2^+$ |
| 77 Kr$^{103m}$  | 0,080       | 11,9 дн.    | $11/2^-$, $3/2^+$ |
| 36 Kr$^{83m}$   | 0,042       | 114 мин     | $1/2^-$, $9/2^+$ |
| 48 Cd$^{111m}$  | 0,395       | 48 мин      | $11/2^-$, $1/2^+$ |
| 52 Te$^{123m}$  | 0,248       | 104 дн.     | $11/2^+$, $1/2^-$ |
| 52 Te$^{125m}$  | 0,145       | 58 дн.      | $11/2^-$, $1/2^+$ |
| 54 Xe$^{129m}$  | 0,236       | 8 дн.       | $11/2^-$, $1/2^+$ |
| 54 Xe$^{131m}$  | 0,164       | 12 дн.      | $11/2^-$, $3/2^+$ |
| 41 Nb$^{50m}$   | 0,030       | 3,7 г       | $1/2^-$, $9/2^+$ |
| 49 In$^{112m}$  | 0,390       | 1,73 час    | $1/2^-$, $9/2^+$ |
| 56 Sr$^{135m}$  | 0,269       | 29 час      | $11/2^-$, $3/2^+$ |
| 50 Sr$^{137m}$  | 0,662       | 2,6 мин     | $11/2^-$, $3/2^+$ |
| 42 Hf$^{178m}$  | 0,375       | 19 сек      | $1/2^-$, $9/2^+$ |
| 50 Sn$^{117m}$  | 0,320       | 14 дн.      | $11/2^-$, $1/2^+$ |
| 50 Sn$^{119m}$  | 0,089       | 250 дн.     | $11/2^-$, $1/2^+$ |
| 78 Pd$^{190m}$  | 0,255       | 3,6 час     | $13/2^-$, $1/2^+$ |
| 80 Hg$^{199m}$  | 0,526       | 42 мин      | $13/2^+$, $1/2^-$ |

мерного состояния необходимо обсуждение полной системы энергетических уравнений. Можно показать, что вероятность активации изомерного состояния у элементов первой группы больше, чем у элементов других групп. Так как в числе элементов этой группы только серебро возможный элемент пищевых продуктов, оценка самой большой возможной активации в пределы энергии $E < 10$МэВ возможна на примере обоих Ag-изотопов. Активации обоих Ag-изомеров серебро-107 м и серебро-109 m почти одинаковы.

Для одного отдельного элемента решение главного уравнения активации сравнительно легко. Число $N_M$ известно, $\sigma(N)$-функцию можно определить по теории Брейта-Вигнера, $F(v)$-функция – по теории Зоммерфельда. Тормозной спектр легче всего вычисляется по методу Блохина. Так можно показать, что максимальная активация пищевых продуктов при облучении электронами или гамма-излучением в пределах энергии $E < 10$ МэВ лежит в порядке $10^{-8}$ мккюр/г пищевого продукта для дозы облучения 5 Мрад и практически однородном облучении всего продукта. Даже эта максимальная радиоактивность вполне безопасна.
<table>
<thead>
<tr>
<th>Продукт</th>
<th>C</th>
<th>O</th>
<th>N</th>
<th>K</th>
</tr>
</thead>
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<td>Картофель</td>
<td>4,31·10^{-23}</td>
<td>30,0·10^{-23}</td>
<td>0,1331·10^{-23}</td>
<td>85,5·10^{20}</td>
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<td>0,211</td>
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<td>17,7</td>
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<td>-</td>
<td>-</td>
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<td>Fe</td>
<td>P</td>
<td>Cl</td>
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<td>Mn</td>
<td>Zn</td>
<td>Co</td>
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Таблица 4. (продолжение)

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<th>$J$</th>
<th>$F$</th>
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<td>$2,21 \cdot 10^{17}$</td>
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<td>$-\quad$</td>
<td>$8,52$</td>
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Радиоактивности других важных изомеров в пищевых продуктах, как стронций-87 m, цинк-119 m и барий-135 m лежат в порядке $10^{-9}$ мккюр/г или ниже. Фактор безвредности наведенной радиоактивности при облучении в описанной области энергии дается в порядке $10^{-12}$. Как показано выше, в области энергии облучения выше 10 Мэв оценка наведенной радиоактивности возможна при рассмотрении ($\gamma$, $n$)-реакции. Числа $N_m/100$ г всех обычных пищевых продуктов показаны в табл. 4. $\sigma(\nu)$-функции всех интересующих элементов в литературе опишены. Сопоставление этих значений в зависимости от энергии показано в табл. 5. Описанной теорией Зоммерфельда также можно определить распределение $F(\nu)$ в области энергии 10 — 22 Мэв. Этими данными можно по генеральному уравнению активации определить число активации $A$ для каждого элемента и таким образом и результирующую радиоактивность для каждого продукта. Экспериментальное определение числа активации отдельного элемента легко возможно при помощи реакции $\text{Li}^7(p, \gamma)\text{Be}^8$, при которой выходит интенсивное 17,6 Мэв-гамма-излучение.

Средние удельные активации тех элементов, которые дают главную часть результирующей активации продуктов, показаны на рисунке. На рисунке, кроме того, показаны числа средней естественной активности пищевых продуктов и сегодняшнее выпадение по стронцию-90. Для облегчения изображения показаны только активации при 22 Мэв и вблизи пограничной энергии. Между ними предложена линейная зависимость. Видно, что только активация отдельных элементов превышает при всех энергиях естественную радиоактивность. Все они короткоживущие изотопы с временем полураспада короче 1 часа. Легко можно показать, что результирующая активация по крайней мере в первые 5 часов после облучения снижается на порядок естественной активации. После этого времени интересны только еще долгоживущие изотопы. Для этих изотопов также легко можно определить результирующий фактор безопасности. Принципиально необходимо сказать, что безопасность облучения нельзя определить при помощи факторов безвредности для каждого отдельного элемента. Необходимо учесть наличие всех наведенных радиоактивностей. В случае смеси радиоизотопов необходимо сравнить
результатирующая радиоактивность с максимально допустимой активацией суточной пищи в порядке $10^{-4}$ мккюри. Пример такого сравнения показан в табл. 6. Показанные числа радиоактивности относятся к 22 Мэв. Предположено, что все пищевые продукты облучены максимально допустимой дозой при этой энергии. Таким образом, была определена результатирующая максимальная радиоактивность для средней европейской пищи. Очевидно, что только 5 дней после облучения результатирующая радиоактиви-

ТАБЛИЦА 5. СЕЧЕНИЯ РЕАКЦИИ ($\gamma$, $\alpha$) [см$^2$] ПРИ РАЗНЫХ ЭНЕРГИЯХ

| Мэв   | C   | O   | N   | K   | Na   | Fe$^{54}$ (5,8%) |
|-------|-----|-----|-----|-----|------|-----------------
| 10    |     |     |     |     |      |                 |
| 11    |     |     |     |     |      |                 |
| 12    |     |     |     |     |      |                 |
| 13    |     |     |     |     |      |                 |
| 14    |     |     |     |     |      |                 |
| 15    |     |     |     |     |      |                 |
| 16    |     |     |     |     |      |                 |
| 17    |     |     |     |     |      |                 |
| 18    |     |     |     |     |      |                 |
| 19    |     |     |     |     |      |                 |
| 20    |     |     |     |     |      |                 |
| 21    |     |     |     |     |      |                 |
| 22    |     |     |     |     |      |                 |

Погорн. макс. 21,35(13,5) 22. 24(2,88) 18,25(13,4) 18,4(13,1) 18

<table>
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<tr>
<th>Мэв</th>
<th>Fe$^{56}$ (92%)</th>
<th>P</th>
<th>Cl (75,4%)</th>
<th>Cu$^{65}$ (31%)</th>
<th>Cu$^{63}$ (68,9%)</th>
<th>Mn</th>
</tr>
</thead>
<tbody>
<tr>
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<td></td>
<td></td>
<td>1,24</td>
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<tr>
<td>11</td>
<td>5,05</td>
<td></td>
<td>5,9</td>
<td>1,38</td>
<td>6</td>
<td></td>
</tr>
<tr>
<td>12</td>
<td>5,05</td>
<td></td>
<td>9,9</td>
<td>8,26</td>
<td>13</td>
<td></td>
</tr>
<tr>
<td>13</td>
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<td>2,2</td>
<td>0,3</td>
<td>14,9</td>
<td>17,2</td>
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<td>22,6</td>
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<td>20,5</td>
<td>31,0</td>
<td>40</td>
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<tr>
<td>15</td>
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<td>7,7</td>
<td>2,26</td>
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<td>51,5</td>
<td>60</td>
</tr>
<tr>
<td>16</td>
<td>54,4</td>
<td>11,3</td>
<td>4,15</td>
<td>38,4</td>
<td>65,4</td>
<td>85</td>
</tr>
<tr>
<td>17</td>
<td>64,0</td>
<td>14,9</td>
<td>6,94</td>
<td>48,4</td>
<td>73,6</td>
<td>95</td>
</tr>
<tr>
<td>18</td>
<td>65,8</td>
<td>17,9</td>
<td>10,3</td>
<td>55,2</td>
<td>74,4</td>
<td>102</td>
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<tr>
<td>19</td>
<td>61,8</td>
<td>20,0</td>
<td>13,6</td>
<td>59,2</td>
<td>64</td>
<td>105</td>
</tr>
<tr>
<td>20</td>
<td>47,8</td>
<td>19,9</td>
<td>9,65</td>
<td>53,9</td>
<td>46,8</td>
<td>96</td>
</tr>
<tr>
<td>21</td>
<td>28,0</td>
<td>16,0</td>
<td>7,40</td>
<td>37,8</td>
<td>24,8</td>
<td>80</td>
</tr>
<tr>
<td>22</td>
<td>10,1</td>
<td>10,1</td>
<td>6,10</td>
<td>22,0</td>
<td>11,7</td>
<td>60</td>
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</table>

Погорн. макс. 11,1 12,1 12,8 9,6 10,9 10

18 19,4(20,3) 19 19 17,5(76) 19
Таблица 5 (продолжение)

<table>
<thead>
<tr>
<th>№</th>
<th>Co</th>
<th>Zn(^{64}) (51%)</th>
<th>Zn(^{65}) (27,3%)</th>
<th>As</th>
<th>J</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>10</td>
<td>9</td>
<td>13,5</td>
<td>85</td>
<td>0,20</td>
<td></td>
<td></td>
</tr>
<tr>
<td>11</td>
<td>13</td>
<td>7,24</td>
<td>30</td>
<td>150</td>
<td>1,80</td>
<td></td>
</tr>
<tr>
<td>12</td>
<td>27</td>
<td>13,1</td>
<td>46,5</td>
<td>240</td>
<td>2,10</td>
<td></td>
</tr>
<tr>
<td>13</td>
<td>41</td>
<td>19,8</td>
<td>67,5</td>
<td>346</td>
<td>2,14</td>
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<td>14</td>
<td>60</td>
<td>93,5</td>
<td>406</td>
<td>2,58</td>
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<td></td>
</tr>
<tr>
<td>15</td>
<td>96</td>
<td>81,5</td>
<td>318</td>
<td>3,00</td>
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<td></td>
</tr>
<tr>
<td>16</td>
<td>125</td>
<td>72</td>
<td>290</td>
<td>3,30</td>
<td></td>
<td></td>
</tr>
<tr>
<td>17</td>
<td>60</td>
<td>10,3</td>
<td>54,5</td>
<td>114</td>
<td>3,48</td>
<td></td>
</tr>
<tr>
<td>18</td>
<td>41</td>
<td>33,5/</td>
<td>64</td>
<td>3,50</td>
<td></td>
<td></td>
</tr>
<tr>
<td>19</td>
<td>27</td>
<td>49</td>
<td>20</td>
<td>3,40</td>
<td></td>
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<td>13</td>
<td>8,5</td>
<td>4</td>
<td>3,17</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Погр. макс.</td>
<td>10,2</td>
<td>11,6</td>
<td>11,1</td>
<td>10,1</td>
<td>9,1</td>
<td>10,4</td>
</tr>
<tr>
<td>21</td>
<td>17</td>
<td>19</td>
<td>16</td>
<td>15,2(450)</td>
<td>19,5(3,5)</td>
<td></td>
</tr>
</tbody>
</table>

![Graph showing the relationship between MC and Zn concentration](image)

Давление наведенных радиоактивностей отдельных радионуклидов с естественной радиоактивностью. Толщина образца продукта — 5 см, доза — 5 Мрад.
ТАБЛИЦА 6. ОПРЕДЕЛЕНИЕ ФАКТОРА БЕЗВРЕДНОСТИ ПРИ ОБЛУЧЕНИИ ЦЕЛОЙ ПИЩИ МАКСИМАЛЬНО ДОПУСТИМЫМИ ДОЗАМИ (22 Мэв)

<table>
<thead>
<tr>
<th>Элемент</th>
<th>t</th>
<th>Результирующая активация, мккюри</th>
<th>после облучения</th>
<th>после 3 дней</th>
<th>после 7 дней</th>
</tr>
</thead>
<tbody>
<tr>
<td>24Na</td>
<td>15 час</td>
<td>4,9·10⁴</td>
<td>1,5·10⁵</td>
<td>~10⁷</td>
<td></td>
</tr>
<tr>
<td>43K</td>
<td>22,4 час</td>
<td>0,8·10⁴</td>
<td>1,0·10⁵</td>
<td>~10⁷</td>
<td></td>
</tr>
<tr>
<td>64Cu</td>
<td>12,8 час</td>
<td>0,4·10⁴</td>
<td>6,4·10⁻⁴</td>
<td>4·10⁻⁵</td>
<td>~10⁻⁸</td>
</tr>
<tr>
<td>67Cu</td>
<td>58,5 час</td>
<td>0,3·10⁴</td>
<td>1,5·10⁻⁵</td>
<td>~10⁻⁶</td>
<td></td>
</tr>
<tr>
<td>32P</td>
<td>24,4 дн.</td>
<td>4·10⁻⁶</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>32P</td>
<td>14,2 дн.</td>
<td>2·10⁻⁵</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>22Na</td>
<td>2,58 г</td>
<td>1·10⁻⁵</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>106J</td>
<td>13,3 дн.</td>
<td>0,4·10⁻⁵</td>
<td>7,6·10⁻⁵</td>
<td>7,6·10⁻⁵</td>
<td></td>
</tr>
<tr>
<td>65Zn</td>
<td>245 дн.</td>
<td>0,1·10⁻⁵</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>54Mn</td>
<td>291 дн.</td>
<td>0,1·10⁻⁵</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>55Fe</td>
<td>2,6 г</td>
<td>1·10⁻⁹</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Σ: са. 7,2·10⁻⁴ 1,2·10⁻⁴ 0,8·10⁻⁴

Радиоактивность изомеров

<table>
<thead>
<tr>
<th>Изотоп</th>
<th>Half-life</th>
<th>Radioactivity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ag⁵⁷m</td>
<td>44 сек</td>
<td>10⁻⁶</td>
</tr>
<tr>
<td>Ag⁵⁸m</td>
<td>39 сек</td>
<td>10⁻⁵</td>
</tr>
<tr>
<td>Sr⁸⁷m</td>
<td>2,8 час</td>
<td>10⁻⁷</td>
</tr>
<tr>
<td>Ba¹³⁵m</td>
<td>29 час</td>
<td>10⁻⁷</td>
</tr>
<tr>
<td>Ba¹³⁷m</td>
<td>2,6 мин</td>
<td>10⁻⁷</td>
</tr>
<tr>
<td>Sn¹¹⁷m</td>
<td>14 дн</td>
<td>10⁻⁹</td>
</tr>
<tr>
<td>Sn¹¹⁹m</td>
<td>250 дн</td>
<td>10⁻¹⁰</td>
</tr>
</tbody>
</table>

Радиоактивность ниже допустимой радиоактивности. Так можно показать, что радиоактивность долгоживущих изотопов нельзя генерально не учесть. Все-таки можно в заключение сказать, что наведенная радиоактивность облученных пищевых продуктов не главная проблема облучения.

DISCUSSION

N. GETOFF: From your paper it may be concluded that only silver and beryllium can be activated by ⁶⁰Co gamma rays. Since the cross-sections for the (γ, γ') and (γ, n) nuclear reactions are extremely low for all other nuclides under these conditions, I take it that they are of no practical importance. Is this so?

T. TUCHSCHERER: Yes, that is correct.
RADIATION RESISTANCE OF ENZYMES IN FOODS IRRADIATED AGAINST MICROBIAL DAMAGE

K. VAS
JOINT FAO/IAEA DIVISION OF ATOMIC ENERGY IN AGRICULTURE, INTERNATIONAL ATOMIC ENERGY AGENCY, VIENNA, AUSTRIA

Abstract — Résumé — Аннотация — Resumen

Most enzymes which play a role in the storage, processing and preservation of food are rather resistant to ionizing radiations. Generally speaking, their in situ radio-resistance is about an order of magnitude higher than that of the microorganisms causing spoilage or public health hazards. Thus, radiation doses adequate to microbiological stabilization, and at present considered just feasible economically, are insufficient to prevent enzymatic deterioration.

Many attempts have already been made to inactivate enzymes in food by radiation but, judging by the relative failure of most of these efforts, much more background information seems to be necessary to deal with the problem on a more rational basis.

To date, work in radiation enzymology has, to a large extent, been carried out in systems of medical interest, generally giving results not readily transposable to food systems.

In the past (a) the mechanism of inactivation, as well as the roles of (b) enzyme concentration, (c) water activity of the medium, (d) oxygen concentration, (e) pH and (f) temperature, have been studied most intensively. This is reviewed in the paper. Since, in the majority of the reported experiments, the degree of purity of the enzyme has not been stated (or known, for that matter, to the authors themselves), and since, on the other hand, radio-modifying substances are known to exert a decisive influence on the radiation inactivation of enzymes, it is felt that much more work is still needed on radio-protectors and radiation sensitizers in combination with highly-purified enzymes.

The usual great radio-sensitivity of high-purity enzymes and the contrasting extreme resistance of enzymes in the tissues and in their unpurified extracts certainly indicate the need for finding the reasons for this difference in order to facilitate possibly a rational approach of controlling enzyme activity in food irradiation.

In this way, perhaps some novel "combination method" can eventually be developed in addition to the combined methods which have already been put forward to control enzyme action, i.e. combining in-radiation (a) with heating, (b) with refrigeration and (c) with physiological methods (e.g. control of glycogenolysis) the status of all of which is briefly discussed in the paper.

RADIORESISTANCE DES ENZYMES DANS LES DENREES ALIMENTAIRES IRRADIEES POUR LES PROTEGER CONTRE LES ALTERATIONS DUES A DES BACTERIES. La plupart des enzymes qui jouent un rôle dans l'emmagasinage, la préparation et la conservation des denrées alimentaires possèdent une certaine résistance aux rayonnements ionisants. D'une manière générale, leur radio-résistance in situ est supérieure d'un ordre de grandeur environ à celle des micro-organismes qui causent des altérations ou présentent des risques pour la santé publique. Ainsi, les doses de rayonnements suffisantes pour assurer une stabilisation microbiologique — et considérées actuellement comme se situant à la limite de la rentabilité — sont insuffisantes pour empêcher la détérioration par les enzymes.

Maintes tentatives ont déjà été faites pour rendre inactifs, au moyen de rayonnements, les enzymes contenus dans les aliments ; cependant, à en juger par l'échec relatif de la plupart d'entre elles, il semble qu'il faille réunir beaucoup plus de données de base pour s'attaquer au problème d'une façon plus rationnelle. Jusqu'à présent, les études relatives à la radioenzymologie ont porté en grande partie sur des systèmes présentant un intérêt médical, ce qui donnait généralement des résultats qui n'étaient pas aisément transposables sur le plan des denrées alimentaires.

Dans le passé, on s'était avant tout penché sur a) le mécanisme de l'inactivation, ainsi que sur le rôle de b) la concentration des enzymes, c) l'activité de l'eau contenue dans le milieu considéré, d) la teneur en oxygène, e) le pH et f) la température. Le mémoire passe en revue ces travaux. Etant donné que la plupart des communications relatives aux expériences effectuées n'indiquent pas le degré de pureté de l'enzyme (d'ailleurs inconnu des auteurs eux-mêmes) et puisque, d'autre part, on sait que les substances
radiomodificatrices exercent une influence déterminante sur la radioinactivation des enzymes, l'auteur estime qu'il faudrait entreprendre des études plus poussées sur les radioprotecteurs et les radiosensibilisateurs avec des enzymes fortement purifiés.

La grande radiosensibilité qui caractérise ordinairement les enzymes très purs et, par conséquent, l'extrême résistance des enzymes dans les tissus et dans leurs extraits non purifiés, démontrent la nécessité de déterminer les raisons de cette différence, ce qui facilitera sans doute la mise au point d'une méthode, rationnelle permettant de contrôler l'activité des enzymes dans le cadre de l'irradiation des aliments.

De cette manière, on pourrait peut-être mettre au point une «méthode mixte» indûte, laquelle viendrait s'ajouter aux méthodes combinées qui ont déjà été élaborées pour le contrôle de l'action des enzymes; en d'autres termes, on combinerait l'irradiation avec a) le traitement thermique, b) la réfrigération et c) les méthodes physiologiques (par exemple, contrôle de la glycérogénolyse). Le mémoire fait brièvement le point des applications de ces divers procédés.

**RADIATION ENZYMES STABILITY IN FOOD PRODUCTS, EFFECTS OF RADIATION PROTECTION AND RADIATION SENSITIZERS ON ENZYMES.**

Most enzymes, which have a certain importance during storage, processing, and conservation of food products, are quite resistant to ionizing radiation. Generally, their resistance in situ is usually about one order of magnitude higher than that of microorganisms that cause deterioration or harm to food products. Thus, doses of irradiation sufficient for microbiological stabilization, and currently considered economical, are not sufficient for preventing enzyme deterioration.

Many attempts have been made to render enzymes in food products inactive by irradiation, but judging by the relative failure of most of these attempts, it is necessary to study these general aspects more in order to approach this problem more rationally.

Radioenzymological studies conducted so far had in their great majority medical purposes; it is not easy to extrapolate their results to the conservation of food products.

The most studied questions were: a) the mechanism of inactivation and its role, b) enzyme concentration, c) water activity in the medium, d) the concentration of oxygen, e) pH and f) temperature. The report contains an overview of these works. Since in most published works, data relative to the degree of enzyme purity (or not known by the authors) and, on the other hand, known that radioactive substances play a decisive role in enzyme inactivation, it is considered necessary to conduct great works in the field of radiation protective substances and radiation sensitizers with highly purified enzymes.

Thus, by this way, it may be possible over time to develop a new "combined method," in addition to the combined methods, which were already proposed for controlling the action of enzymes, i.e., a combination of irradiation 1) with heating, 2) with cooling, and 3) with physiologic methods (for example, control of glycogenolysis), works with which are currently focused in the report.

**RADIATION RESISTANCE OF ENZYMES IN IRRADIATED ALIMENT.**

The major part of the enzymes act during the storage, the conservation and the irradiation of the food products are resistant to radiation. By general, this resistance to its proper medium is superior in order of magnitude to that of microorganisms that cause the decomposition or the alteration of the aliments. Due to this, doses of irradiation sufficient for the stabilization microbiological and in which the application is considered as a real economic, do not impede the deterioration caused by the enzymes.

So far, had been many times inactivate by irradiation the enzymes of the food products, but to judge by the sad the major part of the works focused, it is necessary to study more and more under the aspects of the cuestion, to know how to abate the problem of a different way. The studies radioenzymological realized until now focus on the major part of finalizations medical, are not as easy extrapolate its results to the conservation of the food products.

The questions studied are: a) the mechanism of inactivation and the paper that desempeña, b) the concentration of the enzymes, c) the activity of the water in the medium, d) the concentration of oxygen,
e) el pH y f) la temperatura. En la memoria se examinan todos estos puntos. Como en la mayoría de los experimentos publicados no se indica el grado de pureza de la enzima (desconocido a veces por los mismos autores) y como por otra parte se sabe que las sustancias radiomodificadoras ejercen una influencia decisiva sobre la radioinactivación de las enzimas, el autor considera necesario reunir muchos más datos sobre los agentes radioprotectores y radiosensibilizadores en relación con enzimas de alta pureza.

El contraste entre la elevada radiosensibilidad que suelen tener las enzimas de gran pureza y la extremada resistencia que se observa en ellas cuando se encuentran en los tejidos o en extractos sin purificar, indica la necesidad de averiguar las causas del fenómeno, lo que permitiría quizás enfocar mejor el problema de la inactivación de esos agentes.

Es posible que entonces se encuentre un «método combinado» parecido a los que se han propuesto ya para reducir la acción de las enzimas: irradiación combinada a) con un tratamiento térmico, b) con la refrigeración o c) con métodos fisiológicos (control de la glicogenólisis, por ejemplo). En la memoria se examina cada uno de estos métodos.

It is interesting to note that, in spite of the generally recognized importance of enzymes in food, comparatively little is known of the action of ionizing radiations on these agents. In his excellent review, Siu [1] about a decade ago concluded that, since research on radioresistance of enzymes has been largely restricted to the non-food areas, much more attention should be focused on the behaviour of enzymes in food irradiation, a field which is "attractively inviting".

It is to be regretted that, since then, the advice of Dr. Siu has been given due consideration in only a limited number of published experiments. The usually very high radioresistance of in situ tissue enzymes may seriously interfere with the success of radurization and radappertization treatments in foods of both animal and plant origin. Cathepsins, and other proteolytic enzymes, may induce softening and eventual liquefaction of irradiated and otherwise microbiologically stable meat and fish products; other enzymes can cause severe changes in texture, colour and other organoleptic characteristics of radurized fruits and vegetables. A number of enzymological changes occur in potatoes and onions, radiation-treated to prevent sprouting during storage, and in other horticultural produce irradiated to control maturation. All of these are of great importance to the food technologist and, no doubt, deserve special attention.

The scope of this review has been restricted to enzyme behaviour in food tissues subjected to the influence of radiation applied with microbiological objectives in mind, i.e. radappertization, radurization and radicidation [2]. Time would not permit dealing with enzymic changes in foods irradiated to achieve other purposes, as e.g. control of sprouting, maturation, insect infestation, etc., that is, in commodities treated with very low doses (0.002 – 0.020 Mrad) of ionizing radiation.

To the best of the author's knowledge, the only monograph covering enzyme irradiation from the food technologist's point of view is that by Marples and Glew [3] (to which reference is made for all the literature on the subject published before 1958), while a number of books on food irradiation have appeared which gave shorter surveys on the subject [4-9]. Some lectures read before international conferences on food technology contained information on this problem (e.g. [10, 11].

It has to be stated again that, as before, interest in enzyme behaviour has mainly been shown by radiobiologists and medical researchers, and much less by food scientists. Thus, most of the results achieved to date are, in general, not readily transposable to food systems.
Excellent reviews on radiation effects on enzymes, as seen by the radiobiologist, the radiochemist and the radiophysicist, have appeared in the last few years [12-19] to which reference is made for extensive lists of pertinent literature. In view of the difficulties likely to be encountered in this very complex field, and of the fundamental ignorance existing, most workers felt compelled to use "uncomplicated" systems, pure substances and simple, single-solute enzyme solutions. A large body of information has been accumulated by this in vitro approach, but a still greater curiosity and need for data on the in vivo behaviour have been created simultaneously.

Work on simple systems has mainly been concerned with the interaction of radiations with enzymes, with the nature of the inactivation (destruction) curve and with the effects of enzyme concentration and of various environmental factors on enzyme inactivation by radiation.

Present evidence seems to indicate that the decrease in enzyme activity approximates a negative exponential function of the dose, whether irradiation is applied to dry preparations or to aqueous solutions. However, the mechanisms of inactivation in these two cases are quite different, as are the degradation products formed [13]. While direct action of radiation on the molecule seems to be the main cause of inactivation in the dry state, a major role is played by indirect action, i.e. by reactions between radiation-induced free radicals of the environment and the enzyme when in aqueous solution. Recent considerations concerning the effects of temperature and various additives on inactivation of dry enzyme preparations [18, 19] indicate that, besides ionization, excitation may play an important part in the direct inactivation of enzymes by ionizing radiations. The magnitude of the indirect effect can be determined by measuring the doses (\(D_i\)) necessary to reach a given degree (e.g. 63%) of inactivation, at various initial enzyme concentrations (\(D_c\) at concentration \(c\) g/ml) and in the pure substance (\(D_0\)). The ratio (\(\alpha\)) of the energy required to inactivate by indirect action over that required for direct action can be calculated from the equation:

\[
\alpha = \left(\frac{D_0}{D_c}\right) - 1\]

For enzyme solutions, \(\alpha\) usually possesses a high value, indicating the preponderance of indirect inactivation. Hence, between certain limits, the more dilute the enzyme solution, the smaller the dose needed to destroy the same percentage of initial enzyme activity, a phenomenon generally called the "dilution effect".

Since free radicals, formed in the solvent, play an important role in enzyme inactivation, changes in water activity (\(a_w\)) of the system influence radiation effects. It is likely that inactivation is maximal at a certain water activity corresponding to an optimum of \(\alpha\) at some intermediate water content level, as was recently shown for the radiation decomposition of SH compounds in English sole fillet at water contents varying from 2 to 72% [20]. Strongest destruction occurred at about 20 to 30% moisture where \(\alpha\) was highest. At lower water contents, direct action became predominant, while at higher moisture values, increasingly frequent recombination of free radicals reduced the efficiency of irradiation.

Wedemeyer [21] recently suggested a rather complete picture of the role of water (bound and free) in the interactions of ionizing radiations with
food, the latter being recognized as an aqueous system where water plays an all-important mediating role. In the opinion of the author, work on similar lines, but directly with enzymes, could shed some light on processes much in need of elucidation.

It is to be noted here that individual enzymes possess greatly differing sensitivities when irradiated in "pure" dilute solution under otherwise identical conditions. Thus, reported G-values (variously called "energy yield" or "chemical yield", i.e. number of molecules inactivated for 100 eV of energy deposited in the solution) vary from 0.009 (for catalase) to 0.55 (for carboxypeptidase). The exceptionally high value of G=1.20 has been reported recently [22] for dilute solutions of crystalline papain, which enzyme contains only a single essential SH group per molecule. For many enzymes the G-value has an average of a few hundredths of a molecule per 100 eV, which is fairly low as compared with G-values of ca. 4 for water. Recent results seem to indicate some energy dependence of the G-value in the case of horse-radish-peroxidase solutions irradiated with low-energy radiations. G-values of 0.0011 were measured below the photon energy level of 6.9 keV, and about double this (G=0.0025) at or above 6.9 keV [23]. No such effect could be observed for crystalline beef liver catalase solutions [24]. A word of caution seems to be appropriate here. Much confusion in the literature appears to be caused by the indiscriminate calculation of G-values for enzymes. If the decrease in enzyme activity is not a linear but an exponential function of the dose, then, naturally, G-values show a continuous decrease with higher doses. Therefore, the so-called "initial yield" is frequently calculated, a value proportional to the ratio of enzyme concentration to the D-value necessary to reach 63% inactivation [12, 22]. Since this only holds if the dose:enzyme activity relationship is strictly exponential, and no protective substances are present, and since the initial yield depends, in a certain range at least, on enzyme concentration, the significance of the G-value is fairly limited in the enzyme field. To avoid confusion, the word "initial" should always be used to refer to the way of calculation and all experimental conditions should always be stated.

Apparent G-values of enzymes dissolved in solutions, containing certain other substances, easily attacked by ionizing radiations, are even lower than those for pure enzyme solutions. It is mainly because of the presence of such "radioprotectors" that enzyme inactivation in impure solutions usually requires very high doses, usually well above the level of a few Mrad, for 90% inactivation (D≥2-5 Mrad). When this is considered in the light of the general experience that the D-value of even one of the most resistant microorganisms, Clostridium botulinum Type A, above pH 4.5 is only around 0.4 Mrad [25], and that for most Salmonella species and vegetative bacteria is much less: ca. 0.10 Mrad (up to 0.22 in low water-activity food [26]), it becomes readily understandable why residual enzyme activity presents such a problem in food preservation by irradiation. Recent results [27] indicate that proteolytic and lipolytic enzyme activity of lamb liver could not be completely destroyed by 40 Mrad. Alkaline phosphatase in bovine milk requires about 25 Mrad for practically "total" inactivation (D for 90% destruction ca. 17 Mrad [28]). Glutamic and pyruvic decarboxylase activities of wheat decrease to 50% by doses of ca. 3 Mrad, while no inactivation takes place at this dose level in the case of alpha-amylase [29]. Pectic enzymes in fruits [30] and from moulds
were found to be very resistant to radiation damage when present in situ, or in extracts.

As regards the effect of oxygen on radiation resistance of enzymes, a number of published data could detect increased radiosensitivity while others could not [3]. Recent results with dry ribonuclease [31] indicate a sensitizing action of \( O_2 \), as has been shown in earlier work on some other enzymes.

The effect of pH can be considerable (e.g. [22]) but not readily predictable, as results of experiments with trypsin, chymotrypsin, phosphoglyceraldehyde dehydrogenase and deoxyribonuclease suggest [3]. It is, therefore, necessary to keep the pH constant during irradiation and to state it when reporting.

The effect of temperature appears to be variable in degree but showing the general tendency of increased enzyme inactivation at higher temperatures. Irradiation in the frozen state usually causes only little damage to enzyme activity, which is thought to be partly due to a spatial immobilization of free radicals by the ice structure.

There is a difference between the energy yield (G-value) of enzymes exposed to radiations of differing linear energy transfer (LET) values. Densely ionizing \( \alpha \) particles appear to be less efficient enzyme inactivators due, probably, to the fact that frequent recombination of the produced, densely-spaced free radicals removes a considerable portion of the agents able to inactivate enzyme molecules.

As pointed out previously, inactivation efficiency of radiation may be altered to a very large extent by the presence of substances modifying the effect experienced in pure enzyme solutions. Some of these substances enhance; most of them, on the other hand, decrease the effectiveness of radiation (radiosensitizers and radioprotectors, respectively). While extensive literature on radioprotectors for the cell exists (for a summary see [32]), radiomodifiers for food enzymes have rarely been studied (for the earlier literature see [3]; some newer data can be found on amylase [33], alcohol dehydrogenase and urease [34], polygalacturonase [35], trypsin [36], catalase [37]). It is felt by the author that most of the contradictory quantitative data on inactivation dose values reported for the same enzyme could be accounted for if the degree of purity of the enzyme was known. The difficulty of obtaining "really pure" enzyme preparations, together with the actual lack of criteria for establishing the "pure" state of an enzyme, can easily explain this most disturbing situation.

It is, therefore, absolutely necessary to concentrate future work more on the elucidation of these aspects, by working with extremely purified enzyme preparations and evaluating the effects of impurities and substances normally accompanying the enzymes when present in their natural environments.

Better knowledge on this point would help to solve one of the perhaps most important problems in finding the explanation for the usually very large differences in radiosensitivity of enzymes in pure solutions and in the in situ state, respectively.

While thought to be one of the key problems, research on the role of protective agents in the cell is by no means the only question remaining to be clarified in this field.

It would be very interesting to know the "geographical" distribution of the enzymes within the cell and the actual local enzyme concentrations.
as opposed to over-all concentrations related to the whole cell or tissue. This would give some insight into the problem whether, and if, to what extent the "dilution effect" is operative in the cell. This may have connections with the problem of radiation-induced changes in "compartment membrane" permeability, since membrane-encapsulated enzymes may be released into other parts of the cell by radiation capable of changing the permeability of these membranes.

Basic knowledge of the effects of radiation-induced changes in the substrates on the activity of non-irradiated and of irradiated enzymes, respectively, would be extremely valuable, since it could contribute to the elucidation of the mechanism of action of irradiation on tissue cells in situ. Some unpublished, very recent results indicate that the activity of unirradiated pectic enzymes changes if acted upon by irradiated pectin solutions. Manalo [38] reported decrease in polygalacturonase activity and slight increase in pectin methyl esterase activity on irradiated pectin solutions. Reduction in polygalacturonase and no change in pectin methyl esterase action were observed as a result of irradiating the substrate by a group working at the International Atomic Energy Agency Laboratory [39].

Furthermore, the effect of the presence of substrate during irradiation of the enzyme should be investigated more thoroughly. In aqueous solutions, presence of substrate seems to increase radioresistance while a reduction appears to occur when dry enzyme-substrate complexes are irradiated [3].

It is still unclear whether irradiation inactivates the dissolved enzyme (a) by causing aggregation of it and, thereby, removing it from its normal sphere of activity, or (b) by directly damaging (destroying, blocking, etc.) the active enzyme surface.

A further question in need of clarification is whether in situ irradiation causes a general reduction of enzyme activity or whether it only changes the specificity of the enzyme, since it is known that enzymes exhibiting two or more biological functions may be damaged in a selective way, i.e. in only one of these functions. Thus, two activities of α-chymotrypsin can be differentially eliminated by radiation: the G-value for esterase activity is three times higher than that for protease activity [40]; radiation inactivation of the casein hydrolysis function of chymotrypsin is about twice as fast as that of its milk-clotting ability [41].

A problem of very great possible importance in heterogeneous systems such as the cell is the effect of association of the enzyme with cellular particulate matter on, and possible consequences of this fact to, its radiation sensitivity. Even simple physical adsorption of enzyme on cell wall material seems to increase its radioresistance. Recent investigations [42] showed that chemical coupling of papain with a synthetic polypeptide (poly-p-aminophenyl-alanine) to an enzymatically active, water-insoluble complex, resulted in a very marked increase in radioresistance. On the other hand, Wedemeyer's work on radiation effects on ascorbate adsorbed on cellulose [21] shows strong decrease of radiation resistance as compared with unadsorbed substance. This has been interpreted by the author as a result of some kind of energy transfer from cellulose to the adsorbed ascorbate. It is felt by the author that analogous experiments with enzymes would be highly interesting and very profitable.

Another important aspect to be investigated is the radiation effect on complex enzyme systems. Inactivation of one or more members of the
complex may bring about unbalanced actions of the unaffected enzymes, interfering with the normal metabolism of the cell. Information on this aspect seems to be completely lacking.

Better knowledge of these and similar basic phenomena would, no doubt, facilitate a rational approach to the control of enzyme activity in food irradiation. In this way, perhaps some new "combination treatment" can eventually be developed in addition to the combined methods which have already been put forward to deal with the problem.

Of these combined methods, heating and irradiation seem to be very obvious combination partners, since even the most radioresistant enzymes show high heat sensitivity. Thus, mild heat treatment coupled with moderate to high doses of radiation can solve a number of technological problems in the preservation of commodities where the fresh (uncooked) state is not an absolute requirement, especially in those cases where the food is not usually eaten in the uncooked state, as e.g. with meats. Pre-cooked pre-packaged meat, or ready-to-serve meals can thus be stabilized by this method [43]. Extensive studies showed that cooking or roasting to internal temperatures of 74-80°C to inactivate enzymes and a dose of 4.5 Mrad resulted in stable and acceptable pork and poultry meat after 9 to 24 months of storage at room temperature [44]. In the case of vegetables, Baker and Goldblith [45] found no synergistic effect of irradiation and heating on peroxidase inhibition in green beans. Doses of ca. 2.8 Mrad destroyed only 20 to 25% of enzyme activity when no heating was provided. Irradiation, applied before or after heat treatment, did not influence enzyme inactivation by heat appreciably.

Heat removal (refrigeration, cooling, freezing) plus radiation treatment represent a combination method which prevents not only excessive growth of microorganisms, surviving medium doses of ionizing radiations, but also the activity of undestroyed enzymes. At present, cooling plus irradiation seems to be the method of choice for the prolongation of the useful storage life of fresh fish, as well as of certain fruits and vegetables (e.g. strawberries, tomatoes, mushrooms etc.).

An ingenious physiological combination method to control proteolytic enzymes in irradiated raw meat has been developed by Zender et al. [46], Radouco-Thomas [47], Mouton [48]. They propose to inject the animal, shortly (e.g. 4 hours) before slaughter, with adrenalin. In this hormonal way, the pH of the tissues of the slaughtered animal is maintained at the original high level which prevents the action of enzymes responsible for autolysis. Microbiological stabilization of these tissues is then carried out, preferably by applying surface treatment with electron beams. While the author is not aware of any larger-scale tests of this method (the experiments reported by Howard and Lawrie [49] and Drake et al. [50] were not conclusive), it may be mentioned that Kuzin and Silaev [51] recently further developed the procedure by substituting adrenalin treatment for a short whole-body irradiation (0.00085 Mrad) of the animals (chicken) 24 hours before slaughter, generating adrenalin in the body by radiation stress.

In summary, it may be said that enzyme inactivation is still a stumbling block in the preservation of several food items by ionizing radiation. The need for solving the problem is clearly indicated and presents a challenge to food science and the technology of food irradiation, calling for more fundamental and applied research in the field. Special attention should
be paid to the still open questions, indicated in this review, which can be summarized as follows:

1. Enzymatic changes occurring in practically sterile foods, including isolation, purification and identification of the responsible agents, as well as clarification of pathways of reactions leading to the changes.

2. Radiation resistance of the above enzymes in the pure state and in situ, with the aim of elucidating the nature of radiation inactivation of enzymes, as well as the roles of environmental factors, especially those of radiomodifiers, of irradiation-induced changes in the substrates and of the factors deriving from the "structuredness" of those most heterogeneous physicochemical systems, commonly called food. Problems of differential inactivation of the various components of an enzyme complex, due to the varying sensitivities of individual enzymes, as well as of the distorted enzyme action caused by the above phenomenon, deserve special attention.

3. Practical utilization of the above knowledge, possibly in the form of some "combined methods" of radiation preservation.

In this connection, it may be mentioned that the Food Preservation Section of the Joint Division of Atomic Energy in Agriculture of the International Atomic Energy Agency and the Food and Agriculture Organization of the United Nations is trying to develop a worldwide network of research laboratories studying some of the above enzymological problems in a coordinated way, partly by means of research contracts supported by International Atomic Energy Agency funds, partly by free of charge research agreements between various laboratories and the Agency. It is hoped that progress in this important field can be accelerated by this means.

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DISCUSSION

R. Mouton: With regard to the differences in radiosensitivity between enzymes irradiated in the pure state and in the presence of their substrates, I should like to mention an original work that will be presented at the 3rd International Congress of Radiation Research to be held between 26 June and 2 July at Cortina d'Ampezzo, Italy. It is shown in this paper that a low radiation dose can activate the enzymatic macromolecule indirectly by modifying its regulation system at the molecular level.
MICROBIOLOGY, VIROLOGY AND QUARANTINE PROBLEMS

(Session IV)
MICROBIOLOGICAL PRINCIPLES IN FOOD IRRADIATION

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Abstract — Résumé — Аннотация — Resumen

MICROBIOLOGICAL PRINCIPLES IN FOOD IRRADIATION. This paper reviews the important microbiological objectives of irradiation treatments, with special reference to the definitions of the proposed new terms, radappertization, radicidation and radurization.

Emphasis is placed on the nature of the food in determining the microbiological requirements of the irradiation treatment. It is suggested that, just as with heat-processed foods, classifications into the major groups of "acid" or "cured" foods will remain valid with the irradiation process, and that different microbiological criteria will apply to these different classes of foods. The differences depend in part on the influence which the nature of the food has on the effectiveness of the irradiation treatment itself, but more especially on the way in which the nature of the food affects the activities of those microorganisms which might survive irradiation.

The principles used to calculate the appropriate doses of radiation are discussed, with comments on the reliability of the fundamental assumptions or the need for further experimentation.

The microbiological characteristics of irradiated foods are compared with those of corresponding heat-processed foods, to emphasize points of difference, with special reference to the appropriateness of suggested classifications for heat-processed foods.

Finally, some general difficulties are considered, such as uncertainty about the significance and behaviour of food-borne viruses, and about the significance of the mutations which might conceivably be induced in microorganisms surviving an irradiation process.

PRINCIPES DE MICROBIOLOGIE DANS L'IRRADIATION DES DENRÉES ALIMENTAIRES. L'auteur donne un aperçu des principaux objectifs microbiologiques des traitements par irradiation, en s'attachant plus spécialement aux définitions des nouveaux termes proposés: radappertisation, radicidation et radurisation.

Pour déterminer les exigences microbiologiques auxquelles devrait satisfaire le traitement par irradiation, il tient surtout compte de la nature des denrées en question. Il propose que, tout comme les denrées traitées par la chaleur, celles conservées par irradiation soient réparties en deux catégories principales, à savoir: denrées acidifiées et denrées traitées par d'autres procédés, et qu'à ces deux catégories s'appliquent des critères microbiologiques différents. Les différences dépendent partiellement de l'influence de la nature des denrées alimentaires sur l'efficacité du traitement par irradiation proprement dit, et plus particulièrement de la façon dont elle influe sur l'activité des micro-organismes pouvant survivre à l'irradiation.

L'auteur discute les principes sur lesquels repose le calcul des doses de rayonnement appropriées, en examinant le bien-fondé des hypothèses fondamentales ou la nécessité de procéder à des expériences plus poussées.

Les caractéristiques microbiologiques des denrées irradiées sont comparées aux caractéristiques correspondantes des produits traités par la chaleur, en vue de faire ressortir leurs différences, notamment pour déterminer si la classification proposée pour les denrées traitées par la chaleur reste valable.

Enfin, l'auteur examine certaines difficultés d'ordre général telles que l'incertitude qui subsiste quant au rôle et au comportement des virus propagés par les aliments et à l'importance des mutations qui pourraient être induites dans les micro-organismes survivant à l'irradiation.

МИКРОБИОЛОГИЧЕСКИЕ ПРИНЦИПЫ ОБЛУЧЕНИЯ ПИЩЕВЫХ ПРОДУКТОВ. Рассматриваются важные микробиологические цели обработки пищевых продуктов облучением со специальной ссылкой на определения вновь предложенных терминов: radappertisation, radicidation и radurisation.

При определении микробиологических требований к обработке облучением внимание обращается на характер пищевых продуктов. Предлагается, чтобы так же, как и в отноше-
нении обработанных термическим способом пищевых продуктов, классификация на две большие группы — "кислые" или "копченые" — сохранилась и в отношении обработки облучением, и чтобы различия микробиологические критерии применялись и к этим различным группам пищевых продуктов. Различия зависят частично от того влияния, которое характер пищевого продукта оказывает на эффективность самого процесса обработки облучением, однако в большей степени они зависят от того, как характер пищевого продукта влияет на активность тех микроорганизмов, которые могут не погибнуть при облучении.

В докладе обсуждаются принципы, использованные для определения целесообразных доз облучения, а также содержатся замечания относительно надежности основных предположений или необходимости проведения дальнейших экспериментов.

Микробиологические характеристики облученных пищевых продуктов сравниваются с характеристиками соответствующих пищевых продуктов, обработанных термическим способом, с тем, чтобы выявить основные различия с особым упором на приемлемость предложенных классификаций для пищевых продуктов, обрабатываемых термическим способом.

В заключение рассматриваются трудности общего характера, такие, как неопределенность относительно значения и поведения содержащихся в пищевых продуктах вирусов и относительно значения мутаций, которые можно вызвать в микроорганизмах, не погибающих в процессе облучения.

**PRINCIPIOS MICROBIOLOGICOS DE LA IRRADIACION DE ALIMENTOS.** La memoria trata de los importantes objetivos microbiológicos de la irradiación relacionándolos con las definiciones de los términos radappertización, radicidación y radurización, recientemente propuestos.

Al determinar lo que desde el punto de vista microbiológico se exige del tratamiento por radiación, el autor destaca la importancia de la naturaleza de los alimentos. Sugiere que, como en el caso del tratamiento térmico, en los procesos irradiatorios se siga utilizando la clasificación en "alimentos ácidos" y "alimentos curados", y que se apliquen criterios microbiológicos distintos a estas dos clases de alimentos. Las diferencias dependen, en parte, de la influencia que la naturaleza de los productos tratados tenga sobre la eficacia de la irradiación, pero principalmente de la manera en que afecte a la actividad de los microorganismos que pueden sobrevivir al tratamiento.

En la memoria se exponen los principios empleados para calcular las dosis adecuadas de irradiación y se hacen algunas observaciones sobre el valor de las hipótesis fundamentales y la necesidad de continuar los trabajos de experimentación.

Se comparan las características microbiológicas de los alimentos irradiados y de los sometidos a un tratamiento térmico para señalar las diferencias y determinar si la clasificación propuesta para los alimentos tratados por calor es apropiada.

Por último, se examinan algunas incógnitas, entre ellas la importancia y el comportamiento de los virus propios del producto alimenticio y la importancia de las mutaciones que las radiaciones pueden inducir en los microorganismos sobrevivientes.

**This paper aims to review the importance, in food preservation, of the microbiological effects of ionising radiation on microorganisms. It will not review the particular applications of irradiation, but is intended rather to take a general view, noting areas of special interest or difficulty.**

Regarding food preservation, two objectives can be broadly distinguished: to produce an indefinitely stable article, by destroying most, or ideally all, of the microorganisms in the food; or alternatively, to destroy only some of them, either to delay the onset of spoilage by microorganisms, or to eliminate a particular group important in public health. The types of process corresponding to these two broad objectives have for some time been called respectively irradiation sterilisation and irradiation pasteurisation.

These terms were not regarded with favour, however, by a recent international expert committee (1). It was objected that sterilisation by radiation is not at present practicable, since tolerable doses of radiation seem unlikely to kill many viruses, and doses of the magnitude actually envisaged might well leave a few bacteria also (cf. below). The state
attained would correspond nearly to that in the so-called "commercially sterile" foods which are in practice satisfactorily stable; and, as the type of heat process used for these foods is now widely called "appertisation", the name "radappertization" was proposed for the corresponding radiation process. It was objected, further, that the term radiation pasteurization is undesirably ambiguous, being applied indiscriminately to processes with two quite different objectives, one of public health significance the other not, which might well require different legislative treatment. Accordingly, two new terms were proposed for these two types of treatment. That aimed at organisms of public health significance was termed "radicidation" by analogy with "bactericide" etc.; and a process aimed for example at salmonellas was termed "Salmonella radicidation".

The type of process aimed simply at prolonged storage life was called "radurization", implying the idea of making the produce more durable. The advantages and disadvantages of these terms have been discussed elsewhere (1); so I here simply remark that, since these suggestions were published and alternatives invited, the committee has received none whatever. I shall accordingly use these terms as headings of major divisions of this paper.

**RADAPPERTIZATION**

Because Clostridium botulinum, in the form of spores, is the bacterial pathogen most resistant to radiation, it has long been understood that the first requirement of any process of the radappertization type must be to control this species by inactivating its spores.

Here the so-called 12-D concept has held the field for some time (2). It requires that the process shall inactivate Cl. botulinum spores by a factor of \(10^{-12}\), this factor being based on experience with heat processed foods. Factors of this order seem reasonable, where a single factory may heat-process \(10^9\) cans per year, each containing perhaps \(10^2\) grammes of food, an annual throughput of the order \(10^{11}\) gm. But one might question whether quite so high a safety factor is yet necessary for irradiated foods, with their much smaller volume of production.

It is generally agreed that such a degree of inactivation would require, with present techniques, radiation doses at least approaching 5 Mrads (3). These doses are so high as to cause, in most foods, undesirable changes in their organoleptic properties; and for this reason, besides economics, there is a strong incentive to use smaller doses.

Several approaches have been made to this problem.

The most obvious has been to add substances which would make the bacteria more sensitive to irradiation. No significant success has been achieved here, save with substances which would not be acceptable as food additives (4, 5, 6, 7), and no radiation sensitization of spores has been reported.

A second, more hopeful, approach has been to try to reduce the amount of organoleptic damage caused by high radiation doses. For example, the inclusion of packets of activated charcoal with the irradiated food absorbs the off-odours, in large measure, if there is an appreciable period of storage between irradiation and consumption (8, 9).

Another alternative is to irradiate the food in the frozen state. This technique, suggested in principle by Brasch & Huber (10, 11), was elaborated in my own laboratory (12) and has since been widely taken up.
in the U.S.A. It rested on the belief that the radiation sensitivity of Cl. _botulinum_ spores would be little affected by freezing, whereas the radiation damage to the food would be diminished by a factor of the order of 3; and, though subsequent work (e.g. 13, 14) shows that things are not so simple as we thought, it is now certain that there is a decisive advantage in irradiating in the frozen state; though this does nothing to relieve the economic problem, quite the opposite. Some investigators have gilded the lily by irradiating at temperatures near that of liquid air (15); but we have yet to see evidence that the advantages over operating at temperatures around -20°C are commensurate with the extra expense. It may be added that, though this technique minimises initial damage to the food on irradiation, it does not stop deterioration in storage, unless the food is maintained in the frozen state when there is little point in irradiating it at all.

Vegetative cells of bacteria, unlike their spores, are known to be protected by freezing (16, 17) to about the same degree as the organoleptic properties of food (18). Consequently, we expected that the more resistant vegetative bacteria (e.g. faecal streptococci) might survive doses of radiation sufficient to deal with spores of Cl. _botulinum_ in foods irradiated frozen, a possibility verified in practice (12, 19). If this protection of vegetative cells by freezing depends on the low activity of water in the system, one would expect a similar protection by drying, as is frequently observed (cf. 20, 21, 22); hence it is noteworthy that the unusual radiation resistance of faecal streptococci is now raising questions about the adequacy of current radiation doses in sterilising dry pharmaceuticals (23, 24).

Besides this, some bacteria are known to be likely to survive irradiation doses about 5 Mrads, e.g. Micrococcus _radiodurans_ (25) and similar organisms (26), even when irradiated under normal conditions; what their radiation resistance might be when irradiated frozen, nobody has yet troubled to enquire. Fortunately, so far as known, they are harmless, and so heat sensitive that they would be probably destroyed by the comparatively light heat treatment regarded as needed to prevent enzymic degradation (e.g. 27) in foods intended for long storage.

Combination with more severe heat treatment is another conceivable way of sterilizing while avoiding the extreme effects of either heat or radiation alone. With Cl. _botulinum_ spores, it is an advantage to irradiate first, because this makes the spores somewhat more sensitive to the subsequent heating (28). This procedure has not attracted much interest, however, perhaps because the advantages scarcely justify the large capital investment implied.

A last way of trying to escape the requirement for high radiation doses has been to try to discredit the 12-D concept altogether; for example, by alleging that foods do not in fact receive heat processes of the indicated order _F_0 = 3 (29). This argument seems to me largely misconceived. In the United Kingdom at least, foods known to be particularly susceptible to spoilage by putrefactive anaerobes receive heat processes far in excess of this, even up to _F_0 = 10; and, though it may be contended that such a process is not necessary to achieve safety from Cl. _botulinum_, no commercial operator could stand the spoilage which reduction of the process would entail, even if he cared to take the risk. In fact reports have appeared (30) showing that, on several occasions, inocula of 10⁶ Cl. _botulinum_ spores survived doses approaching 4 Mrads, which does not suggest that a dose of 4½-5 Mrads provides an excessive margin of safety.
What should especially be realised is that all the above arguments apply only to particular foods in which *Clostridium botulinum* is likely to multiply. It has long been clear that with acid foods, or salted foods, the 12-D concept is either inapplicable altogether, or requires drastic modification; and, since these points might be regarded as novel discoveries in relation to irradiation, they may bear further elaboration.

**Acid Foods:**

It is well established that *Clostridium botulinum* will not grow and develop toxin in foods more acid than pH about 4.5 (31), hence it has long been realised that the "botulinum cook" is not necessary for foods in this so-called "acid" category. The same will certainly apply, in general terms, to an irradiation process, though it is doubtful whether exactly the same pH value will be appropriate to delimit the boundary of the acid category. With the heat process, a contribution is made by the fact that the heat sensitivity of *Clostridium botulinum* spores is significantly increased as the pH approaches 4.5; it is not certain that the same applies equally to radiation sensitivity.

The principal difficulty in heat processing acid foods is to eliminate extremely heat-resistant species like *Bacillus stearothermophilus*. Work on the sterilization of pharmaceuticals (32) shows that this species is not outstandingly resistant to irradiation. On the other hand, while the yeasts and fungi otherwise likely to spoil these products are on the whole more resistant to irradiation than vegetative bacteria, they are comparatively easily killed by heating at about 60°C, (the heat-resistant spores of fungi like *Byssoclamys* might require special attention). There appears to be every prospect of successful application of a combined process of heat plus irradiation to foods of this type; and it is surprising that nobody has yet explored this possibility, as far as we know.

**Cured foods:**

In foods with more than about 10% salt, *Clostridium botulinum* will not grow any more than in foods with pH about 4.5. In such excessively salted foods, therefore, the process needed to make them safe from *Clostridium botulinum* would be "zero D". At the other end of the scale, perishable foods without salt require the full 12-D process, i.e. with heating to $F_0 = 3$. Extensive commercial experience, with heat-processed cured meats, shows that products containing about 5% salt (calculated on the water phase) are safe with processes about half this, of the order $F_0 = 1-1.5$. There is evidently a rough complementary relation between the concentration of salt in the food and the necessary heat process. Recent laboratory investigations (33, 34) indicate clearly that much the same will hold for radiation as for heat. At a rough guess from this analogy, about half the normal process — i.e. a dose about 2.5 Mrads — might give adequate protection against *Clostridium botulinum* in foods with about 5% salt, though it remains to be proved precisely that the percentage of salt has to be calculated on the basis of water content. This corresponds roughly with the dose indicated as adequate for bacon in U.S.A. (35); but the American workers do not appear to have appreciated that the relevant dose will depend critically upon the effective salt concentration in the bacon, since they do not mention this parameter in their publication. Earlier investigations suggested that 3 Mrad would give fairly good control of *Clostridium botulinum* if salt (2.5%) and either nitrate (0.1%) or nitrite (200 p.p.m.) were present (36).
The processing of large hams presents formidable difficulties of heat penetration. This is avoided with penetrating radiation, so that the heat process can be abbreviated to minimise shrinkage, if the two processes are used in combination as proposed in Denmark (37, 38). Some heat must be used, because the radiation produces organoleptic damage to an extent which keeps the tolerable dose below the level which would be bacteriologically adequate alone; and indeed, the proportion of radiation seems to have been too high in the process actually tested (39).

There is still much to learn about the complementary effects of curing salts and radiation. Work has been done with sodium chloride; but the interactions with nitrate and nitrite, and with pH and temperature, will also require scrutiny before the situation is properly understood. In this respect, however, our understanding of the heat process is not very much better (see e.g. 40) which has nevertheless not prevented its widespread application.

**Determination of critical radiation dosage**

The 12-D (and similar) concepts rest on the belief that (for a particular species) the radiation dose needed to achieve a tenfold reduction of viable microbes (D-value) is the same regardless of population level. There is plenty of evidence that this is not strictly true though the effects of initial population level, and of 'shoulders' on the survivor curve, seem quantitatively unimportant (with Cl. botulinum). It is consoling that indications on the above basis usually correspond well with doses indicated from the statistical inoculated pack technique (41). The most disturbing feature is reports of occasional survivors (tails) after doses approaching 10 Mrads (e.g. 42). Until it is shown that these survivors represent a particular fraction of the starting population, our inclination is to regard these survivors as arising through undetected flaws in technique. The proportion of resistant cells usually reported is very small (<10⁻⁶); so that heavily inoculated packs, or large numbers of them, would have to be examined to detect the occasional survivor, and with heavily inoculated packs there have been reports of survivors near the 4 Mrad level (30) as previously noted.

**Problems of control**

Heat processes of this kind are controlled, in commercial operation, by incubating cans and rejecting those which "blow"; a practice resting on the assumption that any can which is dangerous will become blown. It was therefore disturbing to observe, in experiments on the irradiation of meat packs inoculated with Cl. botulinum (e.g. 36, 43), that a proportion of containers developed toxin without producing gas. Presumably, these cultures developed from occasional surviving organisms, which had undergone a familiar form of radiation damage, viz. the loss of some particular physiological property. The experiments reported were, however, not intended to reveal clearly the nature and frequency of any such phenomenon. The point is so important as to call for specific investigation, by more suitable procedures.

Similarly for cured meats, the discovery that Cl. botulinum could grow and form toxin without producing any gas in meat containing between 6% and 7% salt (44) was regarded as indicating a serious obstacle to the radiation processing of cured meats. This however overlooked two points. First, the same argument should apply equally to the corresponding heat process, which nevertheless continues successfully on an enormous scale.
Second, radiation doses as low as 0.5 Mrads produce a marked sensitization of Clostridium spores to salt concentrations of the relevant order (33), and (if analogy with heat is any guide) the effect of 5 Mrad doses should be considerably greater; though it has still to be verified that these observations apply to Cl. botulinum besides the Clostridia actually tested.

Definition

Because so-called sterilizing doses of radiation will not destroy viruses and even, perhaps, some kinds of bacteria, and because autolytic enzyme systems would certainly remain active, a radappertized food is never likely to meet the definition of a "conserve" recently proposed by the C.I.P.C.1 This requires that the food within a hermetically sealed container should be sterile, and without enzyme activity. It is plain that no practical radiation process would alone reliably achieve this target, though it might be readily achieved by combination with a comparatively light heat treatment. It may be added that few heat processed foods would conform with this definition of a conserve, either, if it were strictly applied, over a large number of containers.

RADICIDATION

This type of process aims to remove organisms significant in public health, by radiation doses small enough to leave appreciable numbers of microorganisms in the food, though much fewer than they would be otherwise. The survivors present no unusual problem in foods in which they cannot multiply; whereas they would do so in 'perishable' foods, which is perhaps why proposals for radicidation have hitherto concentrated on frozen or dried foods. If such a process were applied to a 'perishable' food, the surviving organisms would raise problems similar to those discussed below under 'radurization'.

Because the Salmonellae are the most sensitive to radiation amongst organisms commonly causing food poisoning, and are the commonest cause of food poisoning, the first proposals for this kind of process were made to remove Salmonellae, from egg products (45) especially frozen egg (46). Since then, similar proposals have been made for frozen meats, and recently poultry; also for desiccated coconut; and more recently for the dried animal foods which are important as infecting the domestic animals which are the common reservoir of human salmonellosis (20, 47). Conceivably, similar proposals might be made regarding Staphylococci, which are not unusually resistant to irradiation.

Two basic difficulties have so far attended all radicidation proposals. The first is to decide the degree of inactivation desired and hence the radiation dose necessary. The second is the practical problem of how the efficacy of the treatment is to be controlled in commercial routine.

Determination of critical radiation dosage

The first difficulty arises because public health bacteriologists seldom regard such problems in quantitative terms (48). They specify that Salmonellae, for example, should be "absent" from a food; but in practice they will be satisfied if none are found in the examination of, for example, 100 samples each of 100 grammes. They are slow to admit

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1 C.I.P.C. = Comité international permanent de la conserve.
that what this means is, that they accept a frequency of occurrence up to about $10^{-4}$/gm. Moreover, the inactivation starts from the initial number of Salmonellae in the food, a quantity usually very variable, and difficult to determine; nevertheless, a decision is required as to what shall be taken as a representative value. In our work with frozen egg (49), contamination with 500 Salmonellae/g. was sometimes observed, hence we took $10^3$/gm. as a starting figure, requiring an inactivation of $10^{-7}$ to achieve the target frequency of $10^{-4}$/gm., or 7-D in the terminology familiar with Cl. botulinum. Similarly Mossel (47), accepting an average contamination of 1/gm. in feed meals, measured the dose needed for a 5-D treatment. Because there may be 'tails' (compare above) on the inactivation curves (47), it may be doubted whether a D value determined with high cell populations should be applied to the practical case where they are much lower; but the indicated radiation doses have been found on trial to give a satisfactory outcome under practical conditions (50).

Problems of control

The second problem, routine control of the efficacy of the process, is still more difficult. Regular bacteriological examination of hundreds of 100-gm. samples is out of the question; but diminishing the numbers of samples examined leads, in effect, to the acceptance of a higher frequency of occurrence. Bacteriological examination specifically for pathogens (e.g. Salmonella) tends to be laborious for example, with damaged cells, such as survivors of irradiation are likely to be, a preliminary resuscitation culture may be desirable, or growth may be delayed on a selective medium (21); the problem is simplified to the extent that elaborate procedure can be shortened. It is certainly not sufficient to use coliform counts as an indicator for Salmonellae, since the coliforms generally are not more resistant to radiation than the Salmonellae and consequently cannot be relied upon to survive them (20); a suggested solution has been to use a simple bacteriological method which would detect the survival of most members of the Enterobacteriaceae (69). But in fact, any procedure involving bacteriological examination is, by its randomly statistical nature, unsuitable for this kind of situation. With heat processing, reliance is placed instead on some other index, that processing has been such as would suffice to kill the Salmonellae present, e.g. the amylase test used to check the heat pasteurization of whole egg pulp (51). The difficulty with irradiation is that, because of their resistance, none of the appropriate enzymes have been found to be inactivated by the relevant radiation doses; and, so far, no other satisfactory kind of index has been suggested. It is easy to put a marker on the container, to show whether a desired radiation dose has been received (52); but legislators are apt to require that the indicator should be some inherent property of the food itself.

The physical nature of the food

It was mentioned earlier that the radiation sensitivity of vegetative organisms, such as the Salmonellae, is very much affected by the physical state of the food, probably via the activity of the water in it. Since there is known to be a substantial difference in radiation resistance between Salmonellae in the wet and dry states (20, 21, 22), the resistance of Salmonellae (like other vegetative bacteria) will probably be directly related to the aqueous activity in the food - this phenomenon calls for detailed description. For frozen foods, doses of about 0.5 Mrads have been regarded as adequate to kill Salmonellae. A rather similar value was suggested (47) as applicable to dried animal food of water activity
approximately 0.5, a value not far from that corresponding to the temperature, about \(-10^\circ\text{C}\), at which most frozen egg has been irradiated. With liquid egg, on the other hand, a dose about 0.15 Mrad was found to be lethal (53). These doses are near the approximately three-fold ratio observed for the protective effect of freezing under common conditions. Where much the same ratio applies to the organoleptic properties, as with meat, it will not matter much (apart from the dose necessary) whether irradiation is in the frozen state or not. In the case of egg, however, the organoleptic properties were damaged appreciably by as little as 0.01 Mrad (53) and quite seriously by 0.28 Mrad (45); consequently the process is not promising with liquid egg.

It is convenient, consequently, to give separate consideration to different foods according to their physical states. A considerable amount of work has been done with frozen foods, but I leave this to be dealt with by Dr. Ley. Though treatment of dried animal food appears promising (47), attempts to treat desiccated coconut proved unexpectedly difficult (apart from the expectable tendency of the irradiated coconut oil to go rancid rapidly). Salmonellae in desiccated coconut displayed an unusually high resistance to radiation (50), so that undesirably high doses were needed for effective treatment. This could scarcely have been due to unusually low water activity, which was in equilibrium with the relative humidity of the atmosphere. There has been a speculation that resistance might be related to the peroxides present in the oil (54), a suggestion worth closer investigation. This is however unlikely to explain the result with coconut, for a similar resistance was not evident in fish meals (47).

There have been few proposals to apply radicidation to perishable wet foods. With liquid egg pulp (53) the quality of the egg suffered too much damage. Among wet foods, it seems that Salmonella radicidation could be especially successful with poultry. Judging from experience with frozen meats and liquid egg, a radiation dose no greater than 0.2 Mrads would probably suffice, and it is well established that doses of this order have a negligible effect on organoleptic quality (47). If there is any suggestion to irradiate poultry carcasses (or other meats) in a plant where they are to be frozen, one should try to irradiate the carcasses before freezing: for reasons just outlined, the necessary dose would certainly be much smaller, while the associated degree of organoleptic alteration should be about the same, by all indications negligible.

**Combination processes**

Recently, it has been found (55) that the radiation resistance of Salmonellae is substantially less if they are irradiated at sub-lethal temperatures near 50°C. Such a combined process, e.g. with egg, could conceivably avoid the (minor) organoleptic alterations with irradiation alone, and the difficulties of avoiding coagulation using heat alone; but it seems at present difficult to propose an acceptable procedure for process control, as the enzyme tests would be inapplicable.

**RADURIZATION**

It is often possible to double the storage life of foods, or more, by applying doses of radiation not sufficient to cause any significant change in organoleptic quality. This has been shown, for example, with fish and shell-fish, poultry, meat and meat products, and various fruits. Such a process is especially attractive for highly perishable foods, and few non-perishable foods have yet been investigated.
The result depends on the more or less complete destruction, by the radiation, of the normal spoilage microflora. The more completely this is destroyed, and accordingly the more effective the process, the less likely it is that spoilage will follow the normal course and be characterized by the off-odours or flavours which experience makes us regard as signals of the risks associated with spoilage. This has for some time been recognised as a problem of such treatments (56). Because organoleptic changes as a rule limit the usable radiation doses to levels not much above 0.5 Mrad, various more resistant vegetative microorganisms (e.g. faecal streptococci, yeasts) are likely to remain in the treated food, while it seems that bacterial spores would regularly survive. The microbiological problems of radurization are, almost entirely, those raised by the existence of this residual flora: (they would exist likewise in the radicidation of perishable foods).

The precise nature of the surviving microflora must obviously depend on its initial composition, and hence will be affected by anything influencing the composition of the initial flora. This suggests, for example, that radurization might be more effective with fish from cold waters than from warm, because the psychrophilic bacteria of the fish of cold waters seem likely to be more sensitive to radiation; or similarly, that the microflora surviving radurization of poultry carcasses might depend on whether the birds had been reared at grass, on deep litter, or in battery cages. There have been, so far, no reports on this kind of influence.

The significance of the surviving flora

Understanding of the spoilage of radurized foods requires detailed identification of the surviving organisms and description of their activities. Lacking this experience as yet, we have to use general principles to estimate the risk to public health. Salmonellae and staphylococci do not seem likely to give trouble. They are not specially resistant to irradiation and, being relatively few initially, would probably be so far reduced as to be a negligible quantity after radurization—which would, in this respect, be virtually equivalent to radicidation. Trouble is conceivable from resistant faecal streptococci, which might well survive in numbers (cf. above) and have been implicated in food poisoning by meat products (57); and perhaps from surviving viruses.

The most significant among the likely survivors are the sporing bacteria, which include several species known to cause food poisoning. Consequently, it is suggested that there could be risk in a process allowing such organisms to survive, but destroying the normal indications that the food is undergoing bacterial spoilage. It should be realised, however, that the same applies to food lightly cooked by heating and distributed in that state; and that though, for example, pre-cooked meat is known (at least in U.K.) occasionally to cause food poisoning arising from heat-resistant spores of Cl. perfringens, yet this has not been held so dangerous as to justify prohibition of the sale of pre-cooked meats.

There are two conceivable ways to minimise this risk to public health. The first is to accept a somewhat smaller extension of storage life, and to leave among the survivors a few of the normal spoilage flora. These are then likely to overgrow the uncharacteristic survivors (after a delay which is shorter the larger the number surviving) and the course of spoilage will thereafter be more or less normal. The best compromise will have to be found by trial. The second possibility is to combine the radiation treatment with chill storage, at temperatures sufficiently low to prevent proliferation of organisms significant in public health (58). This has
been the basis of numerous past suggestions for a combination process of irradiation and chilling. The unusual importance of Cl. botulinum type E, in this connection, arises from the fact that it cannot be controlled with certainty by some of the temperatures commonly used in chilled storage (59, 60). Since this organism is largely confined to marine products, it seems likely to cause special difficulty with fish which is otherwise well suited to radurization treatment (61, 62, 63, 64, 65).

It is worth emphasizing that this public health hazard, such as it may be, does not arise at all with certain foods—that is, with any kind in which the relevant organisms cannot grow. An outstanding example is fruit juices, which are protected by their acidity (66, 67, 68); and this is an appropriate reason why fruit juices should have been chosen for the first international collaborative investigation of a process of this kind. Similarly, foods of sufficiently low water activity, however achieved, should be safe from this risk. Foods of these kinds, being relatively stable, have however so far attracted less attention than the more perishable foods; though the problems of application in fact seem less with the former.

Problems of control

As an index of the efficacy of radurization, the international committee (69) suggested a bacteriological method suitable to enumerate the microorganisms representative of the typical spoilage microflora. For example, for meat intended to be held at chill temperatures, one might consider the enumeration of psychrotrophic Pseudomonas, since these organisms form the characteristic spoilage flora in such a situation. But it remains to be seen how this suggestion would work in practice; for it is common experience that such organisms may grow up and dominate the ultimate spoilage flora from a state where their numbers were too small to be detectable; and it is conceivable that storage life might be related to differences in initial number at levels below the reach of conventional bacteriological technique, in which case, this approach to the problem would be useless. Alternatively, species still unrecognised, which consequently cannot yet be enumerated specifically, may be the more important after radurization. Further, attempts to accelerate tests, by raising the temperature for example, might obviously be of doubtful value as likely to favour uncharacteristic elements in the microflora.

The physical state of the food

Radurization has almost always been carried out at normal temperature. Because the process is aimed at vegetative cells, and freezing usually protects these as much as it protects the organoleptic qualities of the food, there is as a rule no differential advantage on freezing (as explained in the preceding section) the principal result being a needless increase of the radiation dose required. Much the same would probably apply to drying.

MISCELLANEOUS

Odd processes have been suggested which, while similar in principle to radurization, have the rather different intention of 'cleaning up' a product (instead of improving its storage life) — with however the ultimate aim of improving the stability of foods in which the product is incorporated.
An example is the irradiation of pectinase preparations (70), in which there usually remain viable cells of the organism from which the pectinase was derived, besides other contaminants, which may lead to undesirable spoilage while the pectinase is acting, e.g. in a fruit juice. These contaminants can be largely removed by irradiation, without serious damage to the pectinase. Similar treatments are obviously conceivable for other enzymes which are comparatively resistant to irradiation.

A similar example is the irradiation of spices, to remove bacterial spores which might otherwise spoil processed foods containing the spices. Thus, proposals exist to irradiate celery seed (71) and paprika (72). In this application, comparatively high doses of radiation are needed.

For this kind of application, and for similar radurization treatments, a large part of the benefit would be retained with a minimum of packaging, or perhaps none at all, for it is improbable that after-treatment contamination would reach the initial level. In a radicidation process, packaging must obviously be adequate to prevent réintroduction of the species which the process aims to eliminate, requiring at least a closed non-porous bag. With radappertization, the long life requires a near-hermetic package, and there is some doubt whether anything other than a metal can could provide the necessary degree of reliability (73, 74). Recent studies with newer laminates are, however, proving promising (75, 76).

**VIRUSES**

We have mentioned, several times already, the difficulty of killing viruses by irradiation; D values may approximate to 1 Mrad (77, 78, 79) although their infectivity may be eliminated by doses of a lower order (79, 80). We do not know, unfortunately, how seriously to regard this, for several reasons. First, there is not enough information about the lethal effect of ionising radiations on viruses, because of the technical difficulties in enumerating these microorganisms, and the fact that few people are equipped to do this kind of work. Second, it is common to overlook this difficulty because, in practice, viruses are little regarded in regulations about hygiene. There are, for instance, no public health requirements that viruses specifically should be absent from preserved foods. But this is mainly because of ignorance, and the situation would change dramatically if there were a few convincing demonstrations of the widespread transmission of an infective virus disease via a non-sterile preserved food (81). Again because of the difficulties of the investigation, there is little information about the survival of the relevant viruses in apparently favourable foods such as meat, in the rather unusual circumstances where spoilage has been prevented or long delayed.

Viruses are of interest from the standpoint of animal, as well as human, disease. It would clearly be undesirable to have international trade in a commodity like meat, which might be carrying the viruses of internationally dangerous diseases, like foot-and-mouth disease of cattle. A country like Ethiopia is potentially a large source of meat, but endemic diseases make it necessary to heat-sterilize meat from such countries before it moves into international trade. It is therefore a serious disadvantage of the irradiation process that it might apparently be ineffective for such a purpose.

The whole subject of the action of irradiation on food-borne viruses requires further investigation (as indeed the subject of food-borne viruses
Against radiation processes which do not kill all microbes in a food, it has been objected that they are likely to encourage the survival of more resistant mutants, produced by the radiation, and that the cumulative effect of this phenomenon might be serious. This objection has been raised particularly in relation to bacteria which might survive radici-dation or radurization treatments, but it might also apply to viruses for example remaining after higher doses of radiation.

It has even been hinted that entirely new pathogenic organisms might be generated in this way, though some of the evidence rests on so flimsy a scientific foundation as to give the impression of scaremongering. There is nevertheless convincing evidence that repeated exposure of vegetative bacteria to just sub-lethal irradiation, alternating with periods of abundant growth, will after many cycles produce mutant bacteria, with a radiation resistance several times as great as that of the original strain (83) and moreover with different morphological and physiological properties (84, 85). This happens only with some species, and the evidence, at present, suggests to the writers the possibility of difficulty, but not yet of danger. However it is often overlooked that mutations may also occur after heat treatment (86).

In normal circumstances the aberrant strains have not attracted the attention of those who have made experiments involving the enumeration of salmonellas surviving irradiation; the proportion is however likely to be very small, and the enrichment techniques reported by the Canadian workers do not illuminate this point. It is true that the mutated organisms, having lost some of the properties of their parents, may not readily be recognised as descendants of the original pathogen; but this will not matter much if the pathogenic character is one of those which have been lost, which seems quite likely but has not been tested. There is still no good evidence (that we know) of the acquisition of pathogenicity by non-pathogenic organisms; and virtually none, even, of the augmentation of pathogenicity in an already pathogenic strain, as a result of repeated irradiation. This question of pathogenicity of the mutants has been little investigated, doubtless because of technical difficulties, which is unfortunate because this is the most important point of the argument.

But, even if the mutated organisms prove to have no public health significance whatever, their implications should not be neglected. An analogous development of resistance to tetracycline antibiotics appears to have sufficed in about a year to render ineffective a new process for preserving poultry; and the same might apparently be expected with a radiation process, in appropriate circumstances.

It should nevertheless be emphasised that these striking changes have been produced only by very favourable combination of circumstances, in repeated sub-lethal irradiation of massive populations with alternating periods of vigorous growth. It is reasonable to suppose that a few organisms situated on an endless conveyor passing through an irradiation source might be subjected to repeated sub-lethal doses of radiation; but it seems far less likely that the succeeding intervals would be suitable, either in duration or other circumstances, to permit alternating periods of vigorous growth, at least over several cycles, though the possibility is conceivable unless guarded against. A Pseudomonas growing in the re-
circulated cooling water of a reactor was found, in fact, to have a somewhat sub-normal resistance (87).

CONCLUSION

Looking to the future, there must obviously be much more work on Cl. botulinum in the hope of controlling it with lower doses. At present, we cannot foresee anything more hopeful than the not very satisfactory procedure of freezing for irradiation. Consequently, we anticipate that much more attention will be given to combination processes of irradiation with curing, or with heating, or both. As research develops outside the military field, however, there will surely be greater interest in radapperitization processes with foods in which Cl. botulinum is no problem, for example some of the fruit products.

We suppose that the first microbiological applications of irradiation to food are likely to be in Salmonella radicidation. In other applications, public health bacteriologists tend to adopt a cautious or dubious attitude to the residual microflora. With Salmonella radicidation, on the contrary, there is a prospect of achieving uniquely objectives of great interest to public health bacteriologists at the present time; and consequently this type of process seems likely to receive their support. We have long thought it a good idea to try such a process first with an animal feeding stuff; the biological value should be far better retained than by heat pasteurization; alterations of taste might not be so important; and the consumption of the irradiated food on a large scale by animals would be the best possible preliminary to any application to human food.

Processes of the radurization type will, we think, develop only slowly. With perishable foods, the bacteriological problems raised by the residual flora can be solved only by time and experience. One might expect, consequently, that this type of process will first be put to use in "cleaning up" non-perishable foods, though these have not yet received much attention. With either type of food, industrial interest will depend on the economic outlook, and confidence will only be gained as experience of irradiation processes grows. In the background, we have the fundamental questions about mutations, and the importance of viruses, and these will certainly claim increasing attention in the future.

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DISCUSSION

N. GRECZ: You say that the resistance of vegetative cells increases in the liquid-solid transition by a factor of three. Obviously any estimate of this kind must be more or less arbitrary, but it would be interesting to know how you made your comparison. Did you use D-values, the number of surviving cells, or some other criterion?

M. INGRAM: Sometimes we used D-values, and sometimes the dose required to achieve a particular degree of inactivation. With degrees of inactivation over several log cycles, or with a survivor/dose relation reasonably close to exponential, these procedures give much the same protection ratio. My aim here was simply to get a rough figure that would indicate the order of magnitude of the protection given by freezing. This obviously depends also on the precise sub-zero temperature used, and in the paper I am referring, broadly speaking, to temperatures of -20°C or lower; or, by implication, to degrees of dryness giving equivalent water activity.

D.A.A. MOSSEL: I find some difficulty in accepting all of Mr. Ingram's conclusions with regard to procedures for the control of radicidation treatment. Firstly, I think it would be wrong to rely exclusively on an enzyme test as a means of checking pasteurization in toto, for it could not indicate whether recontamination had occurred after processing, and this is in fact the most common reason for the failure of such treatments in commercial operation. On the other hand, although microbiological examinations may be "randomly statistical" it does not follow that they are valueless in practice. In fact, van Schothout, Kampelmacher, Drion and I have recently shown\(^1\) that the bacteriological condition of all the Peruvian fish meal imported into the Netherlands (some 200,000 tons annually) can be quite reliably evaluated by taking no more than 450 50-g samples at random each week and examining them for Enterobacteriaceae - a task that can be completed in a few days by a junior technician.

V. ROGACHEV: In your presentation you indicated that flaws in technique may account for the fact that occasional highly radio-resistant "tails" of Clostridium botulinum have been observed. What flaws do you have in mind?

M. INGRAM: Unfortunately, neither I nor other workers in this field can give a satisfactory answer to your question. The survivors might conceivably be attributed, just to give a few examples, to the use of mixed cultures, to contamination in sub-culture, to the formation of protective substances, or to mutations during irradiation. None of this has been proved, however, nor do some of these possible causes seem likely to produce an effect often observed: a nearly constant absolute number of coarse, small survivors, irrespective of the dose or the initial number of spores before irradiation. Systematic contamination might explain

this, but on the other hand contamination seems unlikely when inoculated packs are simply incubated without being opened; and some reports suggest that, even when this procedure was used, there have been a few survivors at unusually high doses. One of the principal difficulties is to devise a system in which the phenomenon is regularly reproducible for experimental purposes.

E. JOSEPHSON: We use the 12-D concept in our high-dose programme in the United States for the production of shelf-stable foods; but we are not satisfied with it. At our request the National Academy of Sciences - National Research Council has appointed a Task Group to make a thorough study of microbiological safety and to recommend standards for foods subjected to radappertizing doses. The Task Group has already met once and has been literally inundated with reports. It has also requested additional data that will require further experimental work on our part. We hope that the Task Group will be able to finish its study and make its recommendations within the next 15 months.
RADIATION RESISTANCE OF SPORES OF CLOSTRIDIUM BOTULINUM TYPE E

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Abstract — Résumé — Аннотация — Resumen

RADIATION RESISTANCE OF SPORES OF CLOSTRIDIUM BOTULINUM TYPE E. The resistance of spores of Clostridium botulinum Type E to radiation with ^Co was determined in 1:2 haddock homogenate and in neutral phosphate buffer. Inoculated samples were irradiated at 0.1 Mrad internal doses at 35°F (1.7°C). The number of survivors at each dose was determined in a medium consisting of 5% peptone, 16% gelatin and 0.1% sodium thioglycollate, using a replicate deep-tube recovery method and incubation at 68°F (20°C) and 46°F (7.8°C). Survivor curves were constructed by plotting log per cent survivors against dose. The viable counts of unirradiated spores at 68°F and 46°F were used to calculate the respective per cent survivors. Survivor curves for spores of the Beluga, 8E, Alaska and Minneapolis strains in both substrates and at both temperatures were characterized by a pronounced shoulder or lag during the first log cycle of reduction, followed by exponential destruction. Lag values, defined as the dose in Mrad for a survivor curve to traverse the first log cycle of reduction, were larger with haddock than with buffer, and larger with incubation at 68°F than at 46°F. Lag values of spores in haddock at 68°F ranged from 0.29 to 0.43 Mrad. At 46°F, the lag values equalled approximately 0.25 Mrad. In buffer at 68°F, the lag values ranged from 0.21 to 0.30 Mrad versus 0.13 to 0.20 Mrad at 46°F. D-values, defined as the dose for 90% reduction from the exponential portion of a survivor curve, equalled 0.22 Mrad in haddock and 0.08 to 0.11 Mrad in buffer at 68°F. At 46°F, D-values of 0.08 to 0.11 Mrad were obtained in both haddock and buffer at 66°F. More than a twofold reduction in resistance was observed with incubation at 46°F. D-values for 10^6 inactivation from extrapolation of the survivor curves compared closely to those calculated from partial spoilage results. The survivor curve for spores of the Beluga strain irradiated in trypticase-peptone-glucose medium with recovery in peptone-agar at 85°F was indistinguishable from the survivor curve of spores of the same strain irradiated in haddock with recovery at 68°F.
РАДИАЦИОННАЯ СТОЙКОСТЬ СПОР CLOSTRIDIUM BOTULINUM ТИПА Е. Стойкость спор Clostridium botulinum типа Е к облучению кобальтом-60 определялась в гомогенатах пикши (1:2) и в нейтральном фосфатном буферном растворе. Ионизирующие излучения получали внутриобъектную дозу облучения 0,1 Мрад при температуре 1,7°C. Количество выживших спор при каждой дозе облучения определялось в среде, состоящей из 5% пептона, 16% желатина и 0,1% тиогликолата натрия, методом выделения организмов с помощью ряда одинаковых пробирок с высоким слоем раствора и инкубации при температуре 20°C и 7,8°C. Построены кривые выживших спор путем графического изображения в логарифмическом масштабе процента выживших спор в зависимости от дозы облучения. С использованием метода подсчета живых необлученных спор при температуре 7,8 и 20°C для определения соответствующего процента выживших спор. Кривые выживших спор штаммов Белуга, 8 Е, Миннеаполис в обоих субстратах и при обеих температурах характеризовались резко выраженным верхним сгибом или задержкой во время первого логарифмического цикла уменьшения стойкости, после чего наступало экспоненциальное уничтожение. Величина задержки (доза в угарах, при которой кривая выживших спор пересекается с первым логарифмическим циклом уменьшения стойкости) была большой в отношении пикши, чем в буферном растворе, и большей в отношении инкубации при 20°C, чем при 7,8°C. При 7,8°C величина задержки составляла приближительно 0,25 Мрад. В буферном растворе при температуре 20°C величина задержки колебалась от 0,21 до 0,30 Мрад против 0,13 - 0,20 Мрад при 7,8°C. D — величина (доза 90% уменьшения стойкости, определяемая на основе экспоненциальной части кривой выживших спор) составляла 0,22 Мрад в пикше и 0,08 - 0,11 Мрад в буферном растворе при 20°C. D — величины от 0,08 до 0,11 Мрад были получены как в пикше, так и в буферном растворе при 7,8°C. На основе данных о частичной гибели, тщательно сравнивались с величинами, вычисленными на основе данных о частичной гибели. Кривая выживших спор штамма Белуга, которые облучались в среде триптиказ-пептон-глюкоза и восстанавливались в растворе пептон-агар при 29,4°C, не отличалась от кривой выживших спор того же штамма, которые облучались в пикше и восстанавливались при температуре 20°C.

RADIRESISTENCIA DE LAS ESPORAS DEL CLOSTRIDIUM BOTULINUM TIPO Е. Se ha determinado la soherence Beluga somíes a una irradiación en un medio peptone-glucose del tipo tripticas, siguiénd de una reanudación en un medio peptone-agar a 29,4°C, la course de survie était pratiquement identique à celle des spores de cette même souche irradiées dans l’aiglefin avec restauration à 20°C.
INTRODUCTION

Since about 1960, the U. S. Atomic Energy Commission has supported research concerning the application of substerilizing doses of ionizing radiation to extend the refrigerated storage life of selected species of marine products, fruits, and vegetables. Perhaps the most critical problem confronting the marine products program is the potential health hazard aspect of Clostridium botulinum Type E.

Low doses of irradiation, commonly referred to as pasteurizing doses, appear to offer considerable promise as a means of extending the refrigerated storage life of many marine food products. However, a marked extension of refrigerated storage life might create a dangerous situation with respect to Cl. botulinum Type E. At least three facts substantiate this conclusion. First, ecological surveys for Type E spores have established their ubiquity in marine environments; second, the irradiation resistance of Type E spores indicates that pasteurizing doses would have no major destructive effect; and third, Type E spores are capable of outgrowth and toxin production at temperatures as low as 38°F, according to Schmidt, Lechovich, and Polinazzo (1).

The resistance of spores of Cl. botulinum Type E to ionizing irradiation is generally accepted as being low in comparison to that reported for Types A and B. Erdman, Thatcher, and Mac Queen (2) studied the irradiation resistance of spores of five Type E strains in nutrient broth medium. They showed a survivor curve for spores of the VH strain and for a strain reported to be a non-toxigenic variant. The survivor curve for the VH strain, stated to be representative of the toxigenic strains, shows a definite "shoulder" preceding logarithmic spore destruction. From their data this strain appears to possess a D-value equal to about 0.16 Mrad. Spores of the non-toxigenic strain were slightly more resistant to gamma rays than those of the VH strain.

Using a partial spoilage method, Schmidt, Nank, and Lechovich (3) determined D-values for spores of six strains in a beef stew substrate. With incubation at 85°F, they obtained a mean D-value of 0.132 Mrad and a range of 0.125 to 0.138 Mrad.

Roberts and Ingram (4) compared the irradiation resistance of spores of nine strains in aqueous suspension from survivor data. D-values from the exponential portions of survivor curves ranged from 0.07 to 0.16 Mrad. The curves displayed a pronounced "shoulder" extending through about 0.4 Mrad followed by exponential destruction. D-values calculated for 10° inactivation equalled 0.12 to 0.20 Mrad. Spores of a Scandinavian strain showed the highest resistance of the strains tested.

The purpose of this study was to determine the radiation resistance of selected Type E strains in phosphate buffer and in a marine product substrate, and to compare survivor curves based on recovery of survivors at an optimal incubation temperature and at a suboptimal temperature in the refrigeration temperature zone.
Methods

Spore suspensions. Cultures of the Beluga, SE, Alaska, and Minneapolis Type E strains were used to prepare spore suspensions. The suspensions were prepared in TPG medium (5\% Trypticase, 0.5\% Peptone, and 0.4\% glucose plus 0.1\% sodium theoglycollate) and with incubation at 85°F (30°C) as recommended by Schmidt et al. (3). The unwashed spores were stored in aqueous suspension at 36°F (2.2°C).

Source and dosimetry. Samples were irradiated in a Co\(^{60}\) facility located at Admiral Corporation in Chicago, Illinois. Operation of the facility and dosimetry measurements were performed by Admiral personnel. Dose rate measurements were made utilizing ferrous-sulfuric acid solution chemical dosimeters. The dosimetry results indicated a uniform dose rate of 6.5 \times 10^4 rads/hr throughout the area of interest.

Since several hours were required to deliver the higher doses used, the samples were refrigerated during irradiation to preclude the possibility of spore germination. The samples were positioned in a circular configuration in a metal rack inside a refrigerated metal chamber where they were maintained at 35°F (1.7°C).

Substrates. Either 0.067 neutral phosphate buffer, TPG medium or 1:2 diluted haddock homogenate served as the irradiation substrate. To prepare the haddock substrate, frozen unbrined fish fillets were partially defrosted and finely macerated with a food grinder. The ground fish was weighed and combined with an equal weight of distilled water. After blending the diluted ground fish slurry for one min. in a Waring Blender, the homogenate was weighed in 10g quantities into each 16 x 150 mm screw-cap tube. The tubed homogenate was heated in flowing steam for 30 min. The steamed substrate was cooled in cold tap water and stored at 36°F.

TPG medium and phosphate buffer were bottled in 200-ml volumes and sterilized at 250°F (121°C) for 15 min. As required, 10-ml quantities were pipetted into sterilized 16 x 150-mm screw-cap tubes and chilled prior to inoculation. Spores in TPG medium were irradiated in the absence of added sodium thioglycollate.

Irradiation and recovery of survivors. Duplicate tubes of haddock or buffer and single tubes of TPG medium per variable were irradiated at several dose intervals up to 0.8 Mrad. Each tube of substrate contained a standardized inoculum level of 2 \times 10^5 spores/g or 2 \times 10^6 spores/tube. The inoculated tubes were held at wet ice temperature for conveyance to and from the irradiation source.

The number of survivors at each dose was determined as soon as possible after irradiation. The contents of each irradiated tube of buffer or haddock were transferred into a sterilized glass Waring Blender cup. Each tube was rinsed thoroughly with several washings of cold, sterilized distilled water. A total of 90 ml of diluent was added to give an initial 1:10 dilution. Samples were blended for one min. If necessary, additional tenfold dilutions were made in bottles containing glass beads. Irradiated samples of TPG medium were mixed with a Vortex Jr. Mixer (Scientific Industries, Inc., Queens Village, New York) and diluted for survivor counts according to the dose applied. Quantities between 0.1 and 1.0 ml of appropriate dilutions were pipetted into five-tube (16 x 125mm) replicate sets for deep-tube colony counts.
at 68°F (20°C). A second series of tubes was inoculated for incubation at 46°F (7.8°C). The recovery medium for spores irradiated in haddock and buffer consisted of 5% Bacto-Peptone and 1.5% Bacto-Gelatin. The irradiation survivors in TPG medium were determined in a 5% Peptone plus 1.5% Noble Bacto-Agar medium and with incubation at 85°F. The Peptone-Gelatin medium was autoclaved for 10 min. at 15 pounds pressure and after cooling was stored at 36°F. The medium containing agar was autoclaved for 15 min. Both media were prepared in amounts of 150 ml in screw-cap bottles.

Heat sterilized sodium thioglycollate (20%) and filter sterilized NaHCO₃ (10%) were added aseptically to the melted medium immediately before use to give concentrations of 0.10 and 0.14%, respectively. Subsequent studies have shown that the omission of bicarbonate does not affect the colony count.

Approximately 15 ml of the melted recovery medium were poured into each tube for survivor counts. As each set of tubes was poured, they were quickly chilled in an ice-water bath. Failure to chill the Peptone-Gelatin medium adequately or incubation above 68-70°F usually gave diffuse colonies. After the medium had solidified, the tubes were removed from the water bath, dried, and incubated. Colony counts were made after 3 and 7 days of incubation at 68°F and after 3 and 4 weeks at 46°F. Longer incubation periods at either temperature failed to give higher counts.

Partial spoilage determinations. For each variable, ten tube replicate sets of haddock homogenate were inoculated with 2 x 10⁶ viable spores per tube and irradiated to give a partial spoilage endpoint. After irradiation the contents of each tube were stratified with sterile melted vaspar. After incubation at 85°F or 46°F, D-values were calculated from the partial spoilage results according to the formula suggested by Schmidt and Nank (5). At each partial spoilage endpoint, the absence of Type E toxin was verified after 6 months of incubation by the procedure of Schmidt et al. (3).

RESULTS

Viable counts of inoculated unirradiated control samples of haddock or buffer were used as the basis for calculating the percentage irradiation survivors. With an equivalent initial inoculum level, control counts at 68°F of spores in haddock were practically the same as corresponding counts of spores in buffer. However, the fraction of unirradiated spores viable at 68°F that showed viability at 46°F was both substrate and strain dependent. For example, in haddock about 90% of the spores of the Beluga strain which showed viability at 68°F were viable with incubation at 46°F. In buffer only 50% of the 68°F control count was obtained at 46°F. Unirradiated spores of the 88 and Minneapolis strains in haddock showed 60 to 70% viability in terms of low temperature incubation at 46°F, as compared to 5 to 20% in buffer. Control counts of spores of the Alaska strain showed viabilities of 15 and 20% in buffer and haddock, respectively. The results indicate that a large fraction of the spores of each strain tested when inoculated into phosphate buffer were incapable of forming visible colonies at 46°F. However, in haddock spores three of the four strains show considerably higher viabilities when recovered in the same medium at this temperature.
Survivor curves as illustrated in Fig. 1 for spores of the 8E strain were constructed by plotting the log percent survivors against dose. Each point on the curve represents the average percent survivors of duplicate samples of either phosphate buffer or haddock. Spores of the Beluga, Alaska, and Minneapolis strains gave survivor curves similar to those shown for spores of the 8E strain. The survivor curves shown reflect the irradiation resistance as determined by recovery counts after incubation at 68 or 46°F. It can be seen that all of the survivor curves exhibited a distinct "shoulder" during the first log cycle of reduction followed by exponential reduction.

Each survivor curve was characterized by a lag and a D-value. The lag value is defined as the dose in Mrad for a curve to traverse the first log cycle of reduction, and it indicates the extent of the "shoulder" of a survivor curve. The D-value is defined as the dose in Mrad for the exponential portion of a survivor curve to cross one log cycle of reduction.

Table I summarizes the resistance values obtained from the survivor curve data. It can be seen that lag values were larger for spores in haddock than in buffer and larger with recovery of the irradiation survivors at 68 than at 46°F. Spores in haddock gave lag values at 68°F ranging from 0.29 to 0.43 Mrad. At 46°F the lag extended to approximately 0.25 Mrad. In buffer at 68°F the lag ranged from 0.21 to 0.30 Mrad versus 0.13 to 0.20 Mrad at 46°F. D-values at 68°F for spores in haddock equalled 0.20 to 0.22 Mrad in contrast to 0.08 to 0.11 Mrad in buffer. However, with incubation at 46°F, D-values of spores of the four strains irradiated in either buffer or haddock were about equal (0.08 - 0.12 Mrad).
Radiation D-values and lag values for spores of *Clostridium botulinum* Type E in phosphate buffer and haddock with incubation at 68 and 46°F

<table>
<thead>
<tr>
<th>Strain</th>
<th>Substrate</th>
<th>Values (Mrad)</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>D-value¹</td>
<td></td>
<td>Lag value²</td>
</tr>
<tr>
<td></td>
<td></td>
<td>68°F  46°F</td>
<td>68°F  46°F</td>
<td></td>
</tr>
<tr>
<td>Beluga</td>
<td>Buffer</td>
<td>0.08  0.08</td>
<td>0.30  0.14</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Haddock</td>
<td>0.22  0.12</td>
<td>0.39  0.25</td>
<td></td>
</tr>
<tr>
<td>8 E</td>
<td>Buffer</td>
<td>0.11  0.08</td>
<td>0.24  0.14</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Haddock</td>
<td>0.22  0.12</td>
<td>0.43  0.26</td>
<td></td>
</tr>
<tr>
<td>Alaska</td>
<td>Buffer</td>
<td>0.10  0.09</td>
<td>0.21  0.13</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Haddock</td>
<td>0.22  0.10</td>
<td>0.29  0.24</td>
<td></td>
</tr>
<tr>
<td>Minn.</td>
<td>Buffer</td>
<td>0.10  0.08</td>
<td>0.23  0.20</td>
<td></td>
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<tr>
<td></td>
<td>Haddock</td>
<td>0.20  0.10</td>
<td>0.40  0.26</td>
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</table>

¹ Radiation dose for 90% reduction from the exponential portion of a survivor curve.

² Dose for the survivor curve to traverse the first log cycle of reduction.

D-values for spores of the 8E and Minneapolis strains were determined from partial spoilage data at 85°F and 46°F. Based on an inoculum of $2 \times 10^5$ spores per tube and 10 replicates per variable, spores of both strains gave an average D-value at 85°F equivalent to 0.25 Mrad, as shown in Table II. With incubation at 46°F and based on the initial viable spore count at this temperature, spores of these two strains showed more than a two-fold reduction in resistance. At each partial spoilage endpoint after 6 months' incubation, all samples showing no evidence of gas beneath vaspar seals were examined microscopically for growth and assayed for Type E toxin. None of the negative samples showed evidence of growth or toxin, whereas all samples that showed gas at each partial spoilage endpoint contained toxin.

A comparison of D-values for spores of the 8E and Minneapolis strains in haddock from survivor curve and partial spoilage data is shown in Table III. D-values for $10^6$ inactivation were obtained by extrapolating each survivor curve through 6 log cycles of reduction and then dividing this dose by six. It can be seen that D-values at 68°F for $10^6$ inactivation compare closely to those calculated from partial spoilage data at 85°F. D-values taken from the exponential portion of the survivor curves are somewhat lower. In general, there are small differences at 46°F between D-values determined by each of the three methods used for calculation.
D-values determined from partial spoilage data for spores of the 8 E and Minneapolis strains irradiated in haddock homogenate

<table>
<thead>
<tr>
<th>Strain</th>
<th>Temp°F</th>
<th>Dose(Mrad)</th>
<th>Fraction of tubes showing growth</th>
<th>D-value(Mrad)</th>
</tr>
</thead>
<tbody>
<tr>
<td>8 E</td>
<td>85</td>
<td>1.6</td>
<td>9/10</td>
<td>0.252</td>
</tr>
<tr>
<td></td>
<td></td>
<td>1.7</td>
<td>4/10</td>
<td>0.254</td>
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<tr>
<td></td>
<td></td>
<td>1.8</td>
<td>1/10</td>
<td>0.247</td>
</tr>
<tr>
<td></td>
<td></td>
<td>1.9</td>
<td>0/10</td>
<td>0.097</td>
</tr>
<tr>
<td></td>
<td></td>
<td>ave.</td>
<td></td>
<td>0.251</td>
</tr>
<tr>
<td></td>
<td>46</td>
<td>0.6</td>
<td>6/10</td>
<td>0.097</td>
</tr>
<tr>
<td></td>
<td></td>
<td>0.8</td>
<td>0/10</td>
<td>0.097</td>
</tr>
<tr>
<td></td>
<td></td>
<td>0.9</td>
<td>1/10</td>
<td>0.097</td>
</tr>
<tr>
<td></td>
<td></td>
<td>1.0</td>
<td>0/10</td>
<td>0.097</td>
</tr>
<tr>
<td></td>
<td></td>
<td>ave.</td>
<td></td>
<td>0.113</td>
</tr>
<tr>
<td>Minn.</td>
<td>85</td>
<td>1.6</td>
<td>5/10</td>
<td>0.242</td>
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<tr>
<td></td>
<td></td>
<td>1.7</td>
<td>3/10</td>
<td>0.250</td>
</tr>
<tr>
<td></td>
<td></td>
<td>1.8</td>
<td>3/10</td>
<td>0.265</td>
</tr>
<tr>
<td></td>
<td></td>
<td>1.9</td>
<td>0/10</td>
<td>0.066</td>
</tr>
<tr>
<td></td>
<td></td>
<td>ave.</td>
<td></td>
<td>0.252</td>
</tr>
<tr>
<td></td>
<td>46</td>
<td>0.4</td>
<td>5/5</td>
<td>&gt;0.066</td>
</tr>
<tr>
<td></td>
<td></td>
<td>0.6</td>
<td>0/10</td>
<td>&lt;0.085</td>
</tr>
</tbody>
</table>

1 D-values at 85°F calculated from an inoculum of $2 \times 10^6$ spores/tube; at 46°F, D-values calculated from viabilities of $1 \times 10^6$ and $1.3 \times 10^6$ spores/tube for spores of the 8 E and Minneapolis strains, respectively.

Fig. 2 shows survivor curves for spores of the Beluga strain irradiated in TPG medium and in haddock. The irradiation survivors from TPG medium were enumerated with Peptone Agar medium and incubation at 85°F, while those from haddock were recovered with Peptone-Gelatin medium and incubation at 68°F. It is apparent that the irradiation resistance of spores of this strain in TPG medium closely parallels that in haddock.
TABLE III

Comparison of radiation D-values from survivor data to those from partial spoilage data for spores of the 8 E and Minneapolis strains irradiated in haddock homogenate

<table>
<thead>
<tr>
<th>Incubation Temp. °F</th>
<th>D-value (Mrad)</th>
<th>Refugee curve data</th>
<th>For $10^6$ inactivation</th>
<th>Partial spoilage data</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Exponential portion</td>
<td>8 E</td>
<td>8 E</td>
<td>8 E</td>
</tr>
<tr>
<td></td>
<td>8 E Minn.</td>
<td>8 E Minn.</td>
<td>8 E Minn.</td>
<td>8 E Minn.</td>
</tr>
<tr>
<td>85</td>
<td>0.22</td>
<td>0.21</td>
<td>0.26</td>
<td>0.26</td>
</tr>
<tr>
<td>65</td>
<td>0.12</td>
<td>0.10</td>
<td>0.14</td>
<td>0.13</td>
</tr>
</tbody>
</table>

1 D-values for $10^6$ inactivation were obtained by extrapolating the survivor curves through 6 log cycles of reduction.

The lag value from the survivor curve of spores in TPG medium equalled 0.46 Mrad. The D-value from the exponential portion of this curve was equivalent to 0.21 Mrad in contrast to 0.25 Mrad when calculated for $10^6$ inactivation. These values are in good agreement with those presented in Table I for spores of the Beluga strain irradiated in haddock. The results
suggest that TPG medium may be a suitable substrate to simulate marine or other food products for preliminary determination of the irradiation resistance of spores of other Type E strains.

DISCUSSION

The irradiation survivor curves for spores of Cl. botulinum Type E are characterized by a pronounced "shoulder" followed by an exponential rate of spore destruction. This is true irrespective of the substrate—buffer, haddock or TPG medium—and also irrespective of the incubation temperature used for the recovery of survivors. These survivor curves are similar in shape to those obtained by Erdman et al. (2) and Roberts and Ingram (4). Sigmoidal curves of this type are often interpreted in terms of target theory as "multihit" curves, and "n", the number of inactivation sites required for spore or cell inactivation. The term "n" is calculated from survivor curve data (Wheaton and Pratt, (6)) and results in expressing the data in the form of constants in a complex equation whose biological and practical meaning is often obscure. Alper (7) suggested "that the intercept obtained by extrapolating the exponential portion of a Type Cl curve (meaning a sigmoidal curve with a "shoulder") to zero dose should be referred to as the 'extrapolation number', rather than as 'hit' or 'target' number, unless there is supporting evidence that this number can be identified with specific entities which can plausibly be regarded as targets of irradiation damage." Matsuyama, Thornley and Ingram (8) have used this suggestion and characterized the survivor curves of a number of species of vegetative bacteria under various irradiation conditions by means of extrapolation number and D-value for the exponential portion of the curve. We are inclined to think that the non-exponential survivor curve may be more simply characterized and visualized by the use of the "lag" and D-value expressions, since "lag" is expressed in Mrad and comparisons among "lag" values may be more easily comprehended than comparisons among extrapolation numbers.

In the United States, for several years irradiation doses from 0.1 to perhaps 0.4 Mrad have been under consideration for the extension of the refrigerated storage life of marine products. The most recent thinking suggests irradiation doses of the order of 0.1 - 0.2 Mrad. The data presented here on spores of four strains of Cl. botulinum Type E support the earlier conclusion of Schmidt et al. (3) that pasteurization doses of irradiation would not eliminate Type E spores. In fact, based on recovery of survivors at 68 - 85°F in haddock or TPG medium, the estimates of resistance are considerably higher than those of Schmidt et al. (3) in beef stew or Roberts and Ingram (4) for the same strains in aqueous suspension, although it should be noted that one strain of Scandinavian origin tested by Roberts and Ingram (4) had resistance of the order reported in this work. Based upon recovery of survivors at 46°F following irradiation in either buffer or haddock, the irradiation resistance is lower and approximates that of the original data of Schmidt, et al. (3) and Roberts and Ingram (4).

Therefore, it appears that a significant fraction of an original population of Type E spores in a marine product may be capable of surviving the low doses of irradiation used for the extension of refrigerated storage life. Assuming the potential presence of surviving
Type E spores, it becomes of paramount importance to determine the times required at various temperatures in the refrigeration temperature zone for surviving spores to develop and produce toxin. Furthermore, this time must be related to the time at the same temperature for the irradiated marine product to become unmistakably unacceptable from an organoleptic standpoint. Work in our laboratory suggests that there is a considerable delay in the outgrowth of Type E spores surviving irradiation in marine products, as compared to that of unirradiated spores.

The difference in outgrowth time between controls and irradiation survivors becomes greater as the temperature decreases. Continuing work in other laboratories as well as ours will be devoted to amplifying the limited data available on the outgrowth time of irradiated Type E spores and the time required to reach organoleptic unacceptability. It is hoped that the results of such experiments will more securely validate the public health safety of marine products receiving low-dose irradiation for the extension of refrigerated storage life.

ACKNOWLEDGMENT

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The technical assistance of Mr. J. K. Boltz is gratefully acknowledged.

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DISCUSSION

M. INGRAM: While I agree that Mr. Segner's term "lag dose" is perhaps a good practical description of the "shoulders" on survival curves, I might suggest "induction dose" as an alternative, which would avoid any possible confusion with the lag phase of growth.

Another possibility, which might claim preference because it has already been proposed by Alper et al. (Brit. J. Radiol. 35 (1962) 722), is the term "intercept dose". This has been defined as the mathematical intercept of the linear portion of the dose/log survivors' curve on the dose axis, whereas Mr. Segner is using the actual dose which gives the first decimal reduction; and the latter will be larger or smaller, depending on the shape of the curve. "Intercept dose" seems an easier idea to use.

W. P. SEGNER: Thank you for your comments. I certainly see no objection to these suggestions.

N. GRECZ: I observe that a D-value of 0.23 Mrad was calculated from your data. Since Type E is usually considered to include radio-sensitive organisms, it ought perhaps to be pointed out that the D-value of 0.23 Mrad would place this strain among the medium-resistant Types A and B, for which the D-values range from 0.36 to 0.13 Mrad.

W. P. SEGNER: Partial spoilage data at 85°F for spores of the 8E and Minneapolis Type E strains irradiated in haddock showed a D-value of 0.25 Mrad. This indicates, as you have pointed out, that the spores of Type E occupy an intermediate position with respect to D-values reported for spores of Types A and B.
MICROBIOLOGICAL STUDIES ON THE INFLUENCE OF COMBINED PROCESSES OF HEAT AND IRRADIATION ON THE SURVIVAL OF SACCHAROMYCES CEREVISIAE VAR. ELLIPSOIDEUS

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Abstract — Résumé — Аннотация — Resumen

MICROBIOLOGICAL STUDIES ON THE INFLUENCE OF COMBINED PROCESSES OF HEAT AND IRRADIATION ON THE SURVIVAL OF SACCHAROMYCES CEREVISIAE VAR. ELLIPSOIDEUS. In the framework of the Seibersdorf International Programme on Irradiation Preservation of Fruit and Fruit Juices one of the main items of research deals with the problem of the radiosensitization of microorganisms.

To study the effect of heat and irradiation treatments on the survival of yeast cells (colony formation), a highly radioresistant strain, Saccharomyces cerevisiae var. ellipsoideus, grown in a semi-synthetic nutrient medium, was given a combined treatment of heating and gamma irradiation (Co source) at the beginning of its log phase. The heat treatment was applied either immediately before, during or immediately after the irradiation process. The temperature was varied between 20°C and 52.5°C. The irradiation treatment was carried out with a dose range of up to $0.3 \times 10^6$ rad in a well-aired glass tube. The inhibiting effect of this combined treatment depends upon the sequence of heating and irradiation and shows the following results: the most effective combination is the simultaneous treatment of heating and irradiation; less effective is this combination wherein irradiation at room temperature follows the heating procedure; and most ineffective is the heating after irradiation at room temperature.

The combined heat/irradiation treatment results in survival curves (survival fractions) which are straight lines in relation to the irradiation dose at a semi-logarithmic scale in the temperature range between room temperature and 45°C. Above 45°C the curves show, at doses lower than 30 krad, an increase of the survivals compared with the unirradiated sample.

By comparing the slopes of the survival curves obtained at different temperatures, one can see that in the case of irradiation at temperatures higher than 40°C there is a high synergistic effect for the simultaneous treatment, e.g. about 2 orders of magnitude at 150 krad.

Based on these results the technological possibilities of this treatment are under investigation on apple and grape juice.

ÉTUDES MICROBIOLOGIQUES SUR L'INFLUENCE D'UN TRAITEMENT MIXTE PAR CHAUFFAGE ET IRRADIAISON SUR LA SURVIE DE SACCHAROMYCES CEREVISIAE VAR. ELLIPSOIDEUS. L'un des principaux sujets de recherche inscrits au programme international sur la conservation des fruits et jus de fruits par irradiation, exécuté à Seibersdorf, est le problème de la radiosensibilisation des micro-organismes.

En vue d'étudier l'effet d'un traitement par la chaleur et l'irradiation sur la survie des cellules de levures (formation de colonies), une souche à forte radio-résistance - Saccharomyces cerevisiae var. ellipsoideus - cultivée sur un milieu nutritif semi-synthétique, a été soumise dès le début de sa phase logarithmique à un traitement combiné par chauffage et irradiation gamma (source au cobalt-60). Le traitement thermique a été appliqué, soit immédiatement avant l'irradiation, soit pendant ou immédiatement après celle-ci. On a fait varier la température entre 20 et 52.5°C. Pour l'irradiation, effectuée dans un tube en verre bien aéré, on a utilisé des doses allant jusqu'à $0.3 \times 10^6$ rad. L'effet d'inhibition de ce traitement mixte dépend de l'ordre de succession du chauffage et de l'irradiation; les résultats obtenus sont les suivants: la combinaison la plus efficace est un traitement simultané par chauffage et irradiation; la combinaison qui consiste à faire suivre le chauffage d'une irradiation à la température ambiante est moins efficace; le moins efficace est obtenue par chauffage après irradiation à la température ambiante.

Le traitement mixte chaleur/irradiation donne des courbes de survie (fractions d'organismes survivants) qui sont des lignes droites ayant pour coordonnées la dose d'irradiation à une échelle semi-logarithmique, et la température dans l'intervalle compris entre la température ambiante et 45°C. Au-dessus de 45°C, les
couches indiquent, à des doses inférieures à 30 krad, un accroissement du nombre des survivants par rapport à l'échantillon non irradié.

En comparant les pentes des courbes de survie obtenues à des températures différentes, on constate que, dans le cas d'une irradiation à une température supérieure à 40°C, le traitement simultané produit un effet synergique prononcé, qui atteint deux ordres de grandeur pour 150 krad.

En partant de ces résultats, on procède actuellement à une étude des possibilités techniques de ce traitement sur des jus de pomme et de raisin.

MICROBIOLOGICHE IССЛΕDΟVANΙЯ ВЛИЯНИЯ СОВМЕСТНЫХ ПРОЦЕССОВ НАГРЕВА И ОБЛУЧЕНИЯ НА ВЫЖИВАНИЕ SACCHAROMYCES CEREVISIAE VAR. ELLIPTISOIDEUS. В рамках международной программы Зайберсдорфской лаборатории по облучению фруктов и фруктовых соков с целью их сохранения одним из наиболее важных исследований является радиационная сенсибилизация микроорганизмов.

Для изучения влияния термической обработки и облучения на выживание дрожжевых клеток (образование колонии) высококоустойчивая к радиации разновидность Saccharomyces cerevisiae var. ellipsoideus, выращенная в полусинтетической питательной среде, подверглась в начале лог-фазы своего развития комбинированной обработке нагревом и гамма-облучением (источник - кобальт-60). Нагрев производился или непосредственно перед процессом облучения, или одновременно с ним, или после него. Температура менялась от 20 до 52,5°С. Облучение велось в хорошо продутом воздухом стеклянном сосуде в интервале доз до 0,3*10⁶ рад. Ингибирующий эффект такой обработки зависит от последовательности нагрева и облучения. Было установлено следующее: наиболее эффективным является одновременное проведение нагрева и облучения, менее эффективным является облучение при комнатной температуре после нагрева; наименее эффективным оказался нагрев после облучения при комнатной температуре.

В результате комбинированной термической и радиационной обработки были составлены графики выживания (фракции выживания), представляющие собой прямые линии относительно доз радиации в полулогарифмическом масштабе в интервале температур от комнатной до 45°С. При температуре выше 45°C в дозах менее 30 крад графики показывают увеличение выживаемости по сравнению с необлученными образцами.

Сравнивая наклон кривых выживания, полученных при различных температурах, можно заметить, что при облучении при температурах выше 40°C наблюдается сильный синергетический эффект, например на два порядка при 150 крад.

На основании полученных результатов сейчас изучаются технологические возможности такой обработки яблочных и виноградных соков.

ESTUDIOS MICROBIOLOGICOS DE LA INFLUENCIA DEL CALENTAMIENTO E IRRADIACION COMBINADOS SOBRE LA SUPERVIVENCIA DEL SACCHAROMYCES CEREVISIAE VAR. ELLIPSOIDEUS. Uno de los principales temas de investigación incluidos en el programa internacional relativo a la irradiación de frutas y zumos de fruta que se viene ejecutando en Seibersdorf se refiere al problema de la radio-sensibilización de microorganismos.

Para estudiar los efectos del tratamiento térmico y del tratamiento por irradiación sobre la supervivencia de las células de levadura (formación de colonias), se sometió a un tratamiento combinado de aplicación de calor y de irradiación gamma (fuente: 60Co), al comienzo de su fase de desarrollo logarítmico, una cepa de elevada radioresistencia -Saccharomyces cerevisiae var. ellipsoideus - cultivada en un medio nutritivo semisintético. El calor se aplicó inmediatamente antes de la irradiación, durante ésta o inmediatamente después. Las temperaturas estuvieron comprendidas entre 20 y 82,5°C. La irradiación se realizó con dosis de hasta 0,3 X 10⁶ rad, en un tubo de vidrio bien aireado. El efecto inhibidor de este tratamiento combinado depende del orden en que se suceden la aplicación del calor y la irradiación; habiéndose llegado a las siguientes conclusiones: la combinación más eficaz consiste en simultaneizar el tratamiento térmico con el tratamiento por irradiación; esta combinación resulta menos eficaz cuando la irradiación a la temperatura ambiente tiene lugar a continuación del tratamiento térmico; la combinación de eficacia mínima consiste en proceder al tratamiento térmico después de haberse efectuado la irradiación a la temperatura ambiente.

El tratamiento térmico combinado con la irradiación se traduce en un gráfico de supervivencia (fracciones de supervivencia) que presenta la forma de línea recta en función de la dosis de irradiación en una escala semilogarítmica para el intervalo de temperaturas comprendido entre la temperatura ambiente y 45°C. Por encima de los 45°C las líneas revelan un aumento de las supervivencias, en comparación con la muestra no irradiada, para dosis inferiores a 30 krad.

Comparando las pendientes de las líneas de supervivencia obtenidas a distintas temperaturas, puede observarse que en el caso de una irradiación a temperaturas superiores a 40°C se produce un acusado efecto
Within the framework of the Seibersdorf international programme on the irradiation preservation of fruit and fruit juices, one of the main items of research deals with the problem of radiosensitization of microorganisms. It is necessary, not only for reasons of wholesomeness, but also from the economic point of view, to lower the preservation dose as much as possible. Organoleptic changes due to irradiation or heating must also be taken into consideration. Therefore a combination of two less drastic procedures seems to be more suitable than one single drastic inactivation method.

Various authors deal with the problem of combined heat and irradiation treatments on microorganisms, one of the most important being Levinson and Hyatt [1], who have made a detailed study of the application of radiation and heat on spores of aerobic bacilli, relating to germination and post-germination development. They found that, to a certain extent, irradiation sensitizes the surviving fraction of spores for subsequent heating, the reverse treatment, however, being ineffective.

The authors studied the effect of heating and gamma irradiation on the survival of yeast cells by investigating their colony formation capabilities. For this purpose a highly radioresistant strain was used, Saccharomyces cerevisiae var. ellipsoideus, from the Institut für Angewandte Mikrobiologie in Vienna. This strain was cultured, as well as heated and irradiated, in a semi-synthetic nutrition medium consisting of:

- Ammonium sulphate 5.0 g
- Potassium dihydrogen orthophosphate 1.0 g
- Magnesium sulphate 0.5 g
- Sodium chloride 0.1 g
- Bacto yeast extract from Difco 7.0 g
- Sucrose dissolved in one litre of distilled water 50.0 g

Heat and irradiation treatments were carried out in this semi-synthetic nutrition medium at the beginning of the logarithmic phase of yeast multiplication, controlled by means of the Warburg technique.

The irradiation source was a $^{60}$Co gamma cell, which has a dose-rate of about $0.8 \times 10^6$ rad, as estimated by Fricke dosimeter [2]. Irradiation and heating were carried out on 3-ml portions of a yeast suspension containing about $0.9 \times 10^8$ cells per millilitre in well-aired glass tubes of a total volume of 5 ml. The temperature of these tubes, even during irradiation, was regulated by a water flow and was controlled, using a wheatstone bridge and thermistors. The heating time always lasted 25 min, whereas temperature and irradiation doses were varied. This relatively long heating time was necessary to irradiate equally up to a dose of $0.3 \times 10^6$ rad without changing the temperature during the irradiation procedure.

Heat treatment was combined with irradiation in three different ways: it was applied either immediately before the irradiation procedure, during...
irradiation or immediately afterwards. In this work investigation was made of the dose range of gamma irradiation up to $0.3 \times 10^6$ rad, and the temperature interval between 20°C and 52.5°C. After these various treatments the samples were diluted with Ringer solution, incubated on agar agar plates and the surviving fraction of yeast cells determined by the Koch method, or by a modified Frost [3] method.

In Fig. 1 are shown examples of the survival curves of Saccharomyces cerevisiae var. ellipsoideus for simultaneous heat and irradiation treatment. The logarithm of the surviving fraction $N/N_0$ can be seen plotted against the irradiation dose as was shown after treatment at different temperatures. Within the range from 20°C to 45°C almost straight lines were observed (see 1, 2 and 3). At higher temperatures some stimulation effect was found with low gamma doses, but with higher doses straight lines also occurred.

By comparing the slopes of the survival curves received at different temperatures, it can be seen that there is not only an addition of the effects of irradiation and heating, but a highly synergistic effect for these
for irradiation carried out at room temperature is $2 \times 10^{-6}$. The corresponding value for irradiation at $45^\circ$C, for example, is about seven times greater. The observed slopes for the linear range of yeast surviving for irradiations done at higher temperatures are greater with the factor 10 for $47.5^\circ$C, 13 for $50^\circ$C and 20 for $52.5^\circ$C.

In Fig. 2 can be seen yeast survival curves which were obtained for different kinds of heat/irradiation combinations. The dash-dotted lines show heat treatment immediately following irradiation carried out at room temperature. This means that the samples were irradiated at room temperature, then warmed to the indicated temperature and cooled down again after 25 min. The dashed lines mean the same treatment carried out 5 min before irradiation at room temperature. This indicates that
the samples were kept at the temperature shown during 25 min, then cooled down and irradiated at room temperature.

The black lines show the results for the simultaneous heat and irradiation treatment.

These treatments are shown to have been done at 45°C, 47.5°C and 50°C. For separated heat-irradiation treatments the slopes of curves obtained at different temperatures are nearly the same, but in the case of the simultaneous treatment, a highly synergistic effect can be observed.

It is obvious that the inhibiting effect on yeast multiplication of such combined treatments depends upon the sequence of heating and irradiation. Excluding the zone of stimulation at low gamma doses it shows the following results:

The most effective combination is the simultaneous treatment of heating and irradiation with a highly synergistic effect.

This combination is less effective when irradiation at room temperature follows the heating procedure.

Heating after irradiation at room temperature is the least effective combination.

These results obtained from yeast cultures are also reflected in storage tests on fruit juices. Apple juice and grape juice containing natural microbiological population [4], were poured into 100-ml sera flasks with air as ambient atmosphere. After heat and irradiation treat-
ments the flasks were stored at room temperature and the range of time until the beginning of fermentation was estimated. Each treatment was carried out on at least 20 bottles. Some results of these storage tests can be seen schematically in Fig. 3. The figure shows the average storage time of juices in relation to the irradiation dose. On the left side are shown the results for grape juice. The white lines stand for heat treatment at 50°C immediately after irradiation at room temperature, the black lines for irradiation performed at 50°C. It can be seen that the storage time can be extended from 2.5 d to 6 d after heat treatment alone, up to 19 d if heat treatment has been carried out after irradiating the samples with 500 000 rad, and up to 30 d if heat and irradiation treatment is carried out simultaneously.

Far more promising are the results obtained from apple juice. The storage time can be extended to more than 240 d by irradiating the samples at 50°C with 300 000 rad. This is a very good result if it is considered that a significant threshold level for irradiated apple juice lies at about 200 000 rad, as estimated by means of organoleptic tests.

Tests on grape, as well as on apple juice, prove that the most effective combination is the simultaneous treatment of heating and irradiation.

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DISCUSSION

M. INGRAM: It is interesting that low doses of γ-rays, applied in a few minutes presumably, appear to reverse damage caused by heat. This effect might depend, of course, on how long the heat is applied. Was anything done to ensure that the temperatures you have quoted were actually being applied at the exact moment when irradiation began?

G. STEHLIK: The samples were heated before irradiation, the heating time being maintained consistently at 25 min. Irradiation was carried out during the last phase of this heating period.

G. MOCQUOT: Do you have any idea why there is such a pronounced difference in storage time between grape juice and apple juice?

G. STEHLIK: Yes, it is because the grape juice contains a highly radio-resistant strain of Saccharomyces cerevisiae which requires about 1.8 Mrad at room temperature for its inhibition.
THEORETICAL AND APPLIED ASPECTS OF RADIATION D-VALUES FOR SPORES OF CLOSTRIDIUM BOTULINUM

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Abstract — Résumé — Аннотация — Resumen

THEORETICAL AND APPLIED ASPECTS OF RADIATION D-VALUES FOR SPORES OF CLOSTRIDIUM BOTULINUM. Spores of C. botulinum have been found to have equal or greater resistance to ionizing radiations than spores of other non-toxic food spoilage organisms. For this reason the microbiological processing standards for radiation preservation of foods were invariably related to radiation resistance of spores of C. botulinum. The index of radioresistance is the $D_{10}$-value defined as the dose necessary to inactivate one log cycle (90%) of a given spore population and $12 \times D$ has been arbitrarily defined as the safe radiation preservation dose for food products. Extensive data from the author's laboratory revealed that (a) the $D_{10}$-value of a particular strain depended on temperature, medium and size of spore inoculum and (b) substantially different D-values may be obtained depending on the method of calculation and unknown variations from experiment to experiment. This information provides a basis for reappraisal of the $12D$ concept.

The temperature during radiation can be shown to influence indirect effects of radicals: (a) their formation, (b) chemical reactivity, (c) extent of annealment and (d) diffusion, especially during liquid-solid transition of the medium around 0°C. A combination of these temperature-dependent effects explains why spores are most sensitive when irradiated at 0°C as compared with higher or lower temperatures. In addition to its effect on radicals, the temperature also affects the essential targets (DNA) directly. This involves the vibrational state as well as the extent of hydration of the DNA molecules. The apparent hydration of DNA is related to the range of action of indirect effects which can be calculated for C. botulinum 33A to add an additional 30Å to the radius of DNA (10.5Å), i.e. almost triple the effect of radiation. This change in radiosensitive volume is reflected by a corresponding change in $D_{10}$ value from $1.6 \times 10^4$ rad for the dry spore to $6.6 \times 10^4$ rad for the wet spore.

The suspending medium may either compete for radicals, e.g. most foods and microbiological media are radical scavengers, or it may promote formation of harmful radicals, e.g. phosphate buffer forms phosphinic acid, oxygen forms peroxy and perhydroxyl radicals.

Changes of $D_{10}$-values of an individual strain caused by various environmental conditions can be related to indirect effects, while changes of $D_{10}$ values from strain to strain under standardized conditions relate to the amount and structure of nucleoid DNA in spores. In this respect all strains of C. botulinum studied to date can be tentatively divided into three groups. Group 1 includes strains (A, B and E) with $D_{10}$ values around 0.13 Mrad or less. These spores exhibit single-hit inactivation curves and have probably one chromosome with a low repair probability. Group 2 includes strains 12888 A, 62A, 77A, 9B clustering around $D_{10} = 0.23$ Mrad. Available target data suggest that these spores possess one chromosome of 900μ with a repair multiplicity of 13. Group 3 includes the highly-resistant strains 33A, 36A, 40B, 41B, and 53B clustering around $D_{10} = 0.33$ Mrad. Available target data suggest that these spores possess two chromosomes of 900μ each with a repair multiplicity (N) between 80 and 90, i.e. $N = 13^2/2$.

ASPECTS THERORIQUES ET PRATIQUES DES VALEURS D DE RAYONNEMENT APPLIQUEES AUX SPORES DE CLOSTRIDIUM BOTULINUM. Il a été constaté que les spores de C. botulinum offrent aux rayonnements ionisants une résistance qui est égale ou supérieure à celle des spores d'autres organismes non toxiques provoquant l'altération des denrées alimentaires. Pour cette raison, les normes de traitement microbiologique appliquées pour la conservation des aliments par les rayonnements sont toujours fonction de la radiorésistance des spores de C. botulinum. L'indice de cette radiorésistance est la valeur $D_{10}$ définie comme la dose nécessaire pour inactiver un cycle logarithmique (90%) d'une population de spores donnée, tandis que le terme $12 \times D$ a été arbitrairement défini comme la dose sûre pour la conservation des aliments par irradiation. Il ressort des données détaillées fournies par le Laboratoire de biophysique de Chicago que...
a) значение коэффициента D 10 для сухой споры равно 0,23 Mrad; данные по целям, которые мы располагаем, указывают, что эти споры содержат два хромосомы по 900 Мб.

В зависимости от температуры, среды и размера спор и других факторов, коэффициенты D работают в различных условиях, и это обусловлено различными факторами, которые влияют на радиочувствительность. Это позволяет классифицировать споры Clostridium botulinum на основе их радиочувствительности.

Теоретически и прикладные аспекты коэффициента излучения для спор Clostridium botulinum. Установлено, что споры Clostridium botulinum имеют разную или большую радиочувствительность к воздействию ионизирующих излучений, чем споры других нетоксичных организмов, портящих продукты. По этой причине стандарты микробиологической обработки в целях консервации продуктов с помощью излучений неизменно соотносятся со стойкостью к воздействию ионизирующих излучений. Коэффициент радиочувствительности представляет собой значение D 10, определяемое как доза, необходимая для 90% инактивации одной попытки, и D 12 определяется как безопасное значение, предполагая, что одна спора способна к активации после одной облучения.

Для описания воздействия температуры на радиочувствительность спор Clostridium botulinum, были проведены эксперименты, которые показали, что снижение температуры на 10°С приводит к увеличению коэффициента D 10 на 50%. Это обусловлено тем, что споры, облученные при более низкой температуре, имеют больше времени на восстановление после облучения, что приводит к увеличению их радиочувствительности.

Таким образом, радиочувствительность спор Clostridium botulinum зависит от температуры, среды и других факторов. Это позволяет классифицировать споры на основе их радиочувствительности и выбирать соответствующие методы радиационной обработки для консервации продуктов.
Изменение значений D_{10} отдельного вида, вызванные различными окружающими условиями, могут быть связаны с косвенным влиянием, в то время, как изменения D_{10} при равных условиях связаны с количеством и структурой нуклеоид ДНК в спорах. В этом отношении все виды C. botulinum, изученные в настоящее время, могут быть экспериментально разделены на три группы: группа 1 включает виды (А, В и Е) со значениями D_{10} примерно 0,13 Мрад или менее. Эти споры дают кривые одиночной инактивации соударений и имеют вероятно одну хромосому с низкой степенью восстановления. Группа 2 включает виды 12 885 А, 62 А, 77 А и 9 В, группирующиеся около D_{10} = 0,23 Мрад. Имеющиеся данные о мишенях показывают, что эти споры имеют одну хромосому 900 микрон с коэффициентом восстановления 13. Группа 3 включает высокостойкие виды 33 А, 36 А, 40 В, 41 В и 53 В, группирующиеся около D_{10} = 0,33 Мрад. Имеющиеся данные о мишенях показывают, что эти споры имеют две хромосомы по 90 микрон каждая с коэффициентом восстановления (N) между 80 и 90, т.е. N = 13^2/2.

ASPECTOS TEORICOS Y PRACTICOS DE LOS VALORES D PARA ESPORAS DEL CLOSTRIDIUM BOTULINUM. Se ha comprobado que las esporas del C. botulinum ofrecen una resistencia a las radiaciones ionizantes igual o superior a la de las esporas de otros organismos atóxicos que estropean los alimentos. Por esta razón, las normas de tratamiento microbiológico para la conservación de alimentos se han relacionado siempre con la radioresistência de las esporas del C. botulinum. El índice de radioresistência es el valor D_{10}, definido como la dosis necesaria para inactivar un ciclo de desarrollo logarítmico (90%) de una población dada de esporas, habiéndose fijado arbitrariamente en 12 x D, la dosis para la conservación sin riesgos de los alimentos por irradiación. La copiosa información obtenida por los autores en su laboratorio ha puesto de manifiesto: a) que el valor D_{10} de una determinada cepa depende de la temperatura, del medio y de la cantidad de inóculo de esporas, y b) que según el método de cálculo empleado y como consecuencia de variaciones desconocidas entre un experimento y otro, pueden obtenerse valores D fundamentalmente distintos. Esta información justifica una reevaluación del concepto de 12 x D.

Puede demostrarse que la temperatura empleada durante la irradiación influye indirectamente, de distintas formas, sobre los radicales: a) su formación; b) reactividad química; c) duración del recocido; d) difusión, particularmente durante la transición de líquido a sólido del medio en torno a los 0°C. La combinación de estos efectos, que son función de la temperatura, explica por qué las esporas son más sensibles cuando se las irradiía a 0°C que cuando se empleen temperaturas más altas o más bajas. Además de sus efectos sobre los radicales, la temperatura afecta también, directamente, a los blancos esenciales (ADN). En esto interviene el estado vibracional así como el grado de hidratación de las moléculas de ADN. La hidratación aparente del ADN está relacionada con el intervalo de acción de los efectos indirectos, que para el C. botulinum 36A puede calcularse que añade 30 Â al radio del ADN (10,5 Â), es decir, casi se triplica el efecto de la radiación. Esta variación del volumen radiosensible se refleja en un cambio correspondiente del valor D_{10}, que pasa de 1,6 · 10^4 rad para las esporas secas a 6,6 · 10^4 rad para las esporas húmedas.

El medio de suspensión puede competir por los radicales (por ejemplo: la mayoría de los alimentos y de los medios microbiológicos son depuradores de radicales), o facilitar la formación de radicales perjudiciales (por ejemplo: el fosfato amortiguador forma ácido fosfónico y el oxígeno forma radicales peroxido y perhidroxilo). Las variaciones de los valores D_{10} de una determinada cepa motivadas por diversas condiciones ambientales pueden relacionarse con los efectos indirectos, en tanto que las variaciones en los valores D_{10} entre una cepa y otra en condiciones normalizadas se relacionan con la cantidad y la estructura del ADN nucleoide de las esporas. A este respecto, todas las cepas del C. botulinum estudiadas hasta la fecha pueden ser clasificadas provisionalmente en tres grupos. El grupo 1 comprende las cepas (A, B y E) con valores D_{10} de 0,13 Mrad aproximadamente o menores. Estas esporas proporcionan curvas de activación de impacto único, y probablemente tienen un solo cromosoma, con una probabilidad muy baja de autorregeneración. El grupo 2 comprende las cepas 12 885A, 62A, 77A y 98, cuyo valor D_{10} es del orden de 0,23 Mrad. Los datos de que se dispone sobre los blancos sugieren que esas esporas poseen un solo cromosoma de 900 µm con un factor de autorregeneración de 13. El grupo 3 comprende las cepas sumamente resistentes 33A, 36A, 40B, 418 y 53A, siendo el correspondiente valor D_{10} = 0,33 Mrad. Los datos de que se dispone sobre los blancos sugieren que estas esporas poseen dos cromosomas de 900 µm cada una, con un factor de autorregeneración (N) comprendido entre 80 y 90, es decir, N = 13^2/2.

Available research information indicates that there are some cardinal differences between the effects of heat and radiation as microbial inactivation agents (Table 1). It can be easily seen that the
differences summarized in Table I can all be traced to differences in the basic biophysical action of the two energies on essential cell molecules. While heat disrupts weak hydrogen bonds and occasionally breaks stronger covalent bonds by intense Brownian motion of water particles in the medium, it also puts stress on the biological molecules themselves by intensifying their rotational, vibrational and translational behavior. In general these are relatively weak forces which affect molecular organization but do not disturb the atomic structure of the matter. The quantum of a water particle at 121°C can be calculated to be $8.7 \times 10^{-2}$ eV.

Radiation, on the other hand, carries extremely energetic quanta in the vicinity of $E=1$ MeV. These cause random ionizations and excitations in cell molecules as well as in the surrounding medium, especially water. The latter causes the so-called indirect effects of radiation which involve chemical oxidations and reductions acting somewhat like chemical poisons.

Although the precise cell molecules involved in death of microorganisms from heat have not yet been identified, the great degree of protein denaturation and the requirement of enriched media for survival of bacterial cells seem to suggest that cell enzymes may be involved. However, the possibility of simultaneous damage to DNA has not been excluded. In fact, cell death from heat may perhaps not involve any one specific molecule, but may be related to a certain amount of damage to any kind of molecule. On the other hand, it seems fairly well established that death from ionizing radiations especially under direct hit conditions can be related to nuclear DNA molecules (1). Along with the injury to DNA there is always a certain amount of damage to other cell components; the extent of this non-nuclear damage may vary depending on the extent of indirect effects. It is interesting that this non-nuclear damage by migrating active radicals appears to be the principle cause for the loss of heat resistance by irradiated spores (2).

While DNA has been identified as the site of action responsible for death of cells, the precise mechanism of damage to the DNA molecule is still obscure. It is thought that covalent bonds may be broken resulting in the loss of purine and pyrimidine leading to mutation; or the chain itself may be broken resulting in strand scission and thus affecting DNA replication (3). DNA in bacteria is double stranded; it replicates itself by means of a polymerase in such a way that any one of the strands may act as a complementary template. These two features give DNA a considerable survival value as compared with other molecules. It was estimated that ionization hitting double stranded DNA will produce inactivation only once every ten hits, probably when coincident scission of both strands occurs. However, recently some doubt was expressed concerning the role of chain scission of DNA as the cause of cell death (4).

In addition to direct hits, indirect effect of radiation induced radicals may produce lethal or non-lethal changes in cell components, including DNA. These changes are largely responsible for the changes in radioresistance of bacterial spores. Indirect effects may be modified by temperature and by presence of certain molecules in the medium, e.g. radical scavengers such as sulfhydryl compounds, proteins, glycerin, etc. or molecules potentiating the effect of radiation particularly oxygen, sodium nitrite, etc. Before we consider the factors affecting radiation resistance let us shortly discuss the units and concepts describing radioresistance of bacterial spores.

**D_{10} value and the 12-D concept**

The generally accepted index of sterilization is the $D_{10}$ value which is defined as the dose required to destroy 90% of the population subjected to radiation (or heat). In recent literature $D_{10}$ was used
in preference to the conventional D without subscript to indicate 10% survival (5, 6). $D_{10}$ should be distinguished from $D_{37}$, the 37% survival dose, which plays an important role in theoretical radiation biophysics. $D_{10}$ is useful in calculation of the adequacy of food radiation sterilization processes; it can be determined experimentally by the method of Anellis et al (7) or by the method of Schmidt and Nank (8). The probit method of Anellis (7) appears to be more accurate but it is quite laborious. The method of Schmidt and Nank (8) represents a more direct approach, but requires averaging of several calculations. It uses the formula

$$D_{10} = \frac{\text{Radiation Dose}}{\log M - \log S}$$

where $M$ = the total spore inoculum, i.e. the number of spores per sample times the number of replicate samples, and $S$ = the number of swelled containers or the number of survivors assuming at least one survivor per swelled container.

This calculation method has been borrowed from thermal processing practices. In 1948, Stumbo, (20) developed this formula for the calculation of D values from thermal partial spoilage data. Later in 1960 it has been introduced by Schmidt & Nank (8) into radiation sterilization work, particularly for evaluation of partial spoilage data. The formula assumes a logarithmic rate of destruction of spores. However, a number of survival curves published in the literature in phosphate buffer as well as in food products show a multihit (or multi-target) character indicating a requirement of as many as 90 hits for inactivation of a spore (9). Such radiation survival curves usually consist of 3 distinct portions, (a) a "shoulder" which may be up to 3/4 of the first log cycle of spore inactivation and may constitute as much as 0.6 Mrad of the dose; (b) an exponentially declining portion consistent with classical hit theory at doses up to 2.0 Mrad; and (c) a so-called "tail" portion at 2 to as much as 9.0 Mrad. The tail does not follow classical hit theory and is present regardless of the kind of the suspending medium or the initial concentration of spores used.

12 D. Food processors have adapted the classical studies of Esty and Meyer (10) on heat resistance of spores of Clostridium botulinum (in phosphate buffer) as the accepted norm for thermal sterilization of foods. These studies have indicated that a heat processing equivalent to 2.78 min at 121°C was required to reduce $1 \times 10^{12}$ spores of C. botulinum to less than one surviving spore. Subsequently the heat processing time was reduced to 2.45 min at 121°C (11) by taking into account the come-up time neglected in the original study of Esty and Meyer. Allowing a safety margin of 22% in addition to the 12 D dose, food industry has since used an equivalent of 3.0 min at 121°C for thermal processing of non-acid foods, (p>4.5). Over the years this arbitrary norm, called the 12 D dose, has provided a safe thermal process and therefore has found general acceptance.

Since the emergence of active interest in radiation sterilization of foods, it became essential to develop adequate norms for safe food processing by ionizing radiation. It was argued that the new food sterilization process should provide a minimum sterilization effect equivalent in safety to the accepted 12D thermal process. As a consequence, the 12 D concept was borrowed from the thermal processing industry. By employing the best available data at the time pertaining to radiation survival curves of C. botulinum spores, Schmidt 1957 (12) calculated that a comparable radiation processing to effect the same degree of safety as conventional thermal processing would require 4.45 Mrad, i.e. $D = 0.37$ Mrad.

It may be important to emphasize that the original D values for thermal destruction of spores of C. botulinum were determined in phosphate
Table I

Some known differences between the sporocidal characteristics of heat and radiation

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Heat: Bacillus stearothermo-philus $D_{250} = 28$</th>
<th>Effect: Clostridium botulinum types A &amp; B Max $D_{10}$ is 336 000 rad</th>
</tr>
</thead>
<tbody>
<tr>
<td>Most resistant spores</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Most sensitive spores</td>
<td>Clostridium botulinum type E $D_{250} = 0.0003$</td>
<td>Not known; for C. botulinum 51B $D_{10} = 129,000$</td>
</tr>
<tr>
<td>Difference between most sensitive and most resistant spores</td>
<td>Large (93 000 fold)</td>
<td>Small (2.6 fold)</td>
</tr>
<tr>
<td>Difference between spores and vegetative cells</td>
<td>Infinitely large</td>
<td>Small (For C. botulinum 33A $D_{10}$ for spores = .28 Mrad $D_{10}$ for vegetative cells = .25 Mrad From exponential portion of survival curve)</td>
</tr>
<tr>
<td>Difference between resistance of spores in the dry and wet state</td>
<td>Large</td>
<td>Small</td>
</tr>
<tr>
<td>Mechanism of action</td>
<td>Intense brownian motion breaking H-bonds and occasionally stronger bonds</td>
<td>Random ionizations and excitations; oxidations and reductions</td>
</tr>
<tr>
<td>Cause of cell death</td>
<td>Thermal denaturation of proteins</td>
<td>Inactivation of DNA</td>
</tr>
<tr>
<td>Effect on cell enzymes</td>
<td>Inactivated as spores are killed</td>
<td>Essentially not inactivated</td>
</tr>
<tr>
<td>Effect on preformed botulinum toxin</td>
<td>Inactivated as spores are killed</td>
<td>Essentially not inactivated</td>
</tr>
<tr>
<td>Effect of pH</td>
<td>Strongly pH dependent</td>
<td>Essentially pH independent</td>
</tr>
<tr>
<td>Effect of $O_2$</td>
<td>$O_2$ independent (In wet state)</td>
<td>Strongly $O_2$ dependent</td>
</tr>
<tr>
<td>Effect of enrichment of recovery medium</td>
<td>Enhances Survival</td>
<td>No effect or detrimental to survival (uv)</td>
</tr>
</tbody>
</table>
Analogously $D_{10}$ values for radiation resistance of spores of several strains of *Clostridium botulinum* were determined in phosphate buffer by Anellis and Koch (13). These are summarized and evaluated in terms of the 12 D dose in Table II. It is apparent that 4.0 Mrad represents a 12 D dose, and thus the accepted dose of 4.5 Mrad has an additional safety margin of approximately 10%. Previously, Hannan (15) has considered 16 D or 4.65 Mrad to be necessary for adequate food sterilization; however, the 4.5 Mrad of Schmidt (12) has gained general and lately official acceptance.

**Table II**

Radiation $D_{10}$-values in phosphate buffer and the calculated 12 D food sterilization dose

<table>
<thead>
<tr>
<th>Strains of <em>Clostridium botulinum</em></th>
<th>$D_{10}$ Mrad</th>
<th>12 D Mrad</th>
</tr>
</thead>
<tbody>
<tr>
<td>3. E*, 51B</td>
<td>.134 - .129</td>
<td>1.608 - 1.548</td>
</tr>
</tbody>
</table>

*D*-values from ref. (7) except for Strain E which is from Ref.(14).

**Effect of Temperature on $D_{10}$ values**

The results of a large scale experiment employing 1,725 cans of ground beef inoculated with $10^5$, $10^7$, and $10^9$ spores of *Clostridium botulinum* 33A per radiation dose are summarized in Fig. 1. The data revealed that at lower temperatures progressively larger radiation doses were required for equivalent radiation inactivation of the spores. There was a remarkably high sporocidal effect of radiation at +95° C, in fact, the destruction rate of spores was so rapid that a 10,000 fold difference in spore number caused no apparent difference in radiation dose requirements for comparable sterilization of the inoculated cans. The partial spoilage data were further evaluated in terms of radiation $D_{10}$ values by the method of Schmidt and Nank (8). As indicated in Fig. 2 there was almost no variation in $D_{10}$ values at irradiation temperatures ranging from 0° C to 65° C. At temperatures above 65° C the $D_{10}$-values decreased rapidly. At temperatures below 0° C the $D_{10}$ values increased slowly but steadily. The average decrease in $D_{10}$-values between 65° C and 95° C was 176.7 Krad, i.e. 58.9 Mrad per 10° C, Table III. The lowest spore inoculum level yielded a considerably smaller decrease in $D_{10}$ values in this temperature range than the two higher spore inocula levels. At the same time the average increase in $D_{10}$-values between +25° and -196° C (Table IV) was 300.8 Krad, or an increase in $D_{10}$ value of 13.6 Krad per $10^0$ C decrease in temperature. Here again the lowest spore inoculum yielded a somewhat larger increase in $D_{10}$ values than the two higher spore inocula. The $D_{10}$ values between +25° and -196° C essentially doubled, and more than doubled between +85° and -196° C. In this connection it is important to note the following. It has been repeatedly reported in the literature that radiation resistance of bacterial spores in aqueous media, but not in solid or gas, was lowest at approximately 0° C (16, 17, 18). A very definite decrease in radiation resistance of spores of *Clostridium botulinum* 33A could be observed at 0° C in our laboratory by subculture techniques in tris, borate and phosphate buffers as well as in pork pea broth (Fig. 3). From these
results it appeared that the transition from the solidly frozen state to the liquid state around 0°C causes a considerable one-step change in diffusion rates of radiation induced radicals resulting in a greatly increased efficiency of indirect action of radiation effects in the liquid state around 0°C as compared with the solid state at lower temperatures. As temperature increases above 0°C, processes of radiation protection due to repair, charge transfer, radical annealment or perhaps to an active heat resistance mechanism providing an effective sink for harmful radiation energy become increasing predominant these processes
Effect of Irradiation Temperature on D$_{10}$ Values

(Range: 65°C to 95°C)

<table>
<thead>
<tr>
<th>Irradiation Temp. °C</th>
<th>$D_{10}$ Values (Mrad)</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$10^5$ Spores*</td>
<td>$10^7$ Spores*</td>
<td>$10^9$ Spores*</td>
</tr>
<tr>
<td>+95</td>
<td>.2374</td>
<td>.1587</td>
<td>.1214</td>
</tr>
<tr>
<td>+65</td>
<td>.3874</td>
<td>.3402</td>
<td>.3201</td>
</tr>
<tr>
<td>Difference</td>
<td>-.1500</td>
<td>-.1815</td>
<td>-.1987</td>
</tr>
</tbody>
</table>

*Spore number per radiation dose. Clostridium botulinum 33A in ground beef sealed in TDT cans.

Table IV

Effect of Irradiation Temperature on D$_{10}$ Values

(Range: +25°C to -196°C)

<table>
<thead>
<tr>
<th>Irradiation Temp. °C</th>
<th>D Values (Mrad)</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$10^5$ Spores*</td>
<td>$10^7$ Spores*</td>
<td>$10^9$ Spores*</td>
</tr>
<tr>
<td>-196</td>
<td>.7115</td>
<td>.5895</td>
<td>.6166</td>
</tr>
<tr>
<td>+24</td>
<td>.3629</td>
<td>.3367</td>
<td>.3155</td>
</tr>
<tr>
<td>Difference</td>
<td>.3486</td>
<td>.2528</td>
<td>.3011</td>
</tr>
<tr>
<td>96%</td>
<td>96%</td>
<td>96%</td>
<td></td>
</tr>
</tbody>
</table>

*Spore number per radiation dose. Clostridium botulinum 33A in ground beef sealed in TDT cans.

Contribute to increased resistance of spores above 0°C. The net result is a definite maximum of indirect effects of radiation at 0°C.

We have previously reported (9) that essentially all indirect effects of radiation on C. botulinum 33A could be eliminated by suspending the spores in pork pea broth PPB (19) and lowering the temperature to -196°C. From these data it could be calculated that freezing introduced a water to water molecular bonding which was stronger than the DNA-water bonding and therefore one obtained, in effect, a dry target molecule in the frozen suspension. However, even in the solidly frozen state charge transfer was not entirely eliminated since a considerable amount of...
indirect radiation effect was observed in frozen spore suspensions. In order to eliminate these diffusible effects it was necessary to suspend the spores in PPB, the constituents of which effectively acted as radical scavengers.

From these radiation data it was possible to calculate the range of action of indirect effects due to water surrounding spore DNA. It was found that under conditions of maximum indirect effects, i.e. at 0°C in phosphate buffer, 9-10 water molecules formed an apparent sheath of approximately 30 A around the DNA molecule. If one visualizes that the radius of DNA is considered to be 10.5 A, one can appreciate the magnitude of the relative increase in the target size. As a consequence the $D_{37}$ values between phosphate buffer at 0°C and PPB at -196°C increased from $6.6 \times 10^4$ to $1.6 \times 10^5$ rad, yielding a change in radiation resistance of the spores of some 140%.

In solidly packed ground beef in thermal death time (TDT) cans, we were unable to detect any significant decrease in radiation resistance at 0°C. We have previously reported similar results with ground beef (9). There appears to be a fundamental difference between partial spoilage type of experiments where the organisms remain in the same medium in which they have been irradiated, i.e. ground beef in our case, and experiments attempting to enumerate the survivors by subculture techniques. This observation has not been adequately explained, but one may postulate that some long lived harmful chemical agents produced by radiation in the spore, may be diluted or washed out in the process of routine microbiological subculture.

To our knowledge there is no systematic data available at the present on the effect of temperature on radiation $D_{10}$ values over a very wide range of temperatures such as described here. Numerous reports in the past indicated that the resistance of $C. botulinum$ spores increases at
low temperatures. Our results confirm quantitative data as to the magni-
tude of increase in $D_{10}$ values at low temperatures.

The evaluation of these data in terms of food sterilization norms
presents a new and difficult problem. If one adheres to the 12 D concept,
then prohibitively high radiation doses in the order of 7.1 to 8.5 Mrad
would be required for sterilization of foods at -196°C. However, if one
does not adhere to the 12 D concept, then new standards for safe sterili-
zation of foods at subzero temperatures must be developed.

Effect of Size of Initial Spore Load on $D_{10}$ Values.

Schmidt and Nank (8) have reported no significant difference in
radiation $D$-values determined at 27°C with $10^7$ and $10^9$ spores of C.
botulinum for radiation dose level. This is in agreement with our results
for the same spore load, i.e. $10^7$ and $10^9$ spores. However, when the
initial spore inoculum was lowered to $10^5$ spores, the $D_{10}$-values consistent-
ly and significantly increased. The average $D_{10}$-value increase was
approximately the same at all temperature levels between +95°C through
-196°C (Fig. 2). The average difference in $D_{10}$ values was 69.1 Krad for
the two experiments comparing $10^7$ and $10^9$ spores, and there was no signif-
icant change in $D_{10}$ value between $10^7$ and $10^9$ spores.

Table V

<table>
<thead>
<tr>
<th>Suspending Medium</th>
<th>Spore Number</th>
<th>$D_{10}$ Values (Mrad)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ground Beef</td>
<td>$10^9$</td>
<td>.34</td>
</tr>
<tr>
<td>Ground Beef</td>
<td>$10^7$</td>
<td>.33</td>
</tr>
<tr>
<td>Ground Beef</td>
<td>$10^5$</td>
<td>.41</td>
</tr>
<tr>
<td>Phosphate Buffer</td>
<td>$10^4$</td>
<td>.34</td>
</tr>
</tbody>
</table>

A possible explanation for the increased $D_{10}$-values with $10^5$ spores
may be sought in the relatively high initial radiation protection offered
to spores by the food substrate. Once the initial protective effect is
overcome by the higher radiation doses required for destruction of $10^7$
and $10^9$ spores, the contributory effect of the medium becomes negligible.
This explanation seems to be supported by the fact that $D_{10}$-values
obtained in ground beef with $10^7$ and $10^9$ spores did not significantly
differ from $D_{10}$-values obtained in phosphate buffer, a medium in which a
minimum of radiation protection would be expected (Table V.)

In this connection it was interesting to note that the difference
between radiation doses required for an equivalent sterilization effect of
cans inoculated with $10^5$ and $10^9$ spores at temperatures between 95°C and
-196°C became progressively larger as the temperature was decreased.
The data first summarized in Fig. 1 was recalculated in terms of dose
differences and plotted in Fig. 4. There was a remarkably high sporocidal
effect at 95°C, the same radiation dose 1.7 Mrad, produced sterility in
cans inoculated with $10^5$ and in those with $10^9$ spores. On the other hand,
FIG. 4. Change in radiation doses required to produce an equivalent sterilization effect of cans containing $10^9$ versus $10^5$ spores per radiation level at -196° C almost 2 Mrad more was required to sterilize $10^9$ spores as compared with $10^5$ spores. This observation may, perhaps point to some unforeseen advantages in the combination of heat plus radiation for sterilization of foods. It may also provide potentially fruitful avenues to future experimentation in the area of radiation food technology.

Acknowledgements

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REFERENCES


DISCUSSION

M. INGRAM: I said earlier that there is not much advantage in going below about -20°C when irradiating food in the frozen state, and my contention rests precisely on these observations that Dr. Grecz has made. The eating quality of meat is protected appreciably more at -200°C than at -20°C or even -75°C. Hence it appeared advantageous, as long as we thought the resistance of Cl. botulinum spores was independent of (sub-zero) temperature, to irradiate over liquid air. But Mr. Grecz has shown that, as the temperature is reduced in this part of the sub-zero temperature range, the resistance of the spores increases as much as that of the food, if not more. It seems fair to conclude, therefore, that there is no point in going to lower temperatures.

N. GRECZ: It is of course true that both the food and the microorganisms are protected, yet I am not sure it follows that there is no advantage in going to lower temperatures. Before accepting such a con-
clusion we would have to make a thorough quantitative study of organoleptic and microbiological parameters, comparing the two. Offhand I should say that, with meat, the most advantageous course is to irradiate quite near the freezing point, say at -15°C to -25°C. Frozen food shows much less radiation off-flavour than non-frozen food, and the transition from 0°C to -20°C seems to be particularly important for wet foods like meat. In this respect meat is affected in much the same way as the vegetative cells of bacteria. The transition from non-frozen to frozen does not, however, seem to have much effect on the sensitivity of spores, as I have shown in my paper. This difference between the sensitivity of food and that of bacterial spores could perhaps be used to good advantage in food-irradiation technology.

E. JOSEPHSON: I might usefully add a few comments to Mr. Ingram's remarks. Those of us in the United States who are engaged in high-dose processing of shelf-stable foods do not plan to go below -80°C (± 10° or 20°C), and these low temperatures are to be used only for certain cuts of beef. A programme of inoculated pack work is to get under way on 13 June 1966 with the object of establishing the required radiation dose, so that appropriate applications can be made to the Food and Drug Administration and the Department of Agriculture. The temperatures to be applied during irradiation of chicken, ham, pork, shrimp and some of the beef will be -30°C (±10°); as I said, only certain cuts of beef will be irradiated at lower temperatures. The range indicated by these figures is intended to simulate the conditions that we expect will be encountered in processing on a commercial scale.
IRRADIATION OF DRIED ALBUMIN FROM CATTLE BLOOD: A BACTERIOLOGICAL STUDY. The authors have undertaken a bacteriological study of irradiated albumin obtained from the blood of cattle.

The albumin was obtained by drying blood collected in bulk at a slaughterhouse of the Argentine Meat Producers' Corporation. The blood was separated by centrifuging into two fractions, white and red, the white fraction containing plasma, leukocytes and platelets, and the red fraction consisting of erythrocytes.

The albumin is contaminated by microbes due to: (a) the impossibility of extracting the amount of blood involved (100,000 litres daily) under aseptic conditions; (b) transport of microbes in the blood during slaughter; (c) possible contamination by the blood of sick animals (veterinary examinations are carried out after extraction of the blood); (d) contamination caused by actual carcass processing.

At present this material is used as a fertilizer, and for other industrial applications, but only in a minor degree for human nutrition.

The reaction of the bacterial flora to gamma radiation was studied with the aid of a Gammacell 220 apparatus operating in the dose range 0.5 - 4 Mrad.

In the first test the whole material was irradiated, and total and differential counts performed for the purpose of identifying the different strains. The isolated bacterial flora was then studied together with the particular response, in each case, to different doses.

The authors describe changes in the biochemical behaviour of some strains after irradiation.
OBLECHENIE VYSUŠENNOGO ALBÜMINA IZ KROVI KRUNOGO ROTAČOGO SKOTA - BAKTERIOLÓGICHESCHE ISSLEDONWIJA. Pроведены бактериологические исследо- 
вания облученного альбумина, полученного из крови крупного рогатого скота.

Албумин был получен путем высыхивания крови, собранной большей частью на бойне 
Аргентинской корпорации производителей мяса. Путем центрифугирования кровь разделяли 
на две фракции, красную и белую; белая фракция содержала плазму, лейкоциты и тромбоциты, 
в красная фракция состояла из эритроцитов.

Албумин заражается микробами на бойне, причинами чего являются: а) невозмож- 
ность извлечения всего количества крови (100 000 л ежедневно) в асептических условиях, 
б) перенос микробов в кровь во время убоя; в) возможное заражение через посредство кро­ 
ви больных животных (ветеринарные обследования проводятся после извлечения крови); г) за- 
ражение, вызываемое процессами, имеющими место в тушке.

В настоящее время этот материал используется в качестве удобрения и для других 
промышленных целей, и только малый процент идет в пищу.

Реакция бактериальной флоры на облучение гамма-лучами была изучена с помощью 
прибора гамма-камеры 220, излучающего дозы от 0,5 до 4 мрад.

При первом испытании весь материал был облучен, и в целях установления различных 
видов микробов были проведены общие и дифференциальные расчеты. Изолированная бакте­ 
риальная флора была после этого исследована вместе с определенной в каждом случае устой­ 
чивостью к различным дозам.

Дается описание изменения в биохимическом поведении некоторых видов микробов после 
облучения.

IRRADACION DE ALBÚMINA DE SANGRE DESECADA DE BOVINO: ESTUDIO BACTERIOLÓGICO. 
En el presente trabajo se encara el estudio bacteriológico de albúmina de sangre de bovino irradiada. 
Esta albúmina es el producto del desecamiento de la sangre recolectada a granel durante el 
faenamiento diario de la Planta de la Corporación Argentina de Productores de Carnes. Por centrifugación 
son obtenidos dos tipos: blanca y roja. La primera corresponde a plasma, leucocitos y plaquetas; la segunda 
a hemáties.

El producto se encuentra contaminado por gérmenes. La causa de esta contaminación es múltiple: 
a) Imposibilidad de extracción aséptica por el volumen involucrado (100 000 litros diarios); b) Veticulación 
por vía hemática durante la matanza; c) Posible contaminación con sangre de animales enfermos (el control 
veternario es posterior a la extracción); d) Contaminación debida al tratamiento en sf.

Actualmente dicho material es utilizado como abono y otras aplicaciones industriales, pero solamente 
en menor grado en la alimentación humana.

Se realizó el estudio de la respuesta de la flora bacteriana a la irradiación gamma. Se utilizó el 
Gammacell 220 en dosis desde 0,5 hasta 4 Mrad.

En un primer ensayo se realizaron irradiaciones del material íntegro y se efectuaron recuentos totales 
y diferenciales por identificación de las cepas correspondientes. Posteriormente se estudió la flora bacteriana 
aislada y la respuesta particular, en cada caso, a las distintas dosis.

Se describen cambios de comportamiento bioquímico aparecidos en algunas cepas luego de la 
irradiación.

1. La sangre de ganado vacuno, que se obtiene como subproducto de la 
industria frigorífica, es actualmente utilizada como abono, alimentos ba-
 lanceados para animales, pegamientos para maderas, para estabilizar 
emulsiones bituminosas líquidas, colas y, en menor grado, como alimento 
humano.

Comparativamente presenta un contenido proteico y un valor calórico 
de 66% de la carne magra de vacuno.

Debido a características inherentes al proceso de faenamiento de los 
animales, la sangre es vehículo de gérmenes saprófitos y eventualmente 
patógenos. Teniendo en cuenta, además, que es un buen medio de cultivo, 
solamente puede emplearse en la alimentación humana cuando forma parte 
de un subproducto cuya elaboración se efectúa mediante el calor.

En consecuencia se destina a fines industriales un producto que por 
sus características podría constituir un alimento de alto valor nutritivo. 
Esto resulta de indudable importancia para nuestro país donde la magnitud 
del volumen involucrado es considerable.
2. En los establecimientos frigoríficos de la Corporación Argentina de Productores de Carnes (CAP), la sangre vacuna proveniente de la faena diaria es elaborada, obteniéndose, como resultado final, un producto desecado pulverulento (figura 1).

La sangre normal extraída de animales preferentemente jóvenes (excluyendo toros y vacas) es tratada inmediatamente con una solución de anticoagulante. Posteriormente se realiza la separación por medio de centrífugado continuo de dos fracciones denominadas albúmina blanca y albúmina roja.

La albúmina blanca, que constituye el 60% de la sangre entera, tiene una concentración en sólidos del 7% y es llevada por evaporación a altovació al 30%. Finalmente se deshidrata en torre spray, manteniendo una humedad residual del 8 - 10%. La albúmina roja, cuyo contenido en sólidos es del 33%, se acumula en recipientes de acero inoxidable y luego se la deshidrata en la planta spray. El tenor de humedad final es en este caso del 7 - 9%. El producto obtenido se enfría en corriente de aire, envasándose en bolsas de polietileno recubiertas con arpillera.

En la actualidad la planta de elaboración de la CAP está en condiciones de manufacturar 7500 l/h de albúmina concentrada. Esta cantidad de albúmina, teniendo en cuenta que se aprovechan de cada animal alrededor de 5 litros de sangre entera, corresponde a una matanza de 3000 animales por hora. En el frigorífico donde está instalada la planta desecadora, la faena diaria es de 5000 cabezas. Considerando su capacidad potencial se estaría en condiciones de tratar todo el producto proveniente de los principales mataderos de Buenos Aires y alrededores, cuya faena alcanza a 15 000 animales por día.

El rendimiento por animal es de 240 g de albúmina blanca y de 660 g de albúmina roja, resultando entonces una producción potencial de 3,6 t/d de la primera y 10 t/d de la segunda.

3. La albúmina obtenida, blanca o roja, presenta al momento de terminar su tratamiento una contaminación bacteriana importante. Esta contaminación es motivada por los siguientes factores:

a) Imposibilidad de extracción aséptica por los volúmenes involucrados.
b) Movilización bacteriana por vía hemática durante el período de la matanza.
c) Contaminación con el vómito.
d) Posible contaminación con gérmenes patógenos por animales portadores.
e) Características del tratamiento.

4. La albúmina blanca está constituida por el plasma y los leucocitos, y su composición química es la siguiente:

Proteínas: 70-75%; cenizas: 7-10%; grasas: 0,13-0,5%; humedad: 8-10%; las albúminas representan el 57% del contenido proteico, siguiéndoles en importancia las fibrinoglobulinas y las seroglobulinas.

La albúmina roja está constituida por los eritrocitos y plaquetas, presentando la siguiente composición química:

Proteínas: 90-92%; cenizas: 1-3%; humedad: 7-9%; las proteínas están constituidas por hematinas y globulinas.
PRODUCTO FINAL
SALES MINERALES
GLOBULINA
67°C COAGULA
ACTUALES
(INCOMESTIBLES)
ALIMENTO DE AVES,
AROMES ESPECIALES,
ADHESIVOS,
AGLUTINANTES VÁRIOUS.

ANTICOAGULANTE
(Citrato o polifosfato de sodio o de potasio)

CENTRIFUGACIÓN

ALBUMINA BLANCA 40% 40% ALBUMINA ROJA
Solda 8% D = 1,028
Solda 35% D = 1,022

CONCENTRACIÓN
Por alto vacío
Solda 50%

Deshidratación

SECADO

ENVASADO

FUTUROS
(INCOMESTIBLES)
INDUSTRIA PIDEDERA, INDUSTRIA CONFITERA,
CHACINAR, COMO AGLUTINANTE INCOLORO,
PARA PAMBRES TIPO ALEMAN,
COMO LIGANTE DE CONSERVAS DE CARNE.

FIG. 1. Proceso de obtención del producto utilizado en la CAP
5. Por sus características químicas este derivado podría utilizarse en la industria alimenticia. Así la albúmina blanca tiene aplicación en la fabricación de fideos, chacinados, en la industria repostería, como aglutinante incoloro para fiambres, como ligante de conservas de carne, etc. La albúmina roja, como clarificante de bebidas, en la elaboración de chacinados, etc.

Dada la contaminación existente, la utilización actual se encuentra limitada a otras aplicaciones, según puede apreciarse en la figura 1. La esterilización de este producto por métodos convencionales altera sus características físicas reduciendo sus posibilidades para la alimentación humana. En consideración a este problema, entre el Laboratorio Central de la CAP y el Departamento Fuentes Intensas de Radiación de la CNEA, se ha elaborado un programa de trabajo tendiente a evaluar la posibilidad de aplicar la irradiación para la esterilización del producto.

Este plan incluye los siguientes aspectos:

a) Estudio bacteriológico.

b) Modificaciones físicas y químicas.

c) Comestibilidad.

En el presente trabajo se encara el primer aspecto y se muestran los resultados obtenidos hasta el momento.

6. Se ha utilizado albúmina blanca y albúmina roja de las características y procedencia descriptas. Para el estudio bacteriológico las albúminas fueron tratadas en solución fisiológica isotónica. A continuación se efectuaron siembras en medios de cultivo y de enriquecimiento a diferentes pH y potencial redox. Los aislamientos se hicieron por diluciones sucesivas en medios sólidos, realizándose observaciones macroscópicas y microscópicas, estudiándose luego sus características físicas, químicas, bioquímicas y biológicas.

Los microorganismos fueron clasificados según el Bergey's Manual of Determinative Bacteriology [1], realizándose su determinación de acuerdo al siguiente test: motilidad, cultivos en gelatina, leche, medio de Koser, con fosfato amónico, hidratos de carbono, Voges-Proskauer, rojo de metilo, sulfhídrico, indol, reducción de nitratos, prueba de catalasa, ureasa, reductasa, hidrólisis de gelatina, caseína, almidón, dextrina, agar, tolerancia a diversos agentes químicos, comprobación antigénica.

Las albúminas, envasadas herméticamente en bolsas de polietileno, fueron sometidas a distintas dosis de radiación, realizándose en ellas un recuento total de la flora bacteriana. Con la finalidad de establecer diferencias particulares, se irradiaron posteriormente cepas aisladas. En este caso el tratamiento se efectuó previa siembra en superficie, sobre medio de cultivo sólido, en cápsula de Petri.

Se utilizó como irradiador un equipo de $^{60}\text{Co}$ de 13 000 Ci, con un rendimiento de $10^6$ rad/h (Gammacell 220, Atomic Energy of Canada). Para el recuento total las dosis variaron entre 0,250 Mrad y 4 Mrad. Para las cepas aisladas, entre 0,0033 Mrad y 2 Mrad.

7. Debido a la fluctuante posibilidad de contaminación, justificada por las características del proceso de elaboración, la población bacteriana total presenta variaciones considerables.

Así, en muestras diferentes, ha oscilado entre 64 000 bacterias/g y 320 000 bacterias/g para la albúmina blanca, y entre 883 000 bacterias/g y 3 000 000 bacterias/g para la roja.
FIG. 2. Modificación de los contajes totales por irradiación para la albúmina blanca y la albúmina roja

Los resultados obtenidos irradiando el producto bruto se indican en la figura 2. En ella puede verse que se obtiene una reducción de 10^4 para la albúmina blanca con una dosis de 0,5 Mrad, y para la albúmina roja con una dosis de 2 Mrad.

El análisis bacteriológico de las cepas contaminantes arrojó la siguiente composición para un lote determinado:

**Albúmina blanca**
- Cepa 1 Bacillus Circulans 32%
- Cepa 2 Gaffkia Tetragena 25%
- Cepa 3 Bacillus Laterosporus 9%
- Cepa 5 Bacillus Cereus 34%

**Albúmina roja**
- Cepa 4 Brevi Bacterium Imperiale 21%
- Cepa 5 Bacillus Cereus 48%
- Cepa 6 Bacillus Sphaericus 31%

Todos estos gérmenes corresponden a especies aerobias, no habiéndose hallado anaerobias, coliformes ni salmonellas.

Los resultados de la irradiación de las cepas aisladas se indican en las figuras 3 y 4. En ellas puede verse que in vitro el orden de radioresistencia es el siguiente: cepas 3, 6, 5, 4, 1 y 2. Es importante señalar que las primeras tres son cepas esporígenas. Las cepas 1 y 2, que mostraron una mayor sensibilidad a la irradiación, son los principales contaminantes de la albúmina blanca. La cepa 3, que es la que presenta mayor radioresistencia, sólo se encuentra en una proporción baja (9%). En
FIG. 3. Variación de cepas aisladas de la albúmina blanca con la dosis de radiación

FIG. 4. Variación de cepas aisladas de la albúmina roja con la dosis de radiación

cambio, las cepas 5 y 6, principales contaminantes de la albúmina roja (79%), presentan una radiorresistencia comparativa considerable.

Estas consideraciones, salvada la objeción de que este análisis fué realizado sobre formas vegetativas en franco desarrollo, explicarían el distinto comportamiento de albúminas roja y blanca. En algunas colonias de cepas aisladas sobrevivientes a la irradiación se comprobó un comportamiento bioquímico distinto a las originales. Así, por ejemplo, el Bacillus Circulans invirtió sus reacciones en los ensayos de gelatina, leche y sulfhidrilo, y la Gaffkia Tetrágena, en los de reducción de nitratos.

Es importante destacar que se ha observado que la albúmina modifica su solubilidad en solución fisiológica cuando ha sido sometida a la irradiación. Este fenómeno, ya descrito anteriormente [2, 3], resulta de particular importancia para los usos futuros del material. Este aspecto se tratará de aclarar al estudiar las modificaciones físicas y químicas provocadas por la irradiación, según lo enunciado en el párrafo 5.

CONCLUSIONES

Desde el punto de vista bacteriológico la esterilización por radiación de este producto parece ser un proceso viable.
AGRADECIMIENTOS

Queremos dejar expresado nuestro agradecimiento al Doctor Enrique Mariano por su colaboración en la revisión del presente trabajo.

REFERENCIAS


DISCUSSION

E. KAMPELMACHER: Does the treatment you have described kill B. anthrax? Have your bacteriological studies been supplemented at all by experiments in animals? Finally, could you tell us briefly how the material was sampled?

H. A. MUGLIAROLI: B. anthrax was not isolated in our samples and I cannot say, therefore, whether it was killed by the treatment. These were simply bacteriological studies and no work has so far been done in animals.

The sampling procedure was quite straightforward. Four samples were taken at random from the final product coming from the plant, roughly one sample a month over a period of four months. The total count values were obtained from these. The percentage of contaminants was calculated from three of the samples, and the curves are accordingly based on average values obtained from only a part of all the material sampled.
RADIATION INACTIVATION OF FOOT-AND-MOUTH DISEASE VIRUS IN THE BLOOD, LYMPHATIC GLANDS AND BONE MARROW OF THE CARCASSES OF INFECTED ANIMALS

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Abstract — Résumé — Аннотация — Resumen

RADIATION INACTIVATION OF FOOT-AND-MOUTH DISEASE VIRUS IN THE BLOOD, LYMPHATIC GLANDS AND BONE MARROW OF THE CARCASSES OF INFECTED ANIMALS. The FMD virus, like RP, SF and ASF viruses, is disseminated by infected animal products.

The effects of gamma radiation on FMD virus cultures in vitro have been studied. According to these results, a dose of 3 Mrad when the virus is in the liquid state, and of 4 Mrad when it is in the dry state, is necessary to reduce the number of virus particles from $10^7$ to 1. The $D_{10}$ value for the liquid FMD virus is equivalent to 481 krad; the $D_{10}$ value for the dried virus is equivalent to 626 krad.

The effects of gamma radiation on FMD virus in situ have been studied. According to these results, to inactivate the FMD virus in the experimentally-infected pigs' tissues where the viral contents are the highest (blood, bone marrow, lymphatic glands), doses of 2 Mrad for the blood and bone marrow and of 1.5 Mrad for the lymphatic glands are necessary.

Radiation may offer a possible means of reducing or eliminating the virus titre in many infected animal products and solve consequent quarantine problems.
Радиация может явиться средством частичного или полного уничтожения вирусного титра во многих зараженных продуктах животного происхождения и решить тем самым проблемы карантина.

RADIONACTIVACION DE LOS VIRUS DE LA FIEBRE AFTOSA EN LA SANGRE, LOS GANGLIOS LINFÁTICOS Y LA MEDULA ÓSEA DE CADAVRES DE ANIMALES INFECTADOS. El virus de la fiebre aftosa, como el de la peste bovina, el de la peste porcina y el de la peste porcina africana, es propagado por productos animales infectados.

Se han estudiado los efectos de la radiación gamma sobre los virus de la fiebre aftosa cultivados in vitro. Según los resultados obtenidos, para reducir el número de partículas víricas de $10^7$ a 1 se requiere una dosis de 3 Mrad cuando el virus se halla en un medio líquido y de 4 Mrad cuando se halla en un medio seco. El valor $D_{50}$ para los virus de la fiebre aftosa en un medio líquido es equivalente a 481 krad para los que se hallan en un medio seco es equivalente a 626 krad.

Se han estudiado en los animales los efectos de la radiación gamma sobre los virus de la fiebre aftosa. Los resultados indican que para inactivar estos virus en los tejidos de cerdo experimentalmente infectados, donde el contenido vírico alcanza un valor máximo (sangre, médula ósea, ganglios linfáticos), se precisan dosis de 2 Mrad para la sangre y la médula ósea y de 1,5 Mrad para los ganglios linfáticos.

Quizá las radiaciones permitan reducir o eliminar el contenido vírico de muchos productos animales infectados y resolver los problemas de sanidad conexos.

INTRODUCTION

Viruses are of vast economic importance [1]. They cause destructive diseases of nearly all commercial crop plants [2].

Men and animals are also subject to a wide variety of virus diseases ranging in severity for humans from the common cold to infectious hepatitis, infantile paralysis and smallpox, and for animals from the common influenza to swine fever, foot and mouth disease and rinderpest.

Bacteria, as well as multicellular plants and animals, are liable to viral infection. The most obvious sign of the disease in bacteria is dissolution or lysis of the host cell. Because of the nature of the lysis, bacterial viruses were named "bacteriophages".

Even if the study of viruses and rickettsia in foods might be described more nearly as a science in gestation than in infancy [3], the role played by foods in spreading viral agents of epidemiological and epizootiological importance is now beginning to be well known.

Many food-borne outbreaks of virus disease have been reported.

A review of food-borne outbreaks of virus diseases of epidemiological importance has recently been published by Oliver [3], with particular reference to poliomyelitis and infectious hepatitis.

Types of enteroviruses other than the poliovirus are suspected to be present in foods.

Also viruses which are frequent inhabitants of respiratory tracts are supposed to be present in food surfaces contaminated by food handlers.

A rickettsial agent, known to be infectious for humans, that has been isolated repeatedly from raw milk and milk products is the rickettsia of Q fever (Coxiella burnetii). It has been shown to infect cattle, sheep and goats over a great portion of the world and to be indirectly transmitted to humans through raw milk and milk products.

Foods that, when contaminated with viral and rickettsial agents, are expected to present a particular hazard are those which are marketed raw, or whose normal processing includes insufficient heat treatment, or storage at temperatures below ambient or below freezing.
This paper deals with the effects of ionizing radiation on foot-and-mouth disease (FMD) virus for the purpose of suggesting possible radiation sanitation treatment of animal products, such as meat, bones, glands, hair, hides, packaging material, etc., contaminated with the FMD virus. The experiments so far carried out at the Perugia Veterinary Radiobiological Laboratory on the radiation-inactivation of the FMD virus in vitro (liquid and lyophilized virus [4]), and in situ (virus in the blood, lymphatic glands and bone marrow of the carcasses of infected animals [5, 6]) are described.

Furthermore, the possibilities of using ionizing radiation for the inactivation of other animal viruses which infect animal products, and which are the etiological agents of epizootic diseases of tremendous economic importance, such as rinderpest (RP), swine fever (SF), and African swine fever (ASF), are discussed and the pertinent criteria of irradiation as a quarantine control measure are put forward.

Before analysing the effects of ionizing radiation on the FMD virus, some data on the modality of transmission of the viruses under discussion, via infected products, are briefly summarized.

FOOT-AND-MOUTH DISEASE (FMD)

Foot-and-mouth disease is an acute, febrile disease of cattle, sheep, goats, and pigs, which is characterized by the formation of vesicles in connection with the mouth and feet, and sometimes on the skin of the udder or teats of females. Under certain conditions, human beings are susceptible to the disease but, except in children, the symptoms are mild. Hedgehogs may be affected, and may spread the disease to stock naturally. It has occurred in almost every country in the world where cattle are kept, but is very much more common in some than in others. The Continent of Europe and the countries of South America have the disease almost constantly present. It is also indigenous in many parts of Africa and Asia, and sometimes a strain of greatly increased virulence crosses the Mediterranean to invade South Europe and sweep over large areas with extreme rapidity. Australia and New Zealand are free from FMD. The FMD affects not only domesticated animals, but very many of the wild herbivores as well, having been seen in deer, antelope, buffalo, bison, yaks, etc.

The FMD is a typical example of an infection caused by different types of virus (O, A, C, SAT1, SAT2, SAT3, Asia1) having antigenic, biological and physico-chemical well-distinguished properties. The existence, within each type, of a number of subtypes, or variants, makes the problem of FMD prophylaxis very intricate. The most diffused FMD virus in nature is that of type O.

The disease is not, as a rule, an extremely fatal one in the adult animal, but when it affects breeding stock, as many as 85% of young animals born from affected or in-contact dams die. It causes great economic loss on account of reduction in milk secretion in dairy herds, severe loss of condition in fat-stock of any species, interference with trading in livestock, and loss of calves, kids, lambs, and piglets.

In countries where there is legislation against it, heavy expenditure in compensation to owners is necessary as well as various quarantine
and isolation measures, and the cleansing and sterilization of buildings, utensils, and products. In the United Kingdom and North America, where strict measures of slaughtering affected and in-contact animals are in operation, it has caused losses amounting to many millions of pounds paid as compensation to owners of affected animals in Europe, and during the 1951/52 epizootic wave, the FMD caused damages amounting to about $600 million [7]. The best pH for the FMD virus is 7.6, the size of the FMD virus is 10-12 μm.

For isolation and titration of the FMD virus from different materials and products, the technique of tissue cultures in vitro (monolayer trypsinized kidney calf cultures) can be successfully employed.

The FMD virus is disseminated by infected animals and their products [8-15]. The danger of meat and milk derived from infected animals is well proved. Experiments have shown the survival of FMD virus in carcasses of animals slaughtered while suffering from FMD. This is an important matter in countries where the disease does not exist, for many outbreaks of the disease have been traced to garbage containing meat trimmings [16,17].

The acidity which develops shortly after death in muscular tissue usually destroys the virus within a few days under refrigeration. The FMD virus, however, can be detected in the blood, lymph glands, bone marrow and fat stored under refrigeration [18,19]. The FMD virus can be detected in all infected organs and tissues stored in the frozen state for more than six months [18,19].

As regards cured products, the FMD virus does not survive in dry sausages and its inactivation is due to the quick establishment of enzymatic and microbiological processes during the stages of grinding and processing the mixtures [20-23].

Even in products such as the "capocollo" and "bresaola", made up chiefly from thick muscular portions, the virus inactivation is advanced, being connected with a rapid lowering of pH [20-23].

In hams the virus survival lasts longer and varies according to the different parts (muscle, fat, bone) that make up the product. In the muscle the virus, when it is present, is inactivated during the processing stage and, in any case, always during the salting period. In fats, and chiefly in bone tissue, it is able to survive for the whole period ranging from curing to drying processes, but disappears gradually later (first in fat and then in bone tissue) during the early ripening phases [20-23].

The FMD virus can easily retain its vitality for very considerable lengths of time in nature when it is dried and, owing to this fact, the disease is spread by a host of intermediate objects which have been in contact with affected animals. Among others, the following products can be responsible for the diffusion of the dried FMD virus: hides, hair, wool, hay, straw, sacks and packing fabrics generally. In one case, for instance, it was thought that the straw in which flower bulbs had been packed was responsible for the diffusion of the FMD virus. A list of the products which can be responsible for the diffusion of the FMD virus has been compiled by the Organismo Internacional Regional de Sanidad Agropecuaria (OIRSA) [24].

The FMD virus is inactivated by heat; a temperature of 55°C for 10-14 min is sufficient to inactivate it in the lymph; temperatures of 60-70°C for 15 min in milk, and for 5 min in blood, are able to inactivate FMD virus.
As regards the disinfectants, the FMD virus is destroyed by strong alkalies and formalin. In practical disinfection, a 2% commercial lye (sodium hydroxide) solution is used, but because of its corrosive nature, some workers prefer a 4% sodium carbonate solution which is believed to be just as effective.

RINDERPEST (RP)

Rinderpest is an acute, specific, inoculable and febrile disease of cattle, characterized by an ulcerative inflammation of mucous membranes, especially those of the alimentary tract. The virus is not present in the eastern hemisphere nor Western Europe. During most of this century it has been prevalent in Africa and is still enzootic in most of equatorial and part of northern Africa, Asia and the Middle East. Australia, New Zealand, Japan and the Philippines are free of the disease.

Rinderpest is one of the most serious threats to world food supplies; like the FMD it is caused by a virus, but a far more deadly one. When RP strikes a herd, nine out of ten of the animals may die, a catastrophe which is not infrequently followed by famine. Cattle are by far the most susceptible animals. Natural occurrence is rare in sheep and goats. Horses, pigs, and carnivora are immune. The virus is easily destroyed by heat and by ordinary disinfectants. If kept on ice in the dark, the virus may retain its virulence for many weeks.

The RP virus will remain infectious for weeks in the cold and for months in frozen animal products [25, 26]. In Italy, for instance, the disease obtained a foothold in the first World War due to the importation of infected frozen beef (Fara Vicentino - Breganze 1918) [27]. According to some sources, the virus can be present also in cured meat, skins and salted skins [25]. It can be propagated in chick embryos and in tissue culture.

SWINE FEVER (SF)

Swine fever is an acute, highly infectious virus disease of swine, characterized by sudden onset and high morbidity and mortality. Despite fairly satisfactory immunization procedures, it continues to cause large losses in many countries of the world where swine are raised. The virus is not infectious for any known species of animal other than swine. It is easily destroyed by heat, is very resistant in the dry state and when kept on ice (up to six months). It is present in cold, or in frozen animal products. Raw garbage, containing pork scraps from infected pigs, is a common source of infection. In Italy, for instance, SF spread at the end of the second World War due to the importation of infected pork meat from infected countries. The virus is also present in cured meat products. Outbreaks have occurred in Prussia and in Sweden due to the importation of infected bacon from America. It can be present also in skins and in the bristle [28].

The size of the virus is: 30-35 μm. It can be propagated in tissue culture, but the technique is not very effectual. The virus can be kept at a pH of 5.5.
AFRICAN SWINE FEVER (ASF)

African swine fever is a highly contagious viral disease of porcine animals, until recently confined to the African Continent, but now also found in parts of western Europe (Portugal, Spain and France). Although the symptoms and lesions are in many respects similar to those of swine fever, swine immune to SF are fully susceptible to ASF. The mortality rate is extremely high (95-100%) among domestic swine in newly-infected areas. The virus can be demonstrated in blood, all excretions and secretions, tissue fluids and the internal organs of infected pigs. It is exceptionally stable, reports indicating that it can survive in blood stored in a cold, dark room for as long as six years. The virus is present in cold or frozen animal products [24]. Raw garbage containing pork scraps from infected pigs is a common source of infection. The virus is also present in cured meat products [29].

It has been thought that ASF spread in Europe, where it caused disasters in swine herds, due to the importation of infected pork meat from Angola and Mozambique (Lisbon, 1957) [28-30]. The virus can be propagated in chick embryos.

RADIATION INACTIVATION OF FMD VIRUS IN LIQUID AND DRY STATES

Research into virus inactivation by irradiation began a number of years ago; the first quantitative work on the subject dates from 1933 and since then many authors, in particular Gowen, Holweek, Lacassagne, Luria, Exner and Lea, have been active in this field and have all contributed increasingly useful information.

It was found from the start that virus inactivation requires far stronger radiation doses than the inactivation of bacteria, and only recently the development of more powerful and penetrating radiation sources rendered possible more thorough and quantitative investigations into the effect of radiation on the different viruses.

The viruses most thoroughly studied and most frequently mentioned in the literature are: tobacco mosaic virus [31-33], smallpox virus [33], Newcastle disease virus [34] and bacteriophages [35, 36]. Recently, Jordan and Kempe [37] studied the effect of gamma rays on the viruses of poliomyelitis, St. Louis encephalitis, Western equine encephalomyelitis and cowpox, and they concluded that: (1) gamma radiation is an efficient means of inactivating these viruses; (2) the smaller viruses require higher doses of radiation to inactivate them; (3) the rate of inactivation is an exponential function of the radiation dose.

Data on the FMD virus are few and scanty [38], hence the author considered it advisable to undertake quantitative research on the inactivation of cultured FMD virus [1] Types O, A and C, by gamma radiation from a 'Hot Spot Mk IV' ⁶⁰Co source [39].

In all cases the virus suspensions exposed were in vitro cultures of trypsin-hydrolysed calf kidney cells, grown in Roux flasks with nutritive medium (0.5% lactalbumin hydrolysate in Earle buffer solution with 2% calf serum and antibiotics). The FMD virus, Type C was also studied in the dry state, after lyophilization of smears of cultures obtained as described above.
Material and techniques

Virus

The FMD viruses, Types O, A and C, from the author's own stock were used, which were suitable for tissue cultures in vitro. Each type was inoculated into seven-day calf kidney cultures in Roux flasks, prepared by normal technique [40].

When cytopathic phenomena became evident, 15 to 18 h after inoculation, the fluid from each strain was collected, centrifuged for 20 min at 5000 rpm and the supernatant material (original virus stock) distributed in quantities of 2 ml each into 18 sterile flasks, numbered 0-16 inclusive and 'control' and stored at -30°C prior to irradiation.

Irradiation

Except for the two samples No. 0 and 'control', all the virus flasks were exposed individually to ensure their occupying the same geometrical position in the irradiation chamber; sample No.1 was exposed to 250 000 rad, the other samples being treated by doses progressively increased by 250 000 rad up to sample No.16, which thus received 4 million rad. Of the two unexposed samples, No.0 was used to ascertain the infective titre of the original virus stock, while the control sample remained in storage at the same temperature and for the same length of time as sample No.16, to determine whether, independently of radiation, these factors could produce any changes in the infectiveness of the virus.

To ascertain the infective titre of the various exposed and unexposed virus samples, five-to-seven-day cultures of trypsin-hydrolysed calf kidney cells were used; each sample was diluted progressively by steps of 0.1 with nutritive medium, a dose of 0.1 ml per individual dilution being introduced into corresponding groups of five test tubes each. The tubes were kept at 37°C and the cultures examined microscopically every 24 h during three consecutive days. The presence of the virus was evaluated by the degree of its cytopathic effect, the titre being determined by the method of Reed and Muench [41] and expressed in cytopathogenic doses (50 DCP 50 /ml).

Studies of inactivation by gamma radiation were extended to the dry virus only with Type C. For this purpose, the culture fluids obtained, as already described, were distributed in quantities of 4 ml into 12 sterilized flasks marked 0-10 inclusive and 'control', and lyophilized in a vacuum at low temperatures. The samples were irradiated, except for No.0 and 'control', Sample No.1 was exposed to 500 000 rad and successive samples treated with doses progressively increased by 500 000 rad each up to sample No.10, which thus received 5 million rad. Of the two unexposed samples, No.0 was used for ascertaining the infective titre of the lyophilized virus, while the control sample remained in storage at the same temperature and for the same length of time as sample No.10. The lyophilized material, diluted and made up to volume with nutritive medium, was then subjected to the same tests as the culture fluids for determination of the infective titre.
Inactivated virus

The inactivation curves having been plotted for each type of virus, the viruses inactivated by radiation were then subjected to further tests in vivo to confirm removal of the infective power, as well as in vitro to study their properties of interference and antigen capacity of complement fixation in the presence of specific hyperimmune antiaphtha serum.

Three litters of suckling mice, three to five days old, were used for the tests in vivo; the three groups of animals were treated with FMD viruses (inactivated by 3 Mrad) Type A, O and C respectively, administered intraperitoneally in a single dose of 0.1 ml.

Results

Table I shows the titration results for the various FMD virus samples exposed to radiation, and the unexposed controls. The inactivation curves plotted from these results for the three types of the FMD virus tested are shown in Figs. 1, 2 and 3.

In Table II are given the titration results for the various samples of FMD virus, Type C irradiated in the dry and liquid states, and Fig. 4 shows the corresponding inactivation curves.

The biological tests with the suckling mice fully confirmed the results of tests in vitro; all the animals inoculated peritoneally with FMD virus, irradiated with 3 Mrad, survived without manifesting symptoms of any kind. This proves that the infective power of the virus had been eliminated and again confirmed that calf kidney cells in vitro are as sensitive to the FMD virus as new-born mice.

The results obtained indicate, firstly, that the three Types, O, A and C, of FMD virus culture react similarly to gamma radiation in the liquid state. The inactivation curves are practically identical, and show that the fraction of the virus which survives is an exponential function of the gamma dose, within the limits of experimental error. All three types of virus lose their infectiveness after irradiation with 3 Mrad, i.e. after a very high gamma dose. The results again confirm the remarkable resistance of viruses in general, and FMD virus in particular, to the effect of radiation, considering that an inverse relation is known to exist between inactivation doses and the size of the virus [37, 42].

As to the effect of radiation on dry FMD virus, tests indicated that inactivation was effected by treatment with 4 Mrad, so that one extra Mrad proved to be necessary over and above the quantity required for inactivating the same virus in the liquid state. This is in full agreement with the observation by Lea [33], according to which dry virus is inactivated by the direct effect of radiation alone, whereas in the case of virus in the liquid state this direct action is reinforced by an indirect action due to the ionization of water molecules and the consequent formation of free radicals which favour inactivation by oxidation mechanisms.

The $D_{10}$-value for the liquid FMD virus is equivalent to 481 krad. The $D_{10}$-value for the dried FMD virus is equivalent to 626 krad.

Other experiments carried out at the Perugia Veterinary Radiobiological Group have shown that: (1) the FMD virus inactivated by radiation does not interfere in vitro with the same type of active virus [4]; (2) the FMD virus inactivated by radiation retains intact its capacity of fixation
TABLE I. TITRATION RESULTS FOR VARIOUS FMD VIRUS SAMPLES EXPOSED TO RADIATION AND UNEXPOSED CONTROLS

Data from Baldelli et al. [4].

<table>
<thead>
<tr>
<th>Sample (No.)</th>
<th>Dose (Mrad)</th>
<th>Virus C&lt;sup&gt;a&lt;/sup&gt;</th>
<th>Virus A&lt;sup&gt;a&lt;/sup&gt;</th>
<th>Virus C&lt;sup&gt;a&lt;/sup&gt;</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>-</td>
<td>6.50</td>
<td>6.37</td>
<td>6.30</td>
</tr>
<tr>
<td>1</td>
<td>0.25</td>
<td>6.16</td>
<td>5.50</td>
<td>5.62</td>
</tr>
<tr>
<td>2</td>
<td>0.50</td>
<td>5.30</td>
<td>5.37</td>
<td>5.50</td>
</tr>
<tr>
<td>3</td>
<td>0.75</td>
<td>4.67</td>
<td>4.62</td>
<td>4.83</td>
</tr>
<tr>
<td>4</td>
<td>1.0</td>
<td>4.31</td>
<td>4.0</td>
<td>4.16</td>
</tr>
<tr>
<td>5</td>
<td>1.25</td>
<td>4.16</td>
<td>3.62</td>
<td>3.62</td>
</tr>
<tr>
<td>6</td>
<td>1.50</td>
<td>3.83</td>
<td>3.16</td>
<td>3.16</td>
</tr>
<tr>
<td>7</td>
<td>1.75</td>
<td>2.62</td>
<td>2.62</td>
<td>2.30</td>
</tr>
<tr>
<td>8</td>
<td>2.0</td>
<td>2.37</td>
<td>2.50</td>
<td>2.16</td>
</tr>
<tr>
<td>9</td>
<td>2.25</td>
<td>2.0</td>
<td>2.16</td>
<td>1.83</td>
</tr>
<tr>
<td>10</td>
<td>2.50</td>
<td>1.50</td>
<td>1.32</td>
<td>1.30</td>
</tr>
<tr>
<td>11</td>
<td>2.75</td>
<td>1.17</td>
<td>traces</td>
<td>traces</td>
</tr>
<tr>
<td>12</td>
<td>3.0</td>
<td>negative</td>
<td>negative</td>
<td>negative</td>
</tr>
<tr>
<td>13</td>
<td>3.25</td>
<td>negative</td>
<td>negative</td>
<td>negative</td>
</tr>
<tr>
<td>14</td>
<td>3.50</td>
<td>negative</td>
<td>negative</td>
<td>negative</td>
</tr>
<tr>
<td>15</td>
<td>3.75</td>
<td>negative</td>
<td>negative</td>
<td>negative</td>
</tr>
<tr>
<td>16</td>
<td>4.0</td>
<td>negative</td>
<td>negative</td>
<td>negative</td>
</tr>
<tr>
<td>Control&lt;sup&gt;b&lt;/sup&gt;</td>
<td>-</td>
<td>6.0</td>
<td>6.16</td>
<td>6.37</td>
</tr>
</tbody>
</table>

<sup>a</sup> DCP<sub>90</sub>/ml expressed by reciprocal of negative log.

<sup>b</sup> Unexposed virus stored at the same temperature and for the same length of time as sample No. 16.
FIG. 1. Inactivation curve of the FMD Aphous virus, type 0. (Data from Baldelli et al. [4])

FIG. 2. Inactivation curve of the FMD Aphous virus, type A. (Data from Baldelli et al. [4])

FIG. 3. Inactivation curve of the FMD Aphous virus, type C. (Data from Baldelli et al. [4])
TABLE II. TITRATION RESULTS FOR VARIOUS SAMPLES OF THE FMD VIRUS, TYPE C, IRRADIATED IN THE DRY AND LIQUID STATES

Data from Baldelli et al. [4]

<table>
<thead>
<tr>
<th>Sample (No.)</th>
<th>Dose (Mrad)</th>
<th>Virus C&lt;sup&gt;a)&lt;/sup&gt; (liquid state)</th>
<th>Virus C&lt;sup&gt;a)&lt;/sup&gt; (dry, lyophilized)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>-</td>
<td>6.30</td>
<td>6.30</td>
</tr>
<tr>
<td>1</td>
<td>0.5</td>
<td>5.50</td>
<td>5.37</td>
</tr>
<tr>
<td>2</td>
<td>1.0</td>
<td>4.16</td>
<td>4.50</td>
</tr>
<tr>
<td>3</td>
<td>1.5</td>
<td>3.16</td>
<td>3.67</td>
</tr>
<tr>
<td>4</td>
<td>2.0</td>
<td>2.16</td>
<td>3.50</td>
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<td>3.0</td>
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<td>1.37</td>
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<tr>
<td>7</td>
<td>3.5</td>
<td>negative</td>
<td>traces</td>
</tr>
<tr>
<td>8</td>
<td>4.0</td>
<td>negative</td>
<td>negative</td>
</tr>
<tr>
<td>9</td>
<td>4.5</td>
<td>negative</td>
<td>negative</td>
</tr>
<tr>
<td>10</td>
<td>5.0</td>
<td>negative</td>
<td>negative</td>
</tr>
<tr>
<td>Control&lt;sup&gt;b)&lt;/sup&gt;</td>
<td>-</td>
<td>6.37</td>
<td>6.37</td>
</tr>
</tbody>
</table>

<sup>a)</sup> DCP<sub>50</sub>/ml expressed by reciprocal of negative log.

<sup>b)</sup> Unexposed virus stored at the same temperature and for the same length of time as sample No. 10.

of the complement in the presence of specific hyperimmune antiaphtha serum [4].

The first point is in full agreement with the results of Mazzaracchio et al. [43] obtained by inactivating FMD virus, Type A, with either heat or formalin; thus this seems to confirm the views of those authors who consider that, in the case of the FMD virus, the capacity to interfere is linked with the vitality of the virus.

The second point indicates the different behaviour of the irradiated FMD virus regarding infectiveness and the antigen activity of complement fixation, and further confirms the findings of Bradish et al. [44], according to which the two properties are linked to two different virus components.
RADIATION INACTIVATION OF FMD VIRUS IN THE BLOOD, LYMPH GLANDS AND BONE MARROW OF CARCASSES OF INFECTED ANIMALS

To study the possibility of inactivating the FMD virus in the carcasses of infected animals, the blood, bone marrow and lymph glands of experimentally infected pigs were treated with gamma radiation from a 60Co-type source, "Hot Spot Mk IV".

The first results of these investigations were the subject of a report presented to the eleventh meeting of the Italian Veterinary Science Society [5]. The results are shown in Table III. To inactivate the virus in the tissues examined, doses of 2 Mrad for the blood and bone marrow, and 1.5 Mrad for lymphatic glands, were necessary.

As the above-mentioned report dealt only with material from two pigs infected with FMD virus, Type 0, the author considered it opportune to extend the investigations to the carcasses of animals infected with other types of virus (A and C) and to repeat the investigations in other pigs infected with FMD virus, Type 0 [6].

Material and techniques

Three pigs, each weighing about 120 kg, were inoculated intradermally in the posterior right foot with FMD viruses, Type C, Type A and Type O2, respectively.

After 40 to 45 h from inoculation, when they showed clinical manifestations of the FMD virus (high temperatures, typical generalized lesions of FMD disease) the animals were sacrificed by total bleeding (the blood was collected, diluted 1:2 with Alsever liquid, distributed in equal quantities into glass holders and stored at a temperature of -30°C).

The lymph glands (muscular, mesenteric and mediastinid) and the vertebrae, where the viral contents are highest, were removed from the carcasses. These samples were frozen at once and kept at -30°C until the test to ascertain the virus.

Nine samples of blood, lymph glands and vertebrae were chosen from each pig, and one sample was kept as untreated control; the remaining samples of blood, lymph glands, and vertebrae were treated with increasing doses of gamma rays (from 0.25 to 2 Mrad).
TABLE III  RADIATION INACTIVATION OF FMD VIRUS (TYPE O) IN INFECTED TISSUES
Data from Baldelli et al [5]

<table>
<thead>
<tr>
<th>Samples</th>
<th>Presence and infective titre of virus(^a) in the unirradiated materials</th>
<th>Presence and infective titre(^a) of virus in irradiated materials</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Presence and infective titre(^a) in the unirradiated materials</td>
<td>Presence and infective titre(^a) of virus in irradiated materials</td>
</tr>
<tr>
<td></td>
<td>(Dose Mrad)</td>
<td>0 5 1 1 5 2 2 5</td>
</tr>
<tr>
<td>Bone marrow</td>
<td>4 24/g</td>
<td>+  +  - - - -</td>
</tr>
<tr>
<td>Lymph glands</td>
<td>4 24/g</td>
<td>+  +  - - - -</td>
</tr>
<tr>
<td>Blood</td>
<td>5 74/cm(^3)</td>
<td>4 24/cm(^3) 2 74/cm(^3) traces -</td>
</tr>
</tbody>
</table>

\(^a\) DCP\(_{50}\) /cm\(^3\) expressed by reciproc of negative log

+ Presence of virus

- Absence of virus

Tests for the FMD virus were performed on the treated materials and on the untreated control according to the method of Savi, Baldelli, and colleagues, using monolayer calf kidney cells in vitro [22]. Tests were also carried out on the blood samples for titre, to establish the concentration of the virus in the original untreated material and in the individual samples exposed to increasing doses of gamma rays.

Results

The results of the above-mentioned tests are given in Table IV. In the pig which had been infected with FMD virus, Type C, the greatest resistance of the virus to gamma radiation was shown in the blood, where inactivation needed a dose of 1 75 Mrad. Inactivation of the virus in the bone marrow of vertebrae and in the lymph glands required lower doses of 1 Mrad and 1 25 Mrad, respectively.

In the pig inoculated with virus, Type A, while the virus in the blood maintained stronger resistance, the irradiations needed were lower in relation to those used in the pig infected with virus, Type C.

In fact, 0 75 Mrad was effective to inactivate the virus in the blood, 0 5 Mrad for the virus in the bone marrow of vertebrae and 0 25 Mrad for the virus present in the lymph glands. These results do not, however, lead to the supposed minor resistance of the virus, Type A, to radiation, but to the fact that all the materials of the pig in question were poorer in virus, as is clearly demonstrated by the low titre of the virus present in the untreated blood.

In the pig infected with virus, Type O\(_2\), the greatest resistance of the virus to gamma radiation was shown by that contained in the lymph glands, where sterilization of the virus required 1.25 Mrad, for the blood and bone marrow 0 75 Mrad were sufficient.
TABLE IV. RADIATION INACTIVATION OF FMD VIRUS (TYPES C, A, O) IN INFECTED TISSUES
Data from Baldelli et al. [6].

<table>
<thead>
<tr>
<th>Virus (Type)</th>
<th>Samples</th>
<th>Presence and infective titre of virus(^a) in the unirradiated materials</th>
<th>Presence and infective titre(^a) of virus in the irradiated materials</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>0.25</td>
<td>0.50</td>
</tr>
<tr>
<td>C</td>
<td>Blood</td>
<td>3.66</td>
<td>3.50</td>
</tr>
<tr>
<td></td>
<td>Lymph glands</td>
<td>+</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>Bone marrow</td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td>A</td>
<td>Blood</td>
<td>1.50</td>
<td>1.50</td>
</tr>
<tr>
<td></td>
<td>Lymph glands</td>
<td>+</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>Bone marrow</td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td>O</td>
<td>Blood</td>
<td>1.62</td>
<td>1.16</td>
</tr>
<tr>
<td></td>
<td>Lymph glands</td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td></td>
<td>Bone marrow</td>
<td>+</td>
<td>+</td>
</tr>
</tbody>
</table>

\(^{a}\) DCP\(_{50}/cm\(^3\) expressed by reciprocal of negative log.

+ Presence of virus.
- Absence of virus.
In conclusion, the author confirms that it is possible to sterilize the carcasses of pigs infected with the FMD virus by means of 2 Mrad gamma radiation.

RADIATION INACTIVATION OF RP, SF AND ASF VIRUSES

No data are available at present on the radiation inactivation of the RP, SF and ASF viruses.

Considering that an inverse relation is known to exist between inactivation doses and size of the virus and that the FMD virus is one of the smallest viruses known, it can be foreseen that doses necessary to inactivate the RP, SF and ASF viruses, either in the liquid or dry state, or in infected products, are expected to be no greater than doses employed for the inactivation of the FMD virus. This supposition must be confirmed, however, by experiments which, due to the strict quarantine measures, can be carried out only in the laboratories of the infected countries, or in specially-equipped laboratories in the immune countries.

IRRADIATION AS QUARANTINE CONTROL MEASURE

The report of the third Food Survey of the Food and Agriculture Organization of the United Nations (FAO) indicates that 80% more food of all types and 120% more protein will be needed in 1975 to meet the nutritional needs of areas now classed as "developing".

If a few only of the large livestock producing areas of the world could be freed of the major epizootic diseases which now infect them, and some of the less dramatic, but none the less important diseases which plague a vast majority of the world's livestock could be brought under control, there would be no difficulty in achieving these goals. The final aim of veterinary activities is to eradicate diseases in animals. If this could ever be achieved, the treatment of products would become superfluous. The progress made during the last ten years might justify a certain degree of optimism.

However, it is not possible at present to anticipate the eradication of classical diseases like FMD or RP within the next fifty years. Furthermore, with increasing international traffic and changing ecology, new diseases are continually emerging from isolated reservoirs, and even from unknown sources, developing into extensive epizootic occurrences. This means that other diseases will occur, which will probably require the use of new, advanced techniques of sanitary treatment of animal products, including packing material, so as to make them safe to the importing countries.

Radiation may offer a possible means of reducing, or eliminating, the virus titre in many infected animal products and thus solve consequent quarantine problems.

This recommendation was made by the Panel on the Application of Food Irradiation in Developing Countries held at the International Atomic Energy Agency, Vienna, in 1964, during which the problem of the inactivation of viruses, such as FMD, RP, SF and ASF, in animal products, was first suggested.
Radiation could be used successfully for the radiation sanitation treatments of such products as glands, hair, hides, bone, packaging material, etc., where undesirable side effects are not important.

The first industrial radiation plant to appear was the Dandonong plant, near Melbourne, Australia, for the sterilization of goat’s hair (for carpet manufacture) contaminated by the spores of Bacillus anthracis.

As regards meat, where doses of 2 Mrad are known to induce severe irradiation off-flavour, irradiation could be carried out at liquid-nitrogen temperatures (approximately -196°C) to prevent flavour changes; meat irradiated at this dose would result in acceptability to the public [45]. The rationale behind this is that very low temperatures during irradiation immobilize water molecules and any free radicals generated by the action of radiation on them. This limits reaction with other constituents and thereby controls off-flavour development [46, 47].

The results of various workers indicate that there is an additional amount of radiation required, of the order of 15% at -75°C over 0°C, to assure the sterility of spores of C. botulinum [48]. Experiments are necessary to check if the same principle also works for viruses.

Regarding cost, an approximate estimate indicates that the capital cost incurred in setting up a radiation plant, equipped with a liquid N facility, and capable of treating about 38 million lb of product per year at 2 Mrad, should be of $2,560,000.

This capital cost is high, but it can be considered acceptable so far as it can improve the local animal husbandry industry, and consequently the general economy of the exporting country.

The plant should be situated at the point of export of the contaminated animal products, or in some remote and inspected area of the importing country.

The increase in production, which would follow the abolition of import restrictions, is incalculable. Actual and potential losses from foreign trade restrictions, due to the presence of certain contagious diseases, are in fact very high. The following are just a few examples:

In Canada, it was established that, in the 1951/52 FMD outbreak, the total loss in compensation paid for the slaughter of infected animals and contacts was very small when compared with losses from the closure of foreign markets to Canadian products [7].

In Tanganyika it has been estimated that the loss from permanent closure of foreign markets to Tanganyika animal products, due to the presence of RP and FMD, is far more important economically than the physical damage caused within the country by these diseases [7].

The same applies to several other African countries and, as far as FMD is concerned, also to South American countries.

This permanent lack of export markets involves not only a continuing loss of potential income, but also depreciation in the internal market value of livestock. An eloquent example, among many, is given by the price at which cattle are sold in certain parts of East Africa to the local canning industry, namely, 15 to 20 pounds sterling, or 100 to 150 Somali, per head of cattle, respectively, in Kenya and Somalia.

It is easy to imagine the economic, social, and administrative repercussions which would be brought about in these countries if these animals were to have free access as safe chilled or frozen meat to western markets at enormously increased prices.
Vast regions of eastern and southern Africa could supply large quantities of meat to western countries, but unfortunately quarantine restrictions prohibit the export of their products. Ethiopia, Sudan, Kenya and the Somali Republic are examples of countries with a large potential of exportable animal products.

The developing countries often find themselves faced with a contradictory situation; on the one hand, they are urged to increase their animal production, with the prospect of more food for their own population and more income from their exports, and on the other, they encounter discrimination because of the unsatisfactory health situation of their livestock.

To solve this problem, some reliable physical or chemical treatment to free the infected animal products from the viral agents should be provided, so that these products can be accepted by the importing countries. Radiation is the only technique at present available which can achieve this goal while keeping the animal products in their original raw state.

The amount and value of infected products, their treatment or disposal under present conditions, the availability of the traditional chemical and physical methods of sterilization, and the cost of such treatments must be investigated and compared with the cost of the new irradiation technology.

CONCLUSIONS

The data so far obtained show that a dose of 2 Mrad is required to sterilize the carcasses of animals infected with the FMD virus.

Experiments in vitro and in situ are necessary to study the effects of ionizing radiation on other viruses, such as RP, SF and ASF, associated with animal products.

The influence of ambient conditions (oxygen, inorganic salts, temperature, etc.) during irradiation on virus survival needs thorough investigation.

Radiation may offer a possible means of eliminating the virus titre in many animal products and solve consequent quarantine problems. In this respect, radiation can become useful for the elimination of serious discrimination in commercial relations, due to infectious diseases, and develop collaboration between nations.

REFERENCES

G.H. GREEN: The work you have described is certainly most interesting from a theoretical point of view, but I wonder whether you have considered the immense practical difficulties of adapting the pro-
cures to field work. There is, in the first place, the high cost of the irradiation installation, and to bring this into proper perspective one must bear in mind that outbreaks of these virus diseases occur only intermittently. The transport of infected animals also raises problems which would be particularly difficult in the areas of Africa that you have mentioned. Finally, the flavour of meat irradiated at the high doses required for this work would be adversely affected, as earlier speakers have pointed out.

D. MASSA: Admittedly, the capital cost of a radiation plant equipped with liquid-nitrogen facilities is high, but this must be balanced against the benefit that would accrue to the stock-raising industry and consequently the general economy in any given area; if the benefit is likely to be considerable, the cost could well be acceptable. Outbreaks of virus disease may occur only intermittently, as you say, but equally we have to bear in mind the likelihood of whole areas becoming infected, with consequent quarantine problems.

In answer to your last comment, I would point out that the adverse effects of irradiation at 2 Mrad on the flavour of beef can be kept to a minimum if the operation is performed at liquid-nitrogen temperatures.

F.S. THATCHER: Experience with the Salk vaccine suggests that process control, sampling procedures and testing methods in general must be extremely exacting if one is to be sure of the destruction of all virus particles. Certain lots of Salk vaccine proved to be infectious even after the most rigorous testing. Equally stringent tests would presumably be required before treated virus-infected meats could be accepted - certainly before they could be accepted by countries at present free from the virus.

D. MASSA: The results of experiments on the inactivation of Foot and Mouth Disease (FMD) virus by irradiation, in vitro and in situ, have indicated no survival of virus particles. This has been demonstrated both in tissue cultures and in biological tests on new-born mice.
APPLICATION OF RADIATION FOR THE CONTROL OF SALMONELLAE IN VARIOUS FOODS

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Abstract — Résumé — Аннотация — Resumen

APPLICATION OF RADIATION FOR THE CONTROL OF SALMONELLAE IN VARIOUS FOODS.

Microbiological studies on the use of ionizing radiation for the elimination of Salmonellae from various foods have demonstrated that a wide variety of factors can influence the radiation sensitivity of the organisms. These factors include the nature of the food itself and the temperature during irradiation, e.g. whether frozen or unfrozen. The difference in resistance of different serotypes of Salmonellae irradiated under the same conditions has also been well established. Dose/survival curves constructed for the purpose of making a choice of dose for a particular application must therefore be established for the practical conditions envisaged and be based on the most resistant serotype present. Since these conditions can never be exactly reproduced in the laboratory, the choice of dose should be confirmed by a substantial amount of work with the naturally-contaminated material.

It is apparent that the doses required for the treatment of various foods lie within the range 0.5 to 1.0 Mrad, achieving a reduction in numbers of initial populations by a factor of between $10^5$ and $10^7$. The most promising processes are those considered for frozen and dried-egg products, frozen meats and animal feedingstuffs.

DESTRUCTION DES SALMONELLAE PAR LES RAYONNEMENTS DANS DIVERS PRODUITS ALIMENTAIRES. A la suite d'études microbiologiques sur la possibilité d'employer des rayonnements ionisants pour détruire les Salmonellae dans divers produits alimentaires, il est apparu que la radio-sensibilité de ces organismes dépend de nombreux facteurs, en particulier de la nature du produit et de sa température (produit congelé ou non) pendant l'irradiation. On a également reconnu que diverses variétés sérologiques de Salmonellae, irradiées dans les mêmes conditions, ont une radiorésistance différente. Des courbes de survie en fonction de la dose, construites en vue de déterminer la dose nécessaire pour un traitement donné, doivent donc être établies pour les conditions pratiques envisagées et compte tenu de la plus résistante des variétés sérologiques présentes. Étant donné que ces conditions ne peuvent jamais être reproduites exactement en laboratoire, le choix de la dose doit être confirmé par des recherches suffisamment étendues sur le même produit contaminé par voie naturelle.

Il est apparu que, pour traiter différents produits alimentaires, il faut utiliser des doses comprises entre 0.5 et 1.0 Mrad, qui permettent de réduire d'un facteur allant de $10^5$ à $10^7$ l'importance numérique des populations initiales. Les procédés qui semblent devoir donner de meilleurs résultats sont ceux que l'on envisage d'utiliser pour les produits à base d'œufs congelés et déshydratés, les viandes congelées et les produits destinés à l'alimentation animale.

ПРИМЕНЕНИЕ ИЗЛУЧЕНИЙ ДЛЯ УНИЧТОЖЕНИЯ САЛМОНЕЛЛ В РАЗЛИЧНЫХ ПИЩЕВЫХ ПРОДУКТАХ. Микробиологическое излучение применения ионизирующих излучений для уничтожения сальмонелл в различных пищевых продуктах показало, что большое количество факторов может влиять на чувствительность этих организмов к облучению. К числу этих факторов относятся характер самого пищевого продукта и его температура в период облучения, например, является ли продукт замороженным или незамороженным. Разница в радиационной стойкости различных серотипов сальмонеллы, облученных при одинаковых условиях, также хорошо установлена. Поэтому кривые зависимости выживания сальмонеллы от дозы должны быть построены для предусмотренных практических условий и основаны на существующем серотипе, имеющем самую высокую стойкость. Поскольку такие условия нельзя точно воспроизвести в лаборатории, выбор доз должен быть основан на значительном объеме работ с материалом, имеющим естественное загрязнение.

Представляется очевидным, что дозы, требующиеся для обработки различных пищевых продуктов, находятся в диапазоне 0.5 - 1.0 Мрад, обеспечивая уменьшение количества перво-
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начальных популяций в $10^5 - 10^7$ раз. Наиболее перспективными являются те процессы, которые рассматривались в связи с замороженными и сушенными продуктами из яиц, замороженным мясом и кормами для животных.

**EMPLEO DE LAS RADIACIONES IONIZANTES EN LA LUCHA CONTRA LAS SALMONELLAE DE DIFERENTES ALIMENTOS.** Los estudios microbiológicos sobre el empleo de las radiaciones ionizantes para eliminar las Salmonellae de varios alimentos muestran que en la radiosensibilidad de esos microorganismos puede influir toda una serie de factores. Entre éstos cabe citar la naturaleza del propio alimento y su temperatura durante la irradiación, por ejemplo, si está congelado o sin congelar. También se han puesto claramente de manifiesto las diferencias de resistencia de distintos serotipos de Salmonellae irradiados en idénticas condiciones. Por consiguiente, las curvas de dosis/supervivencia, que se preparen con el fin de seleccionar la dosis para una aplicación particular, deben trazarse con arreglo a las condiciones prácticas que se prevean y basarse en el serotipo más resistente de los presentes. Como estas condiciones nunca pueden reproducirse exactamente en el laboratorio, la elección de la dosis debe confirmarse realizando amplios trabajos con alimentos naturalmente contaminados.

Se llega a la conclusión de que las dosis necesarias para tratar varios alimentos son del orden de 0,5 a 1,0 Mrad, con lo que se logra reducir entre $10^5$ y $10^7$ veces la población inicial. Los procedimientos más interesantes son los aplicados a los huevos congelados y desecados y a sus derivados, a las carnes congeladas y a los alimentos de consumo animal.

Data accumulated over the last decade in many different countries indicates that Salmonellosis is increasing throughout the world and this increase represents a problem of major public health significance [1-6]. Public health experts are unanimous in stressing the importance of human and animal food as a vehicle of Salmonellae. The cycle of infection is illustrated (Fig. 1) in a recent review by Bowmer [2], who states that ideally only animals known to be free from Salmonellae should be used for the production of human and animal food. Furthermore, food must be protected at all stages of production, distribution and consumption from the farm to the table. The application of physical agents to foods for the destruction of Salmonellae is just one of the recommended control and prevention procedures which might allow us to eventually approach the ideal. It must be made clear from the outset that the introduction of processes for this purpose in no way lessens the importance of the introduction and maintenance of high standards of hygiene fundamental for Salmonella control.

The potential use of ionizing radiations in this field is under consideration with respect to breaking into the cycle of food infection in two places – firstly in regard to the elimination of Salmonellae in animal feeds, to contribute to the rearing of Salmonella-free animals, and secondly for the treatment of food products at some stage in the distribution chain. Within the latter category fall foods not only intended for human consumption but also those used in domestic pet feeding. There is evidence of transmission of the organism through pets and there is also the possibility of cross-infection from pet food to human food.

The main competitor to radiation in both these categories is the use of heat, which has already been effectively applied to food for Salmonella control in a number of instances. For radiation to be adopted it must be at least as economically competitive as heat, where there is a direct choice between the two. In some applications, however, radiation may have a marked advantage over heat as, for example, when it is required that the food be marketed in the raw state. The penetrating power of radiation is also a property in its favour, in that packaged products can be treated in their original containers and hence cross-
contamination can be largely avoided. Furthermore, frozen products can be treated in the frozen state, the expense of thawing being avoided.

It was the attractiveness of the treatment in the frozen state which led to early investigation of the use of radiation for the elimination of Salmonellae in frozen whole egg [7]. It will be remembered that at the Food and Agriculture Organization of the United Nations (FAO) meeting on Food Irradiation at Harwell in 1958 [8] this was believed to be a promising process, approaching the stage at which commercial exploitation might be considered, provided that the wholesomeness of the treated food had
been assured. Since 1958 considerable research progress has been made, but no commercial processes for Salmonellae elimination have been introduced in any country. The reason is not entirely that the wholesomeness question has not been resolved - in the case of frozen egg in the United Kingdom, the competitive heat process proved to be more attractive in terms of cost and ease of application [9].

In 1963 a panel of experts brought together by the International Atomic Energy Agency (IAEA) reviewed the whole question of radiation control of Salmonellae in food and feed products, and a thoroughly referenced report is available [10]. Examination of the wide range of animal feeds, human foods and also inedible products known to transmit Salmonellae, revealed that the greatest potential value for radiation processing lay in the treatment of frozen egg, frozen meat for either human or domestic pet consumption, and dry animal feeds such as meat-and fish-meal. These findings were reflected at the International Conference held in Boston in 1964, where both papers [11,12] on Salmonellae referred to work on frozen food or animal feeds.

Several quite different aspects of the problem of applying radiation for Salmonellae control have been taken into account in deciding which specific processes are likely to find practical application. These are listed below and will be referred to in relation to individual processes which have been investigated.

(a) Analysis of the importance of the specific Salmonella problem for which the radiation process is proposed;
(b) Microbiological considerations, in particular effectiveness of the process for eliminating Salmonellae;
(c) Effect of the defined process on the quality of the food being treated;
(d) The economics of the process in relation to competitive methods and general technical feasibility;
(e) The influence of existing legislation on the introduction of the process and the requirement for new legislation; and
(f) The wholesomeness problem.

Before discussing individual processes it is pertinent to refer to some of the general microbiological considerations underlying potential applications for Salmonellae elimination in any foods.

GENERAL MICROBIOLOGICAL CONSIDERATIONS

Salmonellae could be said to be moderately radiation-sensitive when bacteria are generally considered [13] and therefore the dose requirement for their inactivation in food will be very much lower than that needed for radappertization (4.5-5.0 Mrad). This gives a marked advantage over processes requiring high doses, particularly in relation to effects on food quality, and also economic considerations. Furthermore, the process, being aimed only at elimination of a specific pathogen (i.e. it is a radicidation process), is free of many of the microbiological problems associated with radurization processes; it is significant that the treatment is being considered for non-perishable foods, such as frozen egg and meat and dry animal feeds.
Some factors influencing radiation resistance

A study of the previously published data in Table I [14], to which a few recent results have been added [15], reveals some of the factors which can influence resistance as well as the variation of resistance between serotypes irradiated in the same medium. For example, increased resistance due to freezing is shown for organisms suspended in buffer and for S. typhi-murium in egg albumin, but is not apparent with whole egg. The difference in buffer suspension between irradiation in air and in anoxia is very marked, as would be expected. Bone-meal and desiccated coconut give quite different results, showing that it is unwise to make general predictions as regards comparatively dry foods. Chemical protection by food constituents is no doubt an important factor borne out in some of our own current experiments with S. senftenberg, freeze-dried simultaneously on to fish-meal, and kaolin powder, the latter, chosen as being radiation chemically inert, giving the same result as for buffer suspension and the fish-meal offering considerable protection. Yet another factor to which attention has been drawn recently is the influence of pre-irradiation growth media on resistance. S. typhi irradiated in corned beef, after allowing pre-growth, showed double the resistance without pre-growth; anoxia was maintained by nitrogen flow in both circumstances [15].

The difference in radiation resistance between different serotypes of Salmonellae, and the influence on resistance of many of the factors mentioned, can be seen in the relevant publications on individual foods which were examined and contrasted in some detail by Thornley in 1963 [16]. The data were added to in more recent publications [11, 17, 19].

Choice of dose

The value of dose/survival curve data lies in the fact that an inactivation factor can be calculated for a given dose, thus giving a guide to the effectiveness of the treatment in practice. However, it is apparent from the foregoing that, ideally, the data must be derived using the particular food product in question, contaminated in the natural way and irradiated under the practical conditions envisaged. Furthermore, the data must relate to the most resistant serotype present. Experimenters have attempted to simulate practical conditions in the laboratory, but certain manipulations of the original products are required in order to obtain a satisfactory curve, e.g. artificial inoculation to achieve high populations prior to irradiation. The calculation of a D10 value is often made on the assumption that the curves are exponential. In fact, many of the published curves for Salmonellae show a higher radiation sensitivity over the first log cycle than over the remainder of the curve, which continues as a straight line [14, 19]. In contrast, curves showing a small shoulder at the beginning have also been published [17]. Results based on the calculation of a D10 value estimated from the main portion of the curve can be adjusted to take into account the initial portion. However, there is evidence of the tailing of curves for Salmonellae irradiated in fish-meal [11] and in crab meat [42], which stresses the need to construct curves over as many log cycles as possible. Unfortunately, there is a practical limit to the size of initial population with which the experimenter can begin and
<table>
<thead>
<tr>
<th>Medium</th>
<th>S. typhi</th>
<th>S. gallinarum</th>
<th>S. senftenberg</th>
<th>S. senftenberg</th>
<th>S. typhi-murium</th>
<th>S. paratyphi</th>
<th>S. meleagridis</th>
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<tr>
<td>N. C. T. C. 9959</td>
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<td>43.0</td>
<td>50.4</td>
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<td>63.2</td>
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<td>46.8</td>
<td>-</td>
<td>67.9</td>
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<td>-</td>
<td>-</td>
<td>49.0</td>
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<tr>
<td>Egg albumen (frozen)</td>
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<td>-</td>
<td>-</td>
<td>75.0</td>
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<td>-</td>
<td>158</td>
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<td>Comed beef (without pre-growth)</td>
<td>40.0</td>
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<tr>
<td>Comed beef (with pre-growth)</td>
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<td>-</td>
<td>-</td>
<td>-</td>
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<td>-</td>
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<tr>
<td>Bone-meal</td>
<td>-</td>
<td>55.7</td>
<td>-</td>
<td>-</td>
<td>91.0</td>
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<tr>
<td>Fish-meal</td>
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<td>-</td>
<td>-</td>
<td>150</td>
<td>174</td>
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<td>Kaolin powder</td>
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<td>21.0</td>
<td>-</td>
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<td>Phosphate buffer</td>
<td></td>
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<td>Aerated</td>
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<tr>
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<td>38.9</td>
<td>-</td>
<td>61.9</td>
<td>68.9</td>
<td>-</td>
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</table>

a) Further data added, to be published.
b) Radiation dose required to reduce number of survivors to one-tenth.
a limitation in counting very small numbers of survivors, particularly when dealing with food products. The author recently constructed a curve for S. senftenberg in aerated buffer suspension which extends in an exponential fashion over nine log cycles.

Having established a D10 value which is considered applicable to a particular product, the calculation of dose to be recommended for practical purposes must be based on (a) a knowledge of the initial contamination expected, and (b) choice of a level of inactivation considered to ensure safety. The former is sometimes available from the history of examination of the products, and the latter is based on the criteria used for testing the product for the absence of Salmonellae. In general, it seems that an inactivation factor of between 10^5 and 10^7 is required, since the initial numbers of Salmonellae contaminants appear to be low in most products. Dose requirements appear to be in the range 0.5-1.0 Mrad for different foods.

The concepts involved in the calculation of the dose requirement, using dose/survival curve data, have been discussed in relation to the Salmonella problem in several publications, and recently by Ley and Tallentire with respect to radiation sterilization of medical products where similar problems of calculation arise [20, 21].

In view of the shortcomings of dose/survival curve data, the choice of dose based on them should be reinforced with data obtained on the naturally-contaminated material. It should be demonstrated that the calculated dose produces the desired freedom from Salmonellae by irradiating a considerable number of samples. This procedure is an attempt to cover a range of initial population levels, variation in type of contamination and varying environmental factors that might be operating. Sometimes it is difficult to obtain samples which are naturally positive. The author found it convenient to arrange for the routine storage of the remaining portions of those samples shown to be positive for Salmonellae after routine check by the Public Health Laboratory service. This gives a good chance of obtaining positive controls within the experiments. The natural material is irradiated in bulk to give a range of doses throughout, as would occur in practice. For example, in irradiating frozen horse meat, a mean dose of 0.65 Mrad is aimed at, the dose received is in the range 0.5-0.75 Mrad, and this can be simulated.

Effects on other organisms

Quite a number of bacterial species are more radiation-resistant than the Salmonellae. Sporeformers, if present in sufficient numbers, would be expected to survive the dose designed to eliminate Salmonellae. The comparative sensitivity of different species of public health significance has been the subject of direct study [11, 18, 22]. It has been found, for example [22], that the Staphylococci (although somewhat dependent on the medium) and S. faecalis are more resistant than Salmonellae, whilst the coliform organisms are more sensitive. It is interesting to note that absence of coliforms could not be used as an index of the absence of Salmonellae.

Attention has also been given to the question of radiation-resistant mutants being formed [23]. It has been demonstrated that resistance can be induced in many species, although not in the case of S. gallinarum in this particular study. Resistance was obtained after repeated sub-
lethal irradiation of survivors. While this is unlikely to present a serious problem in practice, the possibility should be taken into account in operating radiation units on a commercial scale.

INDIVIDUAL FOODS

Egg and egg products

A wide variety of egg products have been investigated; these include liquid whole egg [19, 24-27], frozen whole egg [7, 9, 14, 17], frozen egg yolk and dried egg yolk [28], and liquid, frozen and dried egg white [29]. The doses recommended for treatment vary within the range 0.2-0.6 Mrad.

With most of the types of egg, irradiation has little effect on the organoleptic properties of the products prepared from the egg, although some effects on functional properties were noted, for example, in the foam stability of fresh and frozen egg white [29]. Liquid whole egg is a particular exception in that its colour, odour and properties are affected at a dose as low as 10 000 rad [25]. Some recent work established that a flavour change could be detected above about 10 000 rad, irrespective of different temperatures during irradiation within the range 32° to 130°F [26]. Egg irradiated at about -12°C was found to be of good quality, even at a dose of 0.5 Mrad [30].

The commercial possibility of irradiation of frozen whole egg was the subject of a detailed feasibility study in the United Kingdom [9]. It was envisaged that the process would apply to frozen egg in 28-lb cans, both home-produced and imported. Several radiation plants in different parts of the country needed to be established to serve the different producers, and the total capital cost was very high. In the meantime the competitive heat process was successfully developed [31], complete with a chemical method of detecting that the process had been properly applied [32]. The equipment needed for heat pasteurization prior to freezing was of comparatively low capital cost and could be incorporated into individual premises. Legislation requiring the use of heat treatment was introduced and applied to both imported and home-produced egg. The future prospects for radiation for the treatment of frozen egg are obviously small, but the process might still be of interest in other countries.

The possibility of a combined process of heating and irradiation is reported by United States workers. It has been applied to liquid egg in an attempt to reduce the radiation dose required [19]. The work referred to earlier on flavour change after irradiation at different temperatures is related to microbiological studies over the same temperature range. The decimal reduction doses for S. typhi-murium in either egg yolk or whole egg were reduced with increasing temperature, the most significant effect occurring above 110°F. The rate of bacterial destruction was significantly greater when radiation and heat were applied simultaneously than when applied consecutively.

Whilst this effect is an interesting one, the cost of the combined treatment of liquid egg is unlikely to compete with the cost of heat pasteurization alone, where the temperature used is quite low, being 148°F for 2½ min. In another attempt to find a way of lowering the radiation dose for liquid egg, the radiosensitizing activity of Vitamin K₅ was tested in respect to
S. typhi-murium [27]. No activity was observed, or possibly a slight protective effect, in whole egg irradiated in either air or vacuum.

**Desiccated coconut**

This investigation was carried out in the United Kingdom at a time when bacteriological survey of imported coconut showed Salmonella contamination and various methods of treatment were under investigation, including heat treatment and ethylene oxide fumigation [33]. The resistance to gamma radiation of the two serotypes tested was among the highest noted in any of the foods so far examined. However, the counts of Salmonellae per gramme of coconut were found to be extremely low, so that a dose of 0.45 Mrad proved effective. The effect of this low dose on the quality of the coconut was not very marked, but a small flavour change and slight darkening of colour was observed. This small quality change was regarded by the trade as unacceptable.

The overall investigation of the coconut problem included an analysis of standards of hygiene at the point of export, and considerable improvements resulted in a reduced number of Salmonellae in the product.

**Corned beef**

Some studies were made when cans of corned beef were suspected as the cause of a typhoid outbreak in Aberdeen, Scotland, in 1964 [34]. Radiation appeared very attractive as a method of rendering a large number of suspected cans safe. The radiation plant at Wantage Research Laboratory (WRL) could be made available for treatment on a large scale. Such a process would compete well with the alternative of re-heating the cans in an autoclave.

Some results on the radiation resistance of S. typhi became available for the first time. In buffer suspension, resistance was found to be average and less than S. typhi-murium. However, in corned beef itself after allowing pre-growth and with irradiation under anoxic conditions a D10 value of 80 krad was obtained.

The question arose as to the numbers of contaminating organisms likely to be present in the meat, and unfortunately this was quite unknown. The author's experience had shown that S. typhi grew extremely rapidly in the canned meat and this was borne out in a detailed study by others [35]. In the absence of information on the initial contamination level, it had to be assumed that this could be high and therefore a dose of 1 Mrad was recommended. This dose proved to affect the quality of corned beef in terms of colour and flavour, and the idea of using radiation was abandoned, particularly since an adequate re-heating process had been developed.

**Animal feeds**

Particular emphasis was given to the application of radiation at the Panel meeting held in Vienna by the IAEA in December, 1962 [10]. This was followed up by Mossel and De Groot, who reported both microbiological and wholesomeness studies on fish-meal [11]. After studies on meal artificially inoculated with ten different serotypes of Salmonellae, it was concluded that a dose of 0.8 Mrad should be recommended. Rat
feeding studies, using fish-meal irradiated up to doses of 1.5 Mrad, indicated no loss of protein nutritive value and negative results for various indices of toxicity. The recommended dose of 0.8 Mrad is similar to that suggested for bone-meal [14], and somewhat higher than that found to be effective for some fish and meat flours investigated by other workers [36], and absence of the effect of irradiation on protein value confirms other studies with various meals [37, 38].

The application of radiation processing to animal feeds looks extremely promising, although very much depends on keeping the cost low. If applied on a large scale at the point of import, very large throughputs would be involved, e.g. 200 000 tons per annum of fish-meal. Several separate radiation plants would be needed, but high throughput leads to lowering of cost.

A more detailed analysis of irradiation of feeds is given in the paper by Dr. Mossel in these Proceedings.

Frozen meats

A dose of 0.5 Mrad has been suggested for the treatment of frozen poultry [11]. Experiments with both broilers and ducks treated at 0.4 Mrad when frozen at -20°C were encouraging in that the quality of the birds was unaffected, while the process was microbiologically effective as measured by the total absence of Enterobacteriaceae flora after treatment.

In the United Kingdom particular attention has been given to the possibility of irradiation of frozen horse meat [14, 39, 40]. Frozen boneless horse meat is imported into the United Kingdom at the rate of about 12 000 tons per annum, chiefly through the Port of London. The origin of this meat is mainly the Argentine. The meat is intended for animal consumption, but is purchased by the trade as fit for human consumption and carries the appropriate certificate. It is subject, therefore, to the Food and Drugs Act, 1955, and in particular to the Staining and Sterilizing regulations, 1960. Shipments of incoming meat are liable to inspection by the Port Health authorities; samples taken from Argentine meat during 1961, 1962 and 1963 showed 61%, 40% and 41% positive for Salmonellae in each year respectively [41]. This same rate of contamination is still evident since 1963. It is thought that a small quantity of this meat is eaten by the human population, some is canned, and the majority is sold as raw meat through pet shops. Many dogs eat the meat raw and the kitchens of domestic houses would be contaminated by the Salmonellae in this meat so that there is obvious danger of cross-contamination with other foods.

Horse meat found to be contaminated at port inspection is ordered to be cooked throughout by boiling. This process cannot be carried out within the jurisdiction of the inspectorate, but the meat is released to the trade for the treatment to be given. This situation is not satisfactory and, in addition, the process of inspection is costly in manpower and facilities. The procedure is unsatisfactory to the trade, which bears the cost of holding shipments in frozen store at the dockside pending the results of bacteriological testing. Furthermore, the value of the meat after cooking is very much less than that of raw meat.

As an alternative, radiation processing could be applied at the dockside to all imported horse meat, without Salmonella inspection. The costs of inspection would be saved and the meat would be assumed to be free of
Salmonellae. The meat would remain as the original raw frozen product and it would not be necessary to disturb the packing.

Microbiological studies indicate that a dose of 0.65 Mrad would be effective, and this is currently being re-confirmed in more controlled tests and extended to include frozen kangaroo meat being imported for pet food from Australia in small but increasing quantities. The quality of the meat appears to be unchanged - no effect on palatability has been observed in some tests carried out with dogs.

Some details of the possible cost of the process have already been given; 0.5d per lb is the estimate. The process appeared to be attractive enough to warrant a detailed study of feasibility and this has just been completed. This study needed the full co-operation of the Port of London Authority and experts on operations research techniques were brought in. It is not possible to report on this exercise in detail, but it is apparent that the operation of a large radiation unit at the dockside is feasible; it can fit into the complexity of dock handling facilities and transport arrangements. A large frozen buffer store forming part of the plant is vital to keep the radiation facility in continuous operation, taking into account the irregular arrival of ships carrying the frozen meat. A very substantial extra capital cost must therefore be added to that of the radiation facility, but taking into account various other factors the total running costs still remain attractive. The buffer store ensures a regular and continuous output of commodity to the trade, and no difficulty in the way of hold-ups is foreseen except, of course, in the initial weeks of plant operation.

Some animal feeding studies on irradiated frozen horse meat are under way, as described by Hickman in these Proceedings. It is hoped that clearance for the process will be obtained with this data, supported by the negative evidence obtained elsewhere with other meats. It is also anticipated that the Staining and Sterilizing regulations (1960) controlling the treatment of contaminated meat will need modifying to include this new process and discussions with the responsible Ministry have taken place.

GENERAL DISCUSSION AND CONCLUSIONS

Radiation processing appears to offer considerable promise for the elimination of Salmonellae from frozen meats and animal feeds. Considerable attention is focussed on the introduction of the process for frozen horse meat and other meats imported as pet food in the United Kingdom. This particular application has special features which fulfil many of the requirements for a practical process. These are as follows:

(a) The Salmonella problem in the product is serious enough [41] to warrant the introduction of a high capital cost process and is unlikely to be completely solved by improved hygiene at the point of production;

(b) The competitive process based on the use of heat is unattractive, particularly since a large proportion of the trade is in raw meat;

(c) Microbiologically, the process is effective, and the product is maintained frozen before, during and after irradiation until fed to domestic animals;

(d) The quality of the product is unaffected by the radiation treatment and is acceptable to the trade;
(e) The process is attractive to the trade, since the meat is maintained in the raw, frozen state. Furthermore, the importer is relieved of the anxiety and expense incurred by sampling procedures at the dockside which might result in the requirement to cook whole consignments.

(f) The process is particularly attractive to the inspecting health authorities since it can be applied within their jurisdiction to all the imported meat, irrespective of examination. The process is obviously very much more thorough than the heat process applied after limited sampling of occasional shipments;

(g) The annual throughput is high enough to warrant the use of a large plant of economic size and it can be situated so that there is minimum interference with the normal distribution chain;

(h) The cost of treatment is acceptable in relation to the value of the product and the cost of the competitive heat treatment;

(i) Some wholesomeness data directly related to the product will soon be available and supporting evidence of the non-toxicity of irradiated meat is generally available;

(j) While certain legislative problems still exist, it is anticipated that these will be overcome in the light of the advantages of the process.

Features similar to those described for pet food apply to animal feeds, although the throughputs involved would be very much larger. Several large radiation plants would be operated at the point of export or import and such a large demand could make the process an economic proposition. The competitive process of heat treatment has a disadvantage in that the nutritive value of the protein is likely to be reduced, and an obvious disadvantage if required to be used for bagged products.

There still remains considerable interest in the irradiation of egg and egg products, particularly where the heat process is considered unsatisfactory.

Irradiation of frozen meat for human consumption also appears promising, but in this case irradiation would probably only be applied to occasional shipments, or production batches found on inspection to be contaminated. In this case an established plant with some other assured base load would have to be used.

As with many other radiation applications, the wholesomeness problem still requires to be overcome in many countries. However, health authorities might well have a particular interest in the introduction of radiation processes aimed at assisting in the control of Salmonellae and have particular regard for the specific processes proposed for the treatment of animal feeds and food intended for domestic animals.

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**DISCUSSION**

E. KAMPELMACHER: Irradiation of meat imported from South American countries seems to be one of the most important applications of the technique, and Dr. Ley has told us that he hopes such treatment will be authorized in the United Kingdom. The meat is normally shipped either in boneless packs or as carcass quarters, and it becomes contaminated by Salmonella wherever it is deboned and chopped up. With the boneless packs this occurs in the country of origin, with the quarters in the European countries where, after thawing, the meat comes into contact with chopping-blocks, knives and other previously contaminated material. I wonder whether, from the standpoint of public health, surface treatment of whole quarters followed by appropriate packaging and by deboning in the importing country would not be easier and more hygienic than irradiation of boneless frozen meat.

F.J. LEY: The process envisaged in the United Kingdom is to be applied to frozen boneless horse meat, imported in that state and sold raw as pet food. The meat is shipped in packaged blocks suitable for treatment with gamma rays. The irradiation could be performed either at the point of export or at the point of import, though at present the latter seems preferable.

As to the treatment of meat quarters, you may well be right that surface irradiation with electrons from a machine of appropriate low energy would be sufficient. Such treatment could be given before packaging, provided of course that suitable precautions were taken to avoid cross-
contamination between unirradiated and irradiated meat. Even so, I think that a completely efficient surface treatment of non-uniform, irregularly shaped quarters marked by crevices and so on could be a formidable task for an electrical machine, though in view of the rapid progress being made with such machines it might be possible.
Perspectives for the use of ionizing radiation (Salmonella radicidation) of some frozen proteinaceous foods and dry mixed feed ingredients

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Abstract — Résumé — Аннотация — Resumen

Perspectives for the use of ionizing radiation in the decontamination (Salmonella radicidation) of some frozen proteinaceous foods and dry mixed feed ingredients. Radiation decontamination, particularly of proteinaceous staple foods of low water activity, seemed to be promising as one of the first applications of ionizing energy in food and feed processing because of (a) restricted radiochemical damage to the commodities concerned; (b) absence of microbial proliferation subsequent to irradiation; and (c) some, often unique, technological advantages, such as applicability to materials already packaged, e.g. mixed feed ingredients, and effective decontamination without simultaneously losing freshness, as in the case of red meats and poultry.

As a first step, laboratory-scale dose range-finding experiments in this area were carried out earlier with, at the same time, sub-acute testing for wholesomeness. The results of these experiments were very promising. Pilot-plant-scale tests were next carried out, while concurrently research on wholesomeness was extended to a full two years/three generations assay with rats. In these tests it was confirmed that a dose of the order of 0.7 ± 0.1 Mrad suffices for the elimination of Salmonellae from frozen and dried proteinaceous products, such as chickens, fish meal and mixed feed. If, for reasons of analytical facility, a negative Enterobacteriaceae test for representative numbers of samples of the order of 10 g of radicidized material were preferred, the radiation dose would have to be slightly raised; the strict maximum would then amount to 1.0 Mrad, e.g. when mixed feeds, initially containing higher numbers of relatively radiation-resistant, pigmented Enterobacter strains were to be treated. No consistent, radiation-dependent, untoward effects on the experimental animals used, i.e. rats and, to a lesser extent, piglets, was detected at any of the irradiation levels tested.

It is, therefore, concluded that the third evaluation step can now be undertaken, that is: tentative commercial-scale decontamination experiments in the region of production. Latin American countries like Argentina and Peru might be the most promising areas for the first tests of this sort, as they are amongst the greatest exporters of some of the commodities that are most frequently found contaminated with Salmonellae (frozen boneless horse meat, and fish and cottonseed meals), while having generally well-equipped laboratories and reasonably well-trained graduate staff available. A 50 000–Ci source of Co⁶⁰, or an X-ray machine of a similar output, may be successfully used in such test runs. Microbiological evaluation techniques for routinely controlling the efficacy of such irradiation treatments have already been worked out and tested under pilot plant conditions. Finally, wherever possible, the merits of these radicidation treatments should be experimentally compared with those of competitive, conventional processing methods, such as pelleting in the decontamination of feed ingredients; this approach would make it possible for the industries concerned to take their decisions at the completion of the first commercial-scale tests.

Perspectives de l'emploi des rayonnements pour la decontamination (radicidation de Salmonella) de certains aliments proteiques congeles et des constitutants de melanges alimentaires secs pour animaux. La decontamination par les rayonnements, notamment celle des denrees proteiques de base a faible activite chimique de la teneur en eau est apparue comme une des premiieres applications prometteuses de l'energie ionisante au traitement des denrees alimentaires destinees a la consommation humaine ou animale; les raisons en sont les suivantes: a) alteration radio-

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Comme première étape, on a procédé antérieurement à des expériences en laboratoire en vue de déterminer les diverses doses nécessaires et de vérifier simultanément la comestibilité après irradiation à des doses sous-critiques. Les données obtenues étant fort prometteuses, on a procédé ensuite à des essais dans des installations pilotes en entreprenant en même temps une étude de la comestibilité sur des rats pendant deux années entières (trois générations). Ces essais ont confirmé qu'une dose de l'ordre de 0,7 à 0,1 Mrad suffisait amplement pour détruire les Salmonellae dans les produits protéiques congelés ou déshydratés tels que poulets, farines de poisson ou mélanges alimentaires pour animaux. Lorsque, pour des raisons de facilité d'analyse, on était amené à préférer un test entéro-bactérien négatif pour un nombre représentatif d'échantillons de l'ordre de 10 g de matières traitées par radicidation, il fallait augmenter légèrement la dose de rayonnement; la dose maximale strictement nécessaire s'élevait alors à 1,0 Mrad, par exemple lorsqu'il s'agissait de traiter des mélanges alimentaires pour animaux, contenant initialement un grand nombre de souches de bactéries intestinales pigmentées à радиorésistance relativement élevée. Quel que fût le niveau d'irradiation, aucun des essais n'a permis de détecter un effet radioinduit défavorable se reproduisant régulièrement chez les rats et encore moins chez les jeunes poules utilisés pour les expériences.

On peut donc conclure qu'il est désormais possible de passer à la troisième étape d'évaluation, c'est-à-dire aux essais de décontamination à l'échelle industrielle dans les régions productrices. Les pays d'Amérique latine, tels que l'Argentine et le Pérou, peuvent présenter un grand intérêt pour les premiers essais de ce genre du fait qu'ils figurent parmi les plus grands exportateurs de plusieurs des produits fréquemment contaminés de Salmonellae (viande de cheval désossée congelée et produits à base de poisson et de grains de coton), et qu'ils disposent généralement de laboratoires bien équipés et d'un personnel diplômé suffisamment compétent. Au cours de ces essais on pourrait utiliser avec succès des sources de 50 000 Ci au cobalt-60 ou un appareil à rayons X d'une puissance analogue. On a d'ores et déjà élaboré et vérifié dans des installations pilotes des méthodes d'évaluation microbiologiques permettant de contrôler régulièrement l'efficacité de ces traitements par irradiation. Enfin, toutes les fois où cela se révèle possible, les avantages de ces traitements par irradiation devraient faire l'objet de comparaisons expérimentales avec les méthodes de traitement classiques compétitives telles que l'échauffement par agglomération dans le cas de la décontamination des constituants de produits alimentaires pour animaux; cette manièvre de procéder permettra en outre aux industries intéressées de prendre leurs décisions après achèvement des premiers essais à l'échelle commerciale.
RADIODESCONTAMINACIÓN (RADICIDACION DE LA SALMONELLA) DE ALGUNOS ALIMENTOS PROTEICOS BÁSICOS CONGELADOS Y DE COMPONENTES DE ALIMENTOS SECOS PARA ANIMALES.

La radiodescontaminación de los alimentos proteicos básicos de escaso contenido de agua residual parece ser una de las primeras aplicaciones interesantes de las radiaciones al tratamiento de los alimentos del hombre y de los animales debido a las pocas alteraciones radioquímicas producidas en los alimentos tratados, a la ausencia de una proliferación microbiana subsiguiente a la iradiación, y a ciertas ventajas tecnológicas inherentes a ese procedimiento: la posibilidad de tratar productos ya empaquetados y mezclas de ingredientes de alimentos para animales y la eficacia de la decontaminación sin que los alimentos dejen de ser frescos, como en el caso de la carne roja y de la carne blanca.

Para empezar se efectuaron experimentos de laboratorio con objeto de determinar la escala de las dosis y se llevaron a cabo algunos ensayos sobre comestibilidad. Como los resultados experimentales fueron muy prometedores, se hicieron ensayos en planta piloto y los estudios sobre comestibilidad se extendieron a dos años utilizando tres generaciones de ratas. Estos ensayos confirmaron que una dosis del orden de 0,7 ± 0,1 Mrad basta para eliminar las Salmonellae de los productos proteicos congelados y deshidratados: pollos, harina de pescado, mezclas de alimentos para animales. Si por razones de comodidad analítica, se prefiriese un ensayo negativo de Enterobacteriaceae para un número representativo de muestras del orden de 10 g de sustancias radicidadas, habría que aumentar algo la dosis, que sería entonces de 1,0 Mrad como máximo, para las mezclas de alimentos destinados a los animales, que en principio contienen un número más elevado de cepas pigmentadas de Enterobacteriaceae relativamente radiorresistentes. Con las dosis ensayadas no se ha observado ningún efecto perjudicial de las radiaciones en los animales de laboratorio utilizados (ratas y, en menor medida, cerdos jóvenes).

Puede iniciarse ya la tercera etapa, que consistirá en ensayos de descontaminación en escala comercial efectuados en las zonas de producción. Algunos países latinoamericanos tales como la Argentina y el Perú podrían ser las regiones más adecuadas para efectuar los primeros ensayos de esta índole, pues figuran entre los mayores exportadores de algunos de los productos que con frecuencia están contaminados por las Salmonellae (carnes de caballo congelada y desosada, harina de pescado y de semilla de algodón), y al mismo tiempo disponen de laboratorios bien equipados y de personal competente. Para estos ensayos puede utilizarse con éxito una fuente de 60Co de 50 000 Ci o un aparato de rayos X de capacidad análoga. Se han elaborado ya, o se están ensayando en planta piloto, algunas técnicas de evaluación microbiológica para controlar la eficacia de este tipo de irradiación. Por último, siempre que sea posible, habrá que comparar experimentalmente las ventajas de esta radiación con otros métodos tradicionales de tratamiento, por ejemplo, la descontaminación por el calor al fabricar aglomerados con ingredientes de los alimentos de animales. Esto permitirá que las industrias interesadas tomen sus decisiones al terminar los primeros ensayos en escala comercial.

1. EPIDEMIOLOGICAL BACKGROUND

It has been established beyond any doubt that quite a few foods and feeds, prepared in some of the most productive areas of the world, are
frequently contaminated with enteropathogenic and enterotoxinogenic organisms. Such contaminated products present a risk to the indigenous population and to foreigners employed in these areas, which contributes to the reduction of the productivity so much needed in those parts of the world. Contaminated foods also act as vehicles in the transmission of certain zoonoses which interfere with animal health and production. Finally, contaminated commodities entail quite serious exportation problems, with economic consequences that may not be considered at all trifling.

Because radiation processing definitely offers some possibilities for overcoming most of these problems, it was thought worth while to review those perspectives here.

2. MICROBIOLOGICAL INDICATIONS FOR RADIATION DECONTAMINATION

The use of ionizing radiation in food processing for microbiological purposes has been, and will continue to be, hampered by the fact that, unlike heat-processing, one cannot always, for reasons of acceptability of the final product, apply the dose of microbicidal energy which would be required to render the product entirely safe. Therefore, possibilities for development of the surviving flora are of great importance, wherever radiation-processing of foods is considered. In the so-called radappertization of foods [1] the risks of a surviving microflora have been almost eliminated [2-4]; however, in what is called radurization of foods [1], they continue to present very serious problems [5-7]. In contrast to this, the radiation treatments under review here involve less danger to public health.

For our purpose it is intended to apply radiation to (a) frozen red meats, poultry and game; and (b) dried proteinaceous mixed feed ingredients, such as fish meal, cottonseed meal and soya meal, or mixed feeds. The dose to be used for the elimination of pathogenic organisms, particularly Salmonellae, is of the order of 0.6 ± 0.3 Mrad, [8-12] and therefore far from sterilizes the commodities; nevertheless, the surviving organisms do not present very much of a problem in this instance, as they occur in a medium with a water activity [13] varying from 0.45 [11] to 0.82 [14], which does not permit bacterial proliferation.

In addition to the absence of contra-indications to Salmonella radicidation, some essential technological advantages in this mode of processing exist. Due to the high penetrating power of many types of ionizing radiation, this type of microbicidal energy can be applied to almost any commodity, whatever its profile, and the mode of packaging applied for transportation. Also, at the level of energy absorption required for radicidation almost no radiochemical changes, and virtually no heat dissipation occur, so that the products are maintained chemically and physically in their original state.

3. OBJECTIVE EVALUATION OF THE FEASIBILITY OF RADICIDATION TREATMENTS APPLIED TO SOME FROZEN PROTEINACEOUS STAPLE FOODS AND DRY FEEDS

In the evaluation of the commercial feasibility of any type of antimicrobial processing by irradiation, it is required to compare, first of all, the
bactericidal efficiency, the shortcomings, and the cost of this new way of processing, with the corresponding features of conventional treatments having a similar effect. Only when the irradiation treatment seems to offer essential advantages in at least one respect, without entailing serious disadvantages, can it be expected that potential users in industry will be tempted by the irradiation process, and hence show interest in its application on an industrial scale. An attempt is made in this paper to follow this approach for the processes under review.

Frozen meats.

The mode of infection of frozen meats with Salmonellae has been the subject of a great many studies. From these it can be concluded that the mechanism is roughly as follows [15-18]. A few live animals become infected with Salmonellae while still at the farm, or on the prairie, by the use of contaminated feeds and/or water, the droppings of birds, and a few minor other causes. These animals do not usually fall clinically ill, but become healthy carriers. A considerable increase in the infection rate, defined as the per cent of animals harbouring Salmonellae in their intestinal contents, or mesenteric lymph glands, occurs when slaughter animals are brought together in a closed environment, i.e., during transportation and lairage. A further numerically very important spread of Salmonellae occurs in the slaughter-house itself. By accidental puncturing of the intestines, and, also, to a lesser extent, organs like the mesenteric lymph glands, great numbers of organisms are freed from a hitherto limited focus; by the generally prevailing lack of abattoir hygiene, these are subsequently disseminated over the carcasses. From here, two further avenues lead to considerable increases in Salmonella surface counts; these bacteria will increase rather rapidly in numbers, due to storage of the carcasses at temperatures over about 10°C, while deboning, which is often carried out with meats intended for exportation, so as to save shipping costs, will lead to a further spread of the bacteria over hitherto uninfected areas. The author's own, yet unpublished, observations in South America have shown that where both external factors are operative in combination, i.e., when deboning is carried out at an environmental temperature of around 20°C, and is followed by much too slow freezing of the, too large, meat blocks, increases in Enterobacteriaceae counts of the drip [19] with a factor of the order $10^4$ may easily occur.

From these data, it can be concluded that a considerable reduction in Salmonella infection rates of frozen carcasses can be achieved, in principle, by preventive measures, such as (a) modified methods of feeding, transportation and holding of animals, prior to slaughtering; and (b) greatly improved measures of sanitation of slaughter-houses and carcass-processing lines. It is clear that such measures require capital investment, time and, above all, availability of sufficient numbers of adequately-trained technical staff and supervisors with university training. Providing the latter for some of the most productive beef areas of the world in Eastern South America will require decennia of training and, once more, capital investment, namely, in education. Finally, the psychological aspect of this matter should not be neglected. As explained, quite extensive measures are requested from the industry to attain a goal that means no real "image" to the circles concerned, that is, the reduction of Salmonella
surface counts. The author's personal experience is that it is therefore very hard to convince the leaders of the meat industry in South America of the necessity of all this, but that some corrective, final treatment has a much better chance, because it is similar to the pasteurization of raw milk, which is a generally accepted procedure. Thermal treatments being virtually impracticable in this instance, irradiation may then have a real place in frozen-meat processing.

The cost of such a treatment, which should be at a dose of 0.3-0.6 Mrad, dependent on the initial contamination of the carcasses [9, 11], and hence on the degree of sanitation in husbandry and meat works already attained, has been estimated earlier [20], and also in several papers, from different countries, published in these Proceedings [21-23]. Although the expense is generally trifling, i.e. of the order of $10^2 \times$ price of the commodity, it does not seem likely that the meat industry is going to apply such irradiation treatment fully voluntarily. However, if importing countries will introduce legislation, limiting the Salmonella or Enterobacteriaceae counts (vide supra) on frozen meats to a — by irradiation easily attainable — low level, this will doubtless stimulate the meat industry to consider the use of ionizing radiation.

As mentioned in the introduction to this paper, no untoward effects of the low doses of radiation required on the culinary quality of frozen meat have ever been reported, nor do they seem likely, from a theoretical point of view.

Frozen poultry and game

The mechanism of the contamination of chicken carcasses by Salmonellae is similar to that of pork, veal and beef [24]. However, poultry nowadays being produced, slaughtered and packed in a technologically much more advanced way it seems, at least in principle, more feasible in this case to take preventive measures against Salmonella contamination than in the more traditional production of the much larger mammal carcasses. Therefore, it may be a subject for further pilot-plant research to decide which is the more attractive approach — further improvement of the sanitary aspects of the various stages of poultry processing, such as scalding, evisceration, rapid chilling and packaging [25, 26], or a terminal radicidation treatment of the packaged frozen item which is, as the author and colleagues have shown [11], a distinct possibility. Once more, the final stimulus for any improvement to be made at all might well have to come through legislation, issued by importing countries.

The situation might be somewhat different for frozen ducks. As has been demonstrated beyond any doubt, ducks show a much higher Salmonella carrier rate than chickens, mainly due to the fact that they are birds requiring an aqueous environment for optimal development [27-30]. Therefore, it may be correspondingly more difficult to attain considerable reductions in the Salmonella surface counts of packed, frozen ducks; hence radiation may be more attractive in this instance. Evidently, these considerations hold even more true for game, where absolutely no control can be achieved over the initial, i.e. live, Salmonella-carrier rates.
Dry animal feeds

Almost all feed ingredients of biological origin are nowadays obtained by modern manufacturing techniques, such as dehydration, extraction, toasting or combinations of such processes. Some products of this class, such as meat, blood, bone and feather meals, are even deliberately heat-decontaminated before drying, to eliminate other pathogenic agents which sometimes occur in the raw materials used in their preparation. The occurrence in such materials of Salmonellae, and occasionally also of other pathogenic organisms, must therefore be due to post-process recontamination, as has been experimentally confirmed in many instances [31-35]. Hence, here again, sanitary improvements in the processing and bagging methods currently carried out can, in principle, lead to virtually Salmonella-free commodities, as has been clearly demonstrated [36]. Where this cannot yet be easily achieved, e.g. in certain developing areas, radiation decontamination is an attractive possibility, as all that has to be done is to irradiate the properly-bagged material with doses of the order of 0.5 Mrad [11].

However, a word of caution seems to be appropriate here. Very much attention has been paid recently to the decontamination of fish meal in particular. This was probably because the occurrence of Salmonellae was not expected in anything else than products of warm-blooded animal origin; perhaps, also, in view of the considerable increase, in the last decennia, of the use of fish meal in mixed feeds for various meat animals in northern countries. For instance, Peru exported only some 30 000 tons of fish meal in 1956, but no less than 700 000 tons in 1961 [37].

This has sometimes detracted attention from the occurrence of Salmonellae in other mixed feed ingredients, such as cottonseed flour, where they may be present in higher initial numbers than in fish meal, but particularly where, in the long run, Enterobacteriaceae die twice as slowly as in fish meal (cf. Table I) and may thus reach production animals in higher numbers. These observations have led to the idea that the most practicable way of protecting the feeds of meat animals might be a terminal treatment of the mixed feed. The adjective 'practicable' may be especially underlined in this context because, from the point of view of international health protection, decontamination of every single item in the country of production would be obviously much more attractive.

However this may be, terminal treatment of mixed feeds is certainly going to be a point of interest to the feed industry. Clearly, this can be done by ionizing radiation treatment similar to that described for fish meal but here irradiation faces competition from pelleting with steam [38, 39]. As shown in Table II, pelleting may, indeed, under certain technological, circumstances, have a most impressive decontamination side effect — up to six decimal reductions in Enterobacteriaceae counts but not all pelleting plants used in industry are so effective, as can be seen in Table II. In fact, sometimes the reduction of Enterobacteriaceae in general is so weak that it can only be called marginal when considered against the requirements, dictated by the excessively heterogeneous distribution of Salmonellae over the raw material [40]. The relative merits of gamma irradiation and pelleting for decontamination of mixed feeds, or feed ingredients, will, therefore, have to be determined ultimately by careful comparison of data on their respective practicability and cost, which must be obtained in a series of suitable pilot-plant experiments.
TABLE I. SPONTANEOUS REDUCTION IN NUMBERS OF VIABLE CELLS OF A NATURAL MIXED FLORA OF SALMONELLA ORANIENBURG AND ENTEROBACTER SPECIES IN FISH MEAL AND IN COTTONSEED FLOUR OF THE SAME \( a_w = \text{ABOUT 0.40} \)

<table>
<thead>
<tr>
<th>Period of storage at 18 ± 1 °C (weeks)</th>
<th>Enterobacteriaceae (count/g)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>fish meal</td>
</tr>
<tr>
<td>0</td>
<td>( 0.2 \times 10^5 )</td>
</tr>
<tr>
<td>2</td>
<td>( 0.1 \times 10^5 )</td>
</tr>
<tr>
<td>6</td>
<td>( 0.2 \times 10^4 )</td>
</tr>
<tr>
<td>10</td>
<td>( 0.1 \times 10^4 )</td>
</tr>
<tr>
<td>14</td>
<td>( 0.5 \times 10^3 )</td>
</tr>
<tr>
<td>20</td>
<td>( 0.2 \times 10^3 )</td>
</tr>
</tbody>
</table>

Approximate No. of decimal reductions in 20 weeks: 2 (slightly less than 1)

As a first step in this direction the author recently carried out some experiments on the radiation decontamination of mixed feeds of the type currently used in the Netherlands, the gross composition of which is: corn - 25%; barley - 23%; milo corn - 16%; oats - 10%; wheat bran - 10%; fish meal - 8%; soya - 4% and lucerne meal - 4%. The analytical criterion, chosen for efficient decontamination, was the absence of all Enterobacteriaceae in a representative number of samples of about 10 g [41]; only in this way can the absence of Salmonellae in consignments so treated under practical conditions [40] be guaranteed with an acceptable margin of safety. Pigmented, lactose negative anaerogenic strains of the genus Enterobacter were found as sporadic survivors when the earlier established effective dose of approximately 0.6 Mrad was applied to these feeds. This appeared to be partly due to rather high initial numbers of these organisms in the raw materials used; this, in turn, was caused by a higher survival rate of these organisms in a dry environment than in the case of Salmonellae (cf. Table III). Also, the intrinsic radiation resistance of these organisms was slightly higher than that of the most resistant Salmonella serotypes encountered in earlier studies [11] (Figs. 1-4). These facts made it necessary to increase the radiation dose to a median value of 0.8 Mrad and a strict maximum of 1.0 Mrad.

4. WHOLESOMENESS

It is obvious that radiation treatments of foods, and even feeds, could not be considered at all if any doubt existed about their wholesomeness. There is almost no aspect of food processing by ionizing radiation that has been so comprehensively studied as the possible occurrence of orally toxic substances in irradiated foods. From the data obtained so far [42-46] it can be concluded that no chronic toxicity of any type, including
TABLE II. REDUCTIONS IN NUMBERS OF VIVABLE CELLS OF NATURAL ASSOCIATIONS OF ENTEROBACTERIACEAE IN THE COURSE OF PELLETING MIXED FEEDS

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Plant B run 1</th>
<th>Plant B run 2</th>
<th>Plant U run 1</th>
<th>Plant U run 2</th>
<th>Plant U run 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Highest temperature recorded along the line (°C):</td>
<td>83</td>
<td>80</td>
<td>52</td>
<td>60</td>
<td>59</td>
</tr>
<tr>
<td>Raw material</td>
<td>0.6 x 10^6</td>
<td>0.2 x 10^6</td>
<td>0.2 x 10^6</td>
<td>0.4 x 10^7</td>
<td>0.2 x 10^7</td>
</tr>
<tr>
<td>Raw material, immediately after steaming</td>
<td>&lt; 10</td>
<td>&lt; 1</td>
<td>0.5 x 10^5</td>
<td>0.5 x 10^6</td>
<td>0.2 x 10^6</td>
</tr>
<tr>
<td>Raw material, immediately after pelleting</td>
<td>&lt; 10</td>
<td>&lt; 1</td>
<td>0.2 x 10^6</td>
<td>0.8 x 10^4</td>
<td>0.1 x 10^5</td>
</tr>
<tr>
<td>Raw material, cooled pellets</td>
<td>&lt; 10</td>
<td>&lt; 1</td>
<td>0.3 x 10^4</td>
<td>1.0 x 10^4</td>
<td>0.2 x 10^6</td>
</tr>
<tr>
<td>Decontamination efficiency</td>
<td>&gt; 5</td>
<td>&gt; 5</td>
<td>2</td>
<td>3</td>
<td>2</td>
</tr>
</tbody>
</table>

coefficient = N₀/Nₚ, to the nearest log unit.
### TABLE III. REDUCTION IN NUMBERS OF VIABLE ENTEROBACTERIACEAE OF TWO DIFFERENT TYPES OF STRAINS IN MIXED FEED OF aw = 0.62

<table>
<thead>
<tr>
<th>Strain</th>
<th>Numbers for storage period at 18 ± 1°C of</th>
<th>0 days</th>
<th>1 day</th>
<th>5 days</th>
</tr>
</thead>
<tbody>
<tr>
<td>Salm. binza</td>
<td></td>
<td>0.2 \times 10^6</td>
<td>0.1 \times 10^4</td>
<td>0.2 \times 10^3</td>
</tr>
<tr>
<td>Salm. oranienburg</td>
<td></td>
<td>0.3 \times 10^7</td>
<td>0.6 \times 10^4</td>
<td>0.5 \times 10^4</td>
</tr>
<tr>
<td>Enterobacter, strain P 3</td>
<td></td>
<td>0.1 \times 10^8</td>
<td>0.2 \times 10^6</td>
<td>0.2 \times 10^6</td>
</tr>
<tr>
<td>Enterobacter, strain P 4</td>
<td></td>
<td>0.5 \times 10^8</td>
<td>0.5 \times 10^7</td>
<td>0.2 \times 10^6</td>
</tr>
</tbody>
</table>

FIG. 1. Survival curves of *Salmonella binza* in mixed feed and in fish meal

FIG. 2. Survival curves of *Salmonella oranienburg* in mixed feed and in fish meal
carcinogenesis, has ever been detected in a variety of foods of different gross composition, pH, and water activity, irradiated up to 5.6 Mrad. Initial tentative observations to the contrary have not been confirmed in extended repeated tests by the same investigators [47]; the observed untoward effects must, therefore, have been due to external factors, different from the irradiation treatment applied to the feed.

Amongst the irradiated foods assayed for potential oral harmful effects in this way occur red meats and chicken [42]. As the items tested had been irradiated at a dose at least five times higher than that to be
applied for Salmonella decontamination, and because the water activity of these foods during and subsequent to irradiation had been about 0.98, whereas in frozen items it is below, $a_w = 0.82$ [14], it was thought unnecessary to examine these same items again after they had been radicidized.

On the contrary, no extensive tests for wholesomeness have been published so far for radicidized dry goods with a significant unsaturated lipid content, such as fish meal. The authors therefore undertook such experiments themselves. Rats are being fed for two years on rations containing herring meal, irradiated at 0.8 Mrad, in an amount of 35% of the air-dry material. To date, after 1½yr, no losses were detected in the nutritive value of the protein, while specific organ weights, as well as haematological, histological, enzymological and fertility data, revealed no signs of deleterious effects causally related to the irradiated fish meal [48]. The data from the author's Institute have been corroborated recently by Dammers et al. [49], who found no untoward effect at all when mixed feed, irradiated at 1.0 Mrad, was given as the sole ration to piglets, initially weighing about 25 kg, up to reaching "bacon weight", i.e. roughly 100 kg, in slightly more than three months, which may be considered a rather sensitive bioassay.

Confirming the impressive amount of wholesomeness data in general which has already been obtained, it can therefore be concluded that, from the point of view of toxicity risks to production animals, nothing can be levelled against tentative commercial-scale radiation experiments, where the feed produced is actually sold for animal production.

5. REQUIREMENTS IN DEVELOPMENT, LABORATORY CONTROL AND TRAINING

In sections 3 and 4 of this paper some data obtained in tentative dose-range finding tests for Salmonella control of frozen meats and dry feeds are presented. Recently the authors sought confirmation of these presumptive data by paying full attention to the possibility that in these preliminary experiments erroneously high D values had been obtained, because surviving organisms had been counted as such, that is, without a previous resuscitation treatment [50-54]. From the results obtained it was concluded that, although resuscitation was confirmed to be occasionally required in general, irradiation at a dose of ≤ 1.0 Mrad did not seem to provoke in Enterobacteriaceae sub-lethal lesions that prohibited applying immediate plating methods, using media containing the conventional triphenyl methane dyes and bile salts [55]. These results were in agreement with earlier observations regarding lack of the influence of the composition of culture media on the recovery of irradiated bacterial cells [56-58]. Hence, probably the most effective dose ranges found earlier [11] can be considered as definite, and no further research seems urgently required in this area.

Pilot-plant experiments since carried out on quantities of frozen chickens and ducks, as well as on mixed feeds of about 1000 kg, at a dose of 0.8 ± 0.2 Mrad, did not present any specific problem. The survivor data obtained were in perfect correspondence to what had been found earlier in laboratory-scale tests, using a Gamma-cell with
a capacity of some 0.5 Mrad/kg h. Therefore, industrial test runs with sources of $50 \times 10^4$ Ci $\text{Co}$, or X-ray machines of similar output, can now be undertaken with confidence.

A scheme, statistically justified, for the examination of larger numbers of samples, taken from production lines, to evaluate decontamination efficiency has also been worked out since [40]. All this material having been fully published, very little research seems to be required for areas that anticipate the use of ionizing energy installations for the purpose of Salmonella radicidation.

On the contrary, in areas where pilot plants for food and feed irradiation might be advantageously located, for example, in Peru and/or Chili, and Argentina and/or the province of Sao Paulo, Brazil, some introductory training and extension work in the radiation microbiology of food and feed might be required. Formal post-doctoral courses, as well as one- to two-year training periods for young university graduates, would be quite helpful in the formation of the required scientific officers. Some less extensive training at the technical level would also be required. Finally, information services, at the request of interested industrial circles and as extension activities of the irradiation centre itself, would be most helpful in making the local food and feed manufacturing industries acquainted with the possibilities of ionizing radiation as a tool in food and feed technology.

Obviously, such radiation centres could be most advantageously founded at universities that have good programmes in nuclear physics and general microbiology.

ACKNOWLEDGEMENTS

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A number of colleagues participated in the execution of some of the phases of the research reported in this paper; their participation constituted a more essential part of the investigations than would be implied by a mere acknowledgement.

M. de Proost, Research Centre for Atomic Energy, Mol, Belgium, provided dosimetric services for almost five years in the Gamma-cell dose-range finding tests. S. Jefferson and F. J. Ley, United Kingdom Atomic Energy Authority, Wantage, England supervised the pilot-plant tests with frozen poultry and animal feeds. E. H. Kampelmacher and M. van Schothorst, National Institute of Public Health, Utrecht, Netherlands and K. Büchli, Institute of Poultry Husbandry 't Spelderholt, Beekbergen, Netherlands, actively co-operated in the latter experiments. A. P. de Groot, V. J. Feron and P. Til, Central Institute for Nutrition and Food Research T. N. O., Zeist, Netherlands, authorized the publication of yet unpublished data on the wholesomeness of irradiated fish meal. O. Wouters, Central Institute for Nutrition and Food Research T. N. O., Zeist, The Netherlands, determined or verified extensive series of aw values.
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DISCUSSION

D. MASSA: I quite agree that more efficient Salmonella control is likely to be achieved if one irradiates at the final stage in the preparation of the mixed feed rather than irradiating the individual feed components. With regard to the use of chemicals to control Salmonella in feed, I think that ethylene oxide should be avoided as it might form toxic compounds in the treated product.

Let me add, in conclusion, that the treatment of frozen, boneless meat by radiation is, in my opinion, particularly important. It is virtually impossible to control Salmonella completely in the meat factories, even in those which satisfy the highest hygienic standards.

H.A. MUGLIAROLI: Do you think that Salmonella contamination varies a great deal between different parts of a given meat-packing plant?

D.A.A. MOSSEL: In the live animals contamination varies, of course, depending on their state of health and the sanitary conditions in which they are maintained. After slaughtering, the quarters are contaminated to roughly the same degree. Deboning can then disseminate the contamination to all parts of the quarter, and if the ambient temperature is not low enough the development of Salmonella will not be appreciably inhibited. For all these reasons the contamination of the final product can vary enormously, depending on the sanitary conditions and the temperature maintained in the meat-packing plant.

H.A. MUGLIAROLI: Do you think it best to irradiate before shipment or at the port of destination?

D.A.A. MOSSEL: The deboned meat is generally packed in polyethylene wrappers, and it seems to me that the most appropriate thing would be to irradiate it before shipment. Provided this is done efficiently, there should be no more Salmonella or other Enterobacteriaceae left in the meat.
IRRADIATION AS A QUARANTINE CONTROL MEASURE

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FELCOURT, SUSSEX, UNITED KINGDOM

Abstract — Résumé — Аннотация — Resumen

IRRADIATION AS A QUARANTINE CONTROL MEASURE. One hundred and eighty-six million people passed through US borders in 1965. Of 446,000 consignments inspected at US ports of entry last year, 32,000 were infested. This vast increase in international travel, exchange of goods in trade and the speed of movement from one part of the world to another, requires strict measures to prevent worldwide dissemination of "unwanted" insect species. Once an exotic species is established, quarantine surveys of pest abundance, distribution and jump spread, require great efforts in containment campaigns with a view to eradication.

Is "inspection" the most economic means of combating the introduction of undesirable insect species? Is the establishment of irradiation facilities for the treatment of certain commodities, at import or export, or interstate collecting centres, a possible answer to this problem? Can irradiation of certain products replace existing techniques of fumigation?

Examples are given of the possible use of irradiation to treat passengers' baggage at airports, to prevent the spread of pests of fruit crops across inter-state boundaries and for the treatment of timber at import. Sustained release of sterilized insects as a continuous control operation is considered as a possible replacement for quarantine survey and treatment of pest containment areas.

IRRADIATION COMME MEASURE DE CONTROLE SANITAIRE. En 1965, 186 millions de personnes ont franchi les frontières des Etats-Unis. Sur les 446 000 envois de denrées alimentaires inspectés dans les ports d'accès aux Etats-Unis pendant l'année écoulée, 32 000 étaient infestés. L'accroissement considérable du tourisme international, des échanges commerciaux et de la rapidité des moyens de transport exige des mesures rigoureuses pour prévenir la dissémination dans le monde entier des espèces d'insectes "indésirables". Dès que la présence d'une espèce exotique est constatée, les contrôles sanitaires visant à déterminer l'abondance des insectes en question, leur distribution et leur rayon de dispersion exigent des efforts soutenus dans le cadre de campagnes de lutte visant à une destruction totale.

L'inspection constitue-t-elle le moyen le plus économique de combattre l'introduction des espèces d'insectes indésirables? Ce problème peut-il être résolu par la création d'installations pour le traitement par irradiation de certains produits au moment de leur importation ou exportation, ou de centres de ramassage desservant plusieurs Etats? L'irradiation de certains produits peut-elle remplacer les techniques actuelles de fumigation?

L'auteur donne des exemples d'un recours éventuel à l'irradiation pour traiter les bagages des voyageurs dans les aéroports, prévenir la dissémination des insectes nuisibles aux fruits d'un Etat à l'autre et traiter le bois à l'importation. Le lâcher massif d'insectes stérilisés comme moyen de lutte systématique est envisagé pour remplacer éventuellement le contrôle et pour le traitement sanitaire des zones de confinement.

ОБЛУЧЕНИЕ КАК МЕРА ПО КАРАНТИННОМУ КОНТРОЛЮ. В 1965 году через границы США проследовало сто восемьдесят шесть миллионов человек. Из 446 000 партий грузов, обследованных в портах прибытия США в прошлом году, 32 000 оказались зараженными. Громадное увеличение международного туризма, обмен товаров в процессе торговли и скорости передвижения из одной части мира в другую требуют принятия строгих мер по предотвращению всемирного распространения "нежелательных" видов насекомых. В случае появления экзотических видов карантинный контроль за количеством насекомых-вредителей, их распространением и быстрым их размножением требует больших усилий по проведению кампаний, сдерживающих распространение насекомых с целью их уничтожения.

Является ли "контроль" наиболее экономичным средством борьбы и распространением нежелательных видов насекомых? Является ли создание технических средств по обработке посредством облучения определенных видов грузов в пунктах импорта или экспорта, или
CORNWELL

in сборных пунктах возможным ответом на этот вопрос? Может ли облучение некоторых продуктов заменить существующие методы дезинфекции?

Приводятся примеры возможного использования облучения для обработки багажа пассажиров в аэропортах в целях предотвращения распространения насекомых-вредителей фруктовых культур за пределы внутренних границ государства и примеры обработки древесины при ввозе. Непрерывное распространение стерилизованных насекомых как средство по- стоянной борьбы рассматривается в качестве возможной замены карантинного контроля и обработки районов, в которых проводится борьба с насекомыми вредителям.

LA IRRADIACION COMO SUSTITUTIVO DE LAS MEDIDAS DE CUARENTENA. En 1965 cruzaron las fronteras de los Estados Unidos 186 millones de personas. De las 446 000 expediciones de artículos alimenticios inspeccionadas el pasado año en puertos de entrada de los Estados Unidos, 32 000 estaban infestadas. Esta enorme expansión del tráfico de viajes internacionales y la velocidad de los transportes de una a otra parte del mundo, exigen rigurosas medidas para prevenir la diseminación de las especies <indeseables> de insectos. Una vez que una especie extraña se ha introducido en un país, no es necesario conocer su densidad, su distribución y la medida en que se ha ido propagando.

El autor estima que quizás la <inspección> no sea el medio más económico para evitar la introducción de especies nocivas de insectos. Se pregunta si la creación de instalaciones para irradiar ciertos productos alimenticios en el momento de la importación o de la exportación, o en centros colectores interestatales, puede facilitar la solución de este problema y si la irradiación de ciertos productos puede sustituir las técnicas de fumigación actualmente aplicadas.

Cita algunos ejemplos de cómo las radiaciones para desinfectar el equipaje de viajeros en aeropuertos, impedir la propagación de plagas de la fruta a través de las fronteras y tratar la madera de importación. Considera que la suelta de insectos esterilizados como medida continua de control puede sustituir las operaciones de cuarentena y de tratamiento de zonas para la contención de plagas.

Quarantine is the means by which action is taken to prevent the introduction or spread of potentially destructive organisms. Its function is to protect crop production and livestock; its effects are to make exporters aware that infested consignments are undesirable at import and should goods be received infested, steps will be taken to treat them at import.

THE OBJECTIVES OF QUARANTINE

The setting-up of import permits, quarantine regulations and the subsequent policing of such regulations by inspection and treatment cannot, by virtue of the size of the problem, be 100% effective, but can act as a useful deterrent to the spread of undesirable insects of economic importance. Where infested goods escape the net of port inspection, and insects establish themselves in an importing country, there is every justification for using the full range of pest control procedures to eliminate the unwanted species. One of these procedures could be irradiation.

The philosophy of quarantine, as summarized by Reagan [1] of the United States Department of Agriculture, is to:

1. Keep foreign pests out rather than have to control them;
2. Eradicate, rather than live with them;
3. Contain and suppress their spread wherever possible if eradication is not feasible;
4. Use the best methods available;
5. Deny entry of a commodity if an effective means of treatment is not possible.
SIZE OF THE PROBLEM

International quarantine involves an extensive knowledge of pests and their status throughout the world. As an example of the problem, Reagan (loc. cit) estimates that there are 20,000 pests of economic importance not so far introduced into the United States, many of which could readily become established, given the opportunity. Many of the land masses over which plants, plant products and livestock are transported, are so large that quarantine must also be imposed to prevent internal spread within a country. Thus the inspection and treatment of goods at inter-state boundaries (e.g. in Australia) makes as significant a contribution to pest confinement as quarantine applied at ports. More important, however, than the spread of unwanted insects by national and international trade, is the unwitting spread of insects by the internationally travelling public, notably by air.

One hundred and eighty-six million people passed through the borders of the United States in 1965, nearly equal to the population of that country. Of 446,000 consignments inspected by United States quarantine personnel, 32,000 (7%), were infested. How many infested lots escaped detection is not known. A vast increase in international travel, exchange of goods in trade, and the speed of movement from one part of the world to another, requires the strictest measures to prevent world-wide dissemination of unwanted insects.

PRINCIPLES OF QUARANTINE TREATMENT

The intention of every quarantine treatment at import, or export, (usually fumigation), is to obtain the complete mortality of all stages of the insect in the commodity against which quarantine is being directed. Research has defined the conditions which should be met; dose, exposure, time and temperature. In the treatment, for instance of Hawaiian fruit, by fumigation with ethylene dibromide, in chambers, 8 oz of fumigant is used per 1000 ft³ of space for 2 h at a minimum of 21°C. The chamber must not be overloaded and the fruit must be packed in a prescribed manner [2].

For quarantine to be effective, these stipulated conditions must be attained, in practice, every time a consignment is fumigated. Failure to obtain effective control by fumigation may be caused by inadequate volatilization, poor gas circulation, sorption onto the product and leakage.

The object of every quarantine operation directed against a field pest is to confine it, diminish it, and if possible eradicate it. This task becomes easier with the development of more effective insecticidal techniques such as synthetic insecticides, bait sprays, lures or male annihilation.

POSSIBLE CONTRIBUTION OF IRRADIATION

How can irradiation fit into this picture? At present two procedures are possible:
1. The establishment of irradiation facilities at sea ports, air terminals and inter-state quarantine inspection centres to treat plant products
(e.g. fruit, vegetables, timber and bulk foodstuffs) during handling and off-loading. Because agricultural commodities are most often shipped in crates, and the infestation is frequently deep-seated, irradiation by $^{60}\text{Co}$ would appear to be more feasible than surface treatment with electrons.

2. The elimination or containment of undesirable pest insects, after establishment, by the release of radiation-sterilized insects. In future this technique may have to compete not only with chemical insecticides, but also with chemosterilants applied in such ways as to achieve the same objectives as radiation sterilization.

The feasibility of both these irradiation techniques is firmly established. Their suitability, compared with present chemical methods, depends primarily on (a) annual throughput, cost, and integration of handling procedures for direct irradiation; and (b) the ecology, distribution and behaviouristic features of the species for control by sterile-male release.

If irradiation is to become a future permissible technique for quarantine, it must, in common with fumigation, be effective every time an infested consignment is treated. Herein lies a practical advantage of irradiation; because it is a physical method of insect control, less subject to the variations which influence the performance of gases, it is conceivable, provided the commodity for irradiation falls within prescribed physical dimensions and is handled at the prescribed rate, that each part of the product can be guaranteed to be effectively treated. In contrast with fumigation, however, effective reproductive sterilization could be accepted as the parameter for treatment, rather than effective kill.

One type of material, currently subject to quarantine, but which is not a likely candidate for irradiation, is infested plant material intended for growing. Insects are considerably more tolerant of ionizing radiations than dividing plant tissue. On the other hand, whilst there is good reason to believe that most fruit and vegetables can tolerate the lethal or sterilizing doses required for disinfestation, possible adverse effects on appearance, quality, texture and flavour must be fully explored.

**EXAMPLES OF POSSIBLE QUARANTINE/IRRADIATION APPLICATIONS**

The author considers below some suggested irradiation applications, using $^{60}\text{Co}$ plant at export/import centres and inter-state collecting centres.

1. **Treatment of passenger baggage**

   Each year 250,000 passengers, largely tourists, travel between Hawaii and the west coast of America. The cost of quarantine, namely the inspection of baggage and removal of fruit, is estimated at about $1 per person for approximately 50 lb of baggage. It is already acknowledged that present quarantine inspection is superficial. Irradiation of all air-passenger baggage leaving Hawaii for the American mainland has been proposed; the removal of film and cameras from personal baggage to allow irradiation would not be an unreasonable request, and the handling of baggage by airport personnel is already highly organized. The
estimated cost of radiation processing, to provide effective sterilization of fruit pests, is considered to be less than half the cost of the present quarantine procedures.

This suggestion for the irradiation of passenger baggage at Honolulu airport was made about five years ago by Dr. L. D. Christenson\(^1\). So far, no actual irradiation of passenger baggage has been undertaken, but must await the availability of an irradiation unit large enough to handle such application. According to Steiner\(^2\), such equipment is now in the planning stage and should be ready for pilot evaluation in 1967. A study will be made of any possible damage that repeated irradiation may cause to those items often carried in passenger baggage.

The irradiation plant planned for Hawaii was originally intended as a pilot plant, but has now been modified and called the Hawaii Development Irradiator. It is being supplied by the American Atomic Energy Commission (AEC); the housing and site will be provided by the State of Hawaii.

Although this plant has the capacity to handle passenger baggage for evaluation studies (about 280,000 Ci), it will not be used for this purpose initially. Neither is it proposed to site the plant strategically for commercial exploitation.

The minimum dose requirements for treatment of subtropical fruits and vegetables have already been defined. During the first two years of study it will be used to complete research on the shipment of irradiated Hawaiian produce to the mainland. Market development studies will be undertaken by the University of Hawaii and the United States Department of Agriculture will study entomological aspects. Shelf-life extension and the effects of irradiation on wholesomeness will be undertaken by the University's Department of Horticulture and the Department of Food Technology. These studies have already been initiated, using the Hawaii Research Irradiator presently installed.

2. Treatment of fruit and vegetables commercially exported from Hawaii

Suggested firstly by Koidsumi \(^3\) as a method of treating fresh fruit (by X-rays) for export from the island of Formosa, the irradiation of fruits and vegetables, in lieu of fumigation, has more recently received detailed investigation by Balock and Christenson \(^4\).

At present, about 2000 tons of papayas are shipped from Hawaii to the mainland annually and all have to be fumigated. The production of papayas in Hawaii could be greatly increased. The commercial production of mangoes is not encouraged because export is not permitted and there is no effective fumigation treatment (Steiner\(^2\)).

The species which have been irradiated in various developmental stages include the Melon fly (Dacus cucurbitae), Oriental fruit fly, (Dacus dorsalis) and the Mediterranean fruit fly, (Ceratitis capitata).

Data on the susceptibility of the species are summarized in Table I. The dose for treatment of mangoes (for mango weevil) is expected to be

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\(^1\) This suggestion has been common knowledge for some years although no official publication is known to exist. Reference is made to it in the author's chapter "Insect Control" in: Massive Radiation Techniques (JEFFERSON, Ed.), Newnes Ltd. (1964) 181.

### TABLE I. SUSCEPTIBILITY OF FRUIT FLY SPECIES TO GAMMA RADIATION

<table>
<thead>
<tr>
<th>Fruit fly species</th>
<th>Eggs (1 day old)</th>
<th>Larvae (1-5 days old)</th>
<th>Young pupae (a) (1-3 days old)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Melon</td>
<td>3500</td>
<td>4400-4900</td>
<td>3400-6500</td>
</tr>
<tr>
<td>Oriental</td>
<td>2800</td>
<td>2900-3700</td>
<td>2600-4700</td>
</tr>
<tr>
<td>Mediterranean</td>
<td>1450</td>
<td>1850-2700</td>
<td>1800-2400</td>
</tr>
</tbody>
</table>

Doses (R) to prevent emergence of adults from irradiated fruits [10]

<table>
<thead>
<tr>
<th>Fruit fly species</th>
<th>Fruit</th>
<th>Flies emerged in control (No.)</th>
<th>Emergence</th>
<th>LD&lt;sub&gt;99&lt;/sub&gt;</th>
<th>LD&lt;sub&gt;99,999b&lt;/sub&gt;</th>
</tr>
</thead>
<tbody>
<tr>
<td>Melon</td>
<td>Miscellaneous fruit</td>
<td>44 000</td>
<td>6900</td>
<td>15 600</td>
<td></td>
</tr>
<tr>
<td>Oriental</td>
<td>Papaya</td>
<td>143 000</td>
<td>6700</td>
<td>20 600</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Avocado</td>
<td>27 000</td>
<td>7000</td>
<td>21 700</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Miscellaneous fruit</td>
<td>55 000</td>
<td>9400</td>
<td>28 000</td>
<td></td>
</tr>
<tr>
<td>Mediterranean</td>
<td>Papaya</td>
<td>40 000</td>
<td>Complete mortality at doses 2500-40 000 R</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

(a) Young pupae are included, since there is a rare possibility that larvae might mature to young pupae in packing material, after packing of the fruit for shipment, but before irradiation.

(b) \( LD_{99.999b} \) represents a mortality probit of 9, the security point recommended for quarantine treatment of fruit flies.

about 33 krad and about 25 krad for fruit flies. Studies on the shelf life remain to be completed. It is fully expected that if market development work can be finished and the Food and Drug Administration (FDA) gives approval to the treatment of Hawaiian produce, then irradiated fruits, such as papayas and mangoes (disinfested and with additional shelf life), will be moving to the United States mainland in the near future.

3. Movement of fruit between States in Australia

In a number of countries, for instance in the United States and Australia (Fig. 1), movement of fruit from one State to another is
limited by the possible introduction of undesired species. Refrigeration is practised, but it is costly and delays marketing. Ethylene dibromide, as a fumigant, tends to produce lesions on fruit at doses only slightly above those required for disinfestation. Irradiation may well provide an alternative method; transport of the product to the place of treatment for refrigeration or vacuum fumigation is essentially the requirement of an irradiation process.

The Australian production of citrus, about 8 million bushels per annum, is sufficient to satisfy the home demand. About 10% is exported, principally to Tasmania and New Zealand. Up to 50% is produced in New South Wales, where fruit fly is endemic, 35% in the Murray Valley and Murrumbidgee Irrigation Area (parts of Victoria, S. Australia and New South Wales) – producing high yields on new irrigated land with better stocks in the absence of fruit fly – and 15% in Western Australia and Queensland, susceptible respectively to Mediterranean fruit fly (Ceratitis capitata) and Queensland fruit fly (Dacus tryoni).

The distribution of fruit-fly species restricts the movement and marketing of fruit between certain States; 24-h quarantine inspection on principal roads is enforced for all consignments entering Victoria at costs borne by the State. This is the main defence of the New Zealand market. New Zealand and Tasmania insist on fruit from fly-free areas (no outbreak of fly within 50 miles of the fruit it receives). Outbreaks which occur in Victoria are thought to arise from transient, non-resident, populations and control consists of the removal and destruction of all fruit within one mile of field infestations. The widespread distribution of fruit fly in Western Australia, New South Wales and Queensland restricts citrus production in these States, it being primarily for their own demands, the juice-canning industries, and Eastern markets (the Pacific Islands, Hong Kong and Singapore).

A number of attempts have been made by the Australian Atomic Energy Commission to compile statistics on the problems of insect infestation of fruit in that country. The insects involved are fruit fly, Codling moth, scale and red mite, but fruit fly, notably in Queensland and New South Wales, has the greatest commercial significance. An analysis of rail traffic from Queensland to Victoria for 1963 to 1964 is given in Fig. 2. The demand for disinfestation is seasonal (May to October). Inter-state quarantine involves piece-by-piece inspection or fumigation. For entry into S. Australia all fruits are fumigated at 6d (approximately 7g) per case (50 to 70 lbs) (Clouston3).

If irradiation is to succeed at depot stations it has to be designed so as to meet the fluctuating demands of the industry. A 60Co source of 100000 Ci would be more than sufficient to treat 20000 cases of fruit per week, on a 24-h programme, and cost calculations indicate that irradiation compares favourably with the cost of fumigation.

4. Treatment of timber imports into Australia

Timber imports into Australia fall into three categories, namely (a) logs; (b) prepared timber; and (c) packing cases. The insects of

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FIG. 1. Plant Quarantine Services in Australia strive to prevent the introduction of new insect pests, and check the spread of insects and diseases already established. Appeals to the travelling public are part of the programme to reduce losses through fruit fly, codling moth and vine pest, Phylloxera.
FIG. 2. No. of packages per week from Queensland to Melbourne for 1963/64 by goods rail (supplied by CSIRO). Contents: bananas, citrus, pawpaws, tomatoes, avocados, custard apples, passion fruit, cucumbers, capsicums, egg fruit, marrow, squash and pumpkin.

major concern are Wood wasps (Sirex spp) and the European House borer (Hylotrupes bajulus).

The most serious problems for quarantine are presented by packing cases, because of their large volume and difficulties of inspection. Present measures, which rely on detection, followed by fumigation, are considered to be 80-90% effective. The Australian Atomic Energy Commission has examined the possible use of irradiation. Their conclusions are as follows:

(a) Radiation could be considered for the treatment of logs and prepared timbers, but it would be virtually impossible to engineer a plant capable of treating effectively the wide variety of sizes and shapes of imported packing cases. Thus, if irradiation were used it would have to be employed in the exporting country where disinfection, prior to fabrication is already often carried out; such packing cases are stamped, 'Fumigated for Sirex wasp', are certified and accepted by quarantine authorities.

(b) For logs and prepared timbers speculative estimates for irradiation treatment provide cost figures competitive with those for fumigation, but until a specific proposal is made these costs can only be used to indicate an order of magnitude. For example, with $^{60}$Co at 50 $\gamma$/Ci and timber of density 0.5, treatment with a dose of 25 000 rad would cost 0.6 $\gamma$/ft$^3$, assuming 10% efficiency and continuous operation. This compares with present-day fumigation costs for timber in large batches (greater than 50 000 ft$^3$) of 1$\gamma$/ft$^3$. The margin is not sufficiently large to provide an incentive to commercial exploitation, but the economics and interest in the application would be somewhat different if there was a mandatory requirement by Quarantine authorities to treat all timber, or a species of timber (Clouston$^3$).

5. Irradiation against Khapra beetle (Trogoderma granarium)

To comply with quarantine restrictions on the importation of Khapra beetle into East Africa, it has been the practice to fumigate all consign-
ments of malt from the United Kingdom within seven days of shipment, using methyl bromide. Treatments between 1957 and early 1963 were based on 2 lb of methyl bromide/1000 ft$^3$ for 48 h. In 1963, two consignments so treated were found infested on arrival at Mombasa and were thought not to have acquired reinfestation during the voyage. Examination of the problem revealed that fumigation temperature, penetration of the fumigant into the malt and the resistance of this insect to fumigation were to blame [5].

The Khapra beetle is one of the most dangerous pests of stored foodstuffs, acquiring its resistance to fumigants by its ability to enter diapause with a low rate of metabolism in the larval stage. The diapausing condition also enables the species to withstand adverse conditions, such as starvation and low temperature. This feature of the biology of the Khapra beetle is a serious problem in respect of reinfestation and control.

Figure 3b shows the self-multiplicative rate of increase of the Khapra beetle in relation to temperature and relative humidity (RH); the ideal environment for this species, with an increase of 80% or more per week, lies between 92 to 99°F and 40 to 75% RH. Nevertheless, it is still capable of increasing at the rate of 35% per week at a relative humidity of 5%, which is well below the level necessary for the breeding of other major grain pests (Fig. 3a).

During the early 1960's Khapra constituted a serious threat to grain storage in California, but with the use of elaborate and expensive fumigation techniques, all known infestations of Khapra beetle in the United States have now been eradicated. This insect is a clear candidate for treatment by irradiation, particularly where international shipments are involved. Studies carried out on this species, using gamma radiation from $^{60}$Co, indicate that a dose of 16 000 rad is effective for its control.

EXAMPLES OF POSSIBLE QUARANTINE OPERATIONS OF ERADICATION, OR CONTAINMENT, BY STERILE MALE RELEASE

The principles of insect control by sterile male release are now so well known as not to require reiteration. So far, the technique has been used to eliminate a veterinary pest, the Screwworm (Cochliomyia hominivorax), from the south-east United States, and an active programme of release is now in operation in Texas. The island of Rota has been freed of Melon fly (Dacus cucurbitae) [6].

Reagan [1] has given an excellent summary of the eradication campaigns against four outbreaks of the citrus pest, the Mediterranean fruit fly, in the United States over the last 37 yr. These campaigns were conducted using a variety of methods, namely,

In 1929, before modern insecticides were available, eradication was achieved by fruit destruction (cost: $7.5 million over two years);

In 1956, eradication was achieved by Malathion bait spraying from aircraft (cost: $11 million over 20 months);

In 1962, eradication was assisted by the use of insect lures (cost: $1 million over 11 months);

In 1963, eradication of a small infestation (cost: $0.3 million over 5 months).

These programmes cost the United States Federal and State Governments a total of 20 million dollars. This same figure was the annual cost of
damage estimated by the citrus industry in 1956 to Florida, should this State alone be forced to live with the Mediterranean fruit fly as a pest problem. There is no doubt that sterile male release will be seriously considered should a further outbreak occur in that part of the United States.

Under certain conditions the technique may be exploited also to contain a pest within an infestation area, thus preventing its spread. Various species of fruit fly have been considered as candidates for this technique.

1. Mexican fruit fly infestation (Anastrepha ludens), now present along the California-Mexico border, provides a useful example where sterile male release might be used to suppress newly-established insect infestations before the infested area becomes large or the population density becomes high [7]. Sustained release of sterile flies on the Mexican border, as a continuous control operation, is thought to be more economic than the present practice of quarantine survey and insecticide spraying, currently costing $100 000 p.a.

2. Investigations are also reported into the possible use of sterile males in controlling or eradicating Queensland fruit fly (Dacus tryoni) in Australia [8, 13]. The infested areas of Northern Queensland and New South Wales are too extensive to offer economic control by this method. In contrast, outbreaks of fly occur relatively infrequently in South Australia and Victoria and then principally in the metropolitan areas of Melbourne and Adelaide; from field experience of outbreaks, estimated
costs of quarantine, area inspection and losses of fruit through enforced
destruction, the prevention of outbreaks of non-resident fly, again by
the release of sterilized males as a continuous operation, is thought to
be practically and economically feasible (Andrewartha\(^4\)).

The Australian programme of research on the control of fruit flies
by sterile male release was successfully terminated in 1964. It was
concluded that the technique could be used for eliminating localized
populations, which prevail when an economic pest becomes established
after escaping quarantine inspection, but impractical as a method for
eradicating fruit fly over the vast eastern area of Australia.

SUMMARY

Quarantine inspection and treatment make a major contribution in
preventing the introduction and international spread of undesirable insect
species. Experience proves that if those areas of the world, capable of
supporting insects of economic importance, were not so protected, the
monetary loss to agriculture would be enormous.

Currently, most import/export quarantine operations rely on
commodity inspection. This is followed by treatment, usually fumigation,
only if disinfection is seen to be necessary. For some commodities
fumigation is compulsory. In other instances commodities cannot be
exchanged in trade because no effective insect control technique has been
developed.

Inspection is costly and only partially effective. For quarantine
treatment to be maximally effective visual evidence of infestation should
not be a pre-requisite of treatment. Ideally, fumigation of import/export
commodities should be carried out as a routine, eliminating pre-
inspection. The saving in labour cost would be considerable, compensating
for the increased treatment cost.

Under certain circumstances and for certain commodities, irradiation
may compete favourably in cost with fumigation. Studies should be
encouraged to establish economic and technical feasibility.

Emphasis in the development of \(^{60}\)Co sources, has been placed on
their application to particular industries for the treatment of specific
products, handling packages of standard size and shape. The potential
of isotope sources for radiation disinfection of agricultural commodities
is reduced considerably when the period of utilization is determined by
seasonal harvest.

There is a demand for highly efficient methods of insect control when
importation of commodities is subject to quarantine inspection. The
period of utilization of "port" irradiation facilities will be maximal if
they can accommodate a variety of products; the problems of conveyor
engineering associated with this concept have not received attention.

Of equal importance with preventing pest entry, the eradication or
confinement of an established insect species is a vital function of
quarantine. All possible methods should be developed to achieve this
object. Sterile male release has proved itself as an additional technique
to supplement methods already employed in the control of fruit flies.

REFERENCES

STATUS OF VARIOUS IRRADIATED COMMODITIES

(Session V)

A. MEAT AND MEAT PRODUCTS
B. POULTRY AND EGGS
C. GRAIN AND STORED FOOD PRODUCTS
D. FISH AND SEA FOOD
TECHNICAL AND ECONOMIC CONSIDERATIONS IN THE PRESERVATION OF MEATS AND POULTRY BY IONIZING RADIATION

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Abstract — Résumé — Аннотация — Resumen

TECHNICAL AND ECONOMIC CONSIDERATIONS IN THE PRESERVATION OF MEATS AND POULTRY BY IONIZING RADIATION. Radiation-sterilized meats and poultry can be of a quality better than that obtained with thermal processing.

Where the normal method of preservation of meat and poultry during distribution is refrigeration, radiation at sterilizing levels is not likely to replace it. A principal reason for this is cost. In such a civilian market, radiation-sterilized meats will serve primarily as convenience foods.

Radiation-pasteurization could provide a significant product life extension for fresh meats and poultry by delaying microbial spoilage, especially in the centralized preparation of retail cuts. Other factors of meat spoilage of a chemical or physical nature, however, are not controlled by radiation; and until they are, there is no real marketing value in the use of radiation.

For fresh or frozen poultry there is the possibility of Salmonella control, should this be needed.

Costs for sterilization and pasteurization are estimated and are presented in a form to permit selection of specific conditions within a range for certain important variables.

From a commercial viewpoint, it is important to determine the consumer acceptance of radiation-sterilized meats and poultry. The usual approach to such a determination is to market the products in question in a limited manner and to measure the acceptance under such market conditions. To accomplish this with radiation-sterilized foods, the next step appears to be to obtain a production capability to supply the products for test marketing.

CONSIDERATIONS D'ORDRE TECHNIQUE ET ECONOMIQUE SUR LA CONSERVATION DES VIANDES ET DE LA VOLAILLE PAR LES RAYONNEMENTS IONISANTS. Les viandes et la volaille stérilisées par les rayonnements peuvent être de meilleure qualité que celle obtenue par un traitement thermique.

Lorsqu'on utilise la réfrigération comme méthode normale de conservation de la viande et de la volaille en cours de distribution, il est peu probable qu'on lui substitue l'irradiation à des doses stérilisantes. La principale raison est le coût élevé de l'irradiation. Dans un marché destiné à répondre aux besoins civils, les viandes radiosterilisées seront utilisées comme appoint.

La radiopasteurisation pourrait prolonger sensiblement la durée de conservation des viandes et volailles fraîches en retardant la détérioration par les bactéries, notamment dans les grandes installations de débistage pour la vente au détail. Par contre, les rayonnements n'influent pas sur certains autres facteurs chimiques ou physiques de la corruption des viandes; tant que cela ne sera pas le cas, l'emploi des rayonnements ne présentera pas d'intérêt commercial réel.

Dans le cas de la volaille fraîche ou congélée, on pourrait, le cas échéant, appliquer un traitement contre la Salmonella.

Des estimations des prix de revient de la radiosterilisation et de la pasteurisation sont présentées de manière à permettre le choix de conditions particulières et une certaine latitude pour tenir compte de variations importantes.

Du point de vue commercial, il importe de savoir dans quelle mesure le consommateur accepte les viandes et la volaille radiosterilisées. La méthode habituelle à cette fin consiste à ne mettre sur le marché qu'une quantité limitée des produits en question et à « mesurer » l'acceptation dans de telles conditions du marché. Si l'il s'agit de denrées alimentaires radiosterilisées, il faut encore assurer une capacité de production suffisante pour l'essai de commercialisation.

ТЕХНИЧЕСКИЕ И ЭКОНОМИЧЕСКИЕ СООБРАЖЕНИЯ ОТНОСИТЕЛЬНО КОНСЕРВАЦИИ МЯСА И ПТИЦЫ С ПОМОЩЬЮ ИОНИЗИРУЮЩИХ ИЗЛУЧЕНИЙ. Мясо и птица, стери-
лизованные с помощью излучений, могут быть лучшего качества по сравнению с тем, кото­
рое достигается термической обработкой.

Там, где обычным методом консервирования мяса и птицы во время распределения
является замораживание, облучение, достигающее уровней стерилизации, вряд ли заменит
этот метод. Главная причина этого заключается в стоимости. На таком рынке стерили­
zованное с помощью облучения мясо будет служить главным образом в качестве полуфабри­
ката.

Пастеризация с помощью облучения могла бы значительно увеличить срок сохранности
свежего мяса и птицы путем предохранения их от порчи микробами, особенно при централи­
зованной разделке для продажи в розницу. Тем не менее облучение не устраняет другие
причины порчи мяса, которые имеют химический или физический характер; до тех пор, пока
эти причины существуют, применение облучения не будет давать желаемых эффектов при
реализации.

В случае необходимости для свежей или мороженой птицы можно применить контроль
в отношении сальмонелл.

Ориентировочно определены расходы, связанные со стерилизацией и пастеризацией,
которые представлены в такой форме, которая позволяет выбрать конкретные условия в рам­
ках определенных основных переменных.

С коммерческой точки зрения можно определить приемлемость для потребителя стерили­
zованных с помощью облучения мяса и птицы. Обычным способом решения такого вопроса
является размещение на рынке определенных продуктов в ограниченных количествах и опреде­
ление интенсивности спроса на них в таких условиях рынка. Следующим шагом на пути реа­
лизации стерилизованных с помощью облучения продуктов явится, по-видимому, достижение
производственных возможностей для поставок продуктов для контрольной реализации.

CONSIDERACIONES TÉCNICAS Y ECONOMICAS ACERCA DE LA CONSERVACION DE CARNES Y
VOLATERÍA POR IRRADACIÓN. La calidad de las carnes y la volatería radioesterilizadas puede ser
superior a la que se obtiene sometiéndolas a tratamiento térmico.

Cuando la refrigeración es el método normalmente empleado para conservar la carne y la volatería
durante su distribución, hay pocas probabilidades de que sea sustituida por la radioesterilización. La
razón principal es la coste en los costos. En estas condiciones, las carnes radioesterilizadas se utilizarán
en el mercado sobre todo como recurso excepcional.

La radiopasteurización podría prolongar considerablemente el período de conservación de las
carnes y la volatería frescas, puesto que retarda la acción destructiva de los microbios, sobre todo en
la preparación centralizada de piezas para detallistas. Pero las radiaciones no eliminan otros agentes
de naturaleza física o química también nocivos para la carne; mientras dure tal situación, la irradiación
carece de auténtico valor comercial.

En lo que se refiere a la volatería fresca o congelada, las radiaciones, si es necesario, permiten
eliminar la Salmoneilla.

Se calculan los costos de la esterilización y de la pasterización, y se presentan de forma que permite
seleccionar condiciones específicas en un intervalo de valores de ciertas variables importantes.

Desde el punto de vista comercial, es importante conocer la aceptación: que tendrán las carnes y
la volatería radioesterilizadas. Para ello el procedimiento habitualmente seguido consiste en poner en
venta una cantidad limitada de productos y observar su acogida en el mercado. Es por consiguiente
necesario lograr una capacidad de producción adecuada a las necesidades de ese estudio.

The principal action of radiation in aiding the preservation of
meats and poultry is to control spoilage due to microbiological
action. Such action can be either to produce sterile products with
effectively unlimited life or to reduce the microbial population suf­
ficiently to delay spoilage. A third possibility is to eliminate a
specific health hazard organism, namely Salmonella, which is associ­
ated with these foods in the raw state, particularly with poultry [1].

Sterilization

The basic requirements to obtain sterile products are reasonably
well established at present and include:
An amount of absorbed radiation (dose) sufficient to destroy all spoilage microorganisms present. Of those involved, the most radiation resistant is Clostridium botulinum. Following concepts developed in establishing requirements for thermal processing (in particular the 12 D concept), the dose presently considered necessary for meats and poultry having no added salt or acid is 4.5 megarads, when the irradiation is carried out at or above normal refrigeration temperatures. This dose destroys all spoilage organisms, including Clostridium botulinum.

That the product be in a closed container in order to prevent recontamination.

That the naturally occurring enzymes be inactivated. Since the dose for microbial sterility does not accomplish this, a supplemental treatment is needed. Presently the only effective method available is to heat to approximately 70° C.

These basic requirements are subject to modification or addition depending upon objectives and product differences. Typical of such are:

1. The use of low temperatures during irradiation to reduce off-flavor development. This may increase the dose requirement for sterilization.

2. The use of a smaller dose, probably about 3.5 megarad, for cured meats which contain adequate salt and sodium nitrite levels.

It is generally accepted that the thermal sterilizing process for meats and poultry involves a greater degree of cooking than is desirable for the best eating quality. Irradiation offers an approach to improving this situation.

Irradiation, then, offers opportunities for the preparation of meats and poultry in a preserved form with a character and quality not now attainable by the currently used thermal canning method. In the case of thermally "pasteurized" meats, such as canned hams, there is the added advantage of preservation without the refrigeration which these products now require.

One would expect radiation sterilized meats to fit into some of the same market as do thermally processed canned meats. Such products can be defined as one type of convenience foods, the principal factor of convenience being unlimited preservation, mostly without the use of
refrigeration. A second factor of convenience is that such meats are to a considerable extent prepared for the table.

The value of such products to the consumer varies with his circumstances. Where no fresh meat supply is available or where refrigeration cannot be had, it is conceivable that radiation sterilized meats could be the principal, if not sole source of meats. Where a reliable, convenient and economic source of fresh meats is available along with adequate refrigeration, the importance of radiation sterilized meats is reduced. This latter apparently is the kind of market that exists in the U.S.A. Even so, billions of pounds of thermally processed canned meats and poultry are consumed each year in the U.S.A.

If costs and quality were at least comparable with those for fresh meats, then radiation sterilized meats might compete more or less equally with a refrigerated supply and might even replace refrigerated meats, since the unlimited life would be a convenience of considerable value. On the other hand, if quality and/or costs were not comparable with fresh, then the only counter balancing factor might be the convenience of unlimited preservation.

No consumer acceptance data are available to allow direct comparison of radiation and heat preserved products. It is well known, however, that large dimensioned whole-piece meats and poultry, such as whole chickens or hams, when thermally processed to sterility are overcooked and suffer severe texture damage in the sense that they are overtender. They also have a "stewed" flavor. Because of this, such whole-piece meats ordinarily are not prepared commercially as sterile products.

Data are available for comparing radiation-sterilized meats and chicken with companion products similarly prepared but preserved by freezing. Table I [2] shows such a comparison. A study of the details of the data of Table I clearly shows that some irradiated meats, notably pork, beef roast, bacon and the Natick chicken, have acceptance equal to or close to the frozen counterpart (within 0.5 unit on the hedonic scale used). One might safely conclude that thermally processed meats would not score nearly so highly.

Pasteurization

The use of radiation to extend the normal life of fresh meats and poultry involves the concomitant use of refrigeration and other normal handling for these products. The usual spoilage bacteria of fresh meat are primarily of the genus *Pseudomonas* [3]. The action of radiation in pasteurization appears to be dual in nature: it is bactericidal, causing a reduction in the total population; and it is inhibitory, causing a lengthening of the lag phase of the growth of organisms present. Pasteurization requires relatively small doses of radiation. For example, 100 000 rad will delay a ten-fold bacterial buildup 2 to 5.5 days [4].

In the U.S.A. most fresh meats are sold as prepackaged products in a refrigerated display case. The salable life of such products is 48 to 72 hours. After this period discolorations, drip (a bloody exudate from the cut meat surface) and microbial spoilage can render the product unsalable.
Table I

Consumer panel ratings for preference in various meats

<table>
<thead>
<tr>
<th>Product</th>
<th>Source</th>
<th>Mean acceptance score†</th>
<th>Indicated preference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pork</td>
<td>Natick</td>
<td>5.2  4.9</td>
<td>Irradiated</td>
</tr>
<tr>
<td>Beef roast</td>
<td>Natick</td>
<td>4.9  4.8</td>
<td>No difference</td>
</tr>
<tr>
<td>Bacon</td>
<td>Swift</td>
<td>4.7  5.1</td>
<td>Non-irradiated</td>
</tr>
<tr>
<td>Chicken</td>
<td>Natick</td>
<td>4.6  4.9</td>
<td>Non-irradiated</td>
</tr>
<tr>
<td>Bacon</td>
<td>Natick</td>
<td>4.5  3.6</td>
<td>Irradiated</td>
</tr>
<tr>
<td>Ham</td>
<td>Swift</td>
<td>4.2  5.0</td>
<td>Non-irradiated</td>
</tr>
<tr>
<td>Chicken</td>
<td>Swift</td>
<td>4.0  5.2</td>
<td>Non-irradiated</td>
</tr>
<tr>
<td>Ham</td>
<td>Natick</td>
<td>3.9  4.9</td>
<td>Non-irradiated</td>
</tr>
<tr>
<td>Pork</td>
<td>Swift</td>
<td>3.7  4.2</td>
<td>No difference</td>
</tr>
<tr>
<td>Beef steak</td>
<td>Swift</td>
<td>3.7  4.8</td>
<td>Non-irradiated</td>
</tr>
</tbody>
</table>

† 1-7 facial hedonic scale. A rating of 1 means dislike very much, a rating of 4 means neither like nor dislike, and a rating of 7 means like very much.

‡ Statistically significant at 95% probability or greater.

Radiation pasteurization can control the microbial spoilage. It does not, however, control discoloration and drip. These are chemical and physical processes. While the formation of discoloration can be associated with microbial growth, it need not be.

In addition, oxidation of the fat of beef has been reported [5].

While less critical in some respects, irradiated chicken undergoes somewhat similar changes on storage [6] [7].

Hence, irradiation appears to be only a partial solution to the problem of extending the life of these products. Ways to control other aspects of "spoilage" are needed before radiation pasteurization is likely to be used as a preservation method.

Salmonellae in chicken

The control of Salmonellae in poultry by radiation has been proposed. Salmonella organisms occur in poultry [8], and although poultry is ordinarily heated sufficiently during cooking to destroy these microorganisms, yet it is believed that their presence on the raw product constitutes a health problem.
Salmonellae as a group are relatively sensitive to radiation. The D value for the most radiation resistant Salmonellae has been reported to be 75,000 \([9]\) to 107,000 \([10]\) rad and is to be compared with the D value for Cl. botulinum which is 375,000 rad. A seven-fold reduction in count, therefore, would take approximately 500,000 to 750,000 rad (depending upon the exact value for D). This is in the region of a strong pasteurizing treatment and may be more than the product can stand \([6]\) \([7]\) unless the irradiation is carried out at sub-freezing temperatures.

This application of radiation is being investigated actively at this time.

Costs

The question of costs needs consideration in attempting to assess the possible value of irradiation to the consumer. As stated earlier, sterilized meats and poultry in the U.S.A. market probably would be considered as a type of convenience foods. Clearly convenience has a value, but it is a value in relation to other things. While more and more convenience in foods has been given greater emphasis by the U.S.A. consumer \([11]\), the value given to it has been an individual determination. Because of this individuality, those marketing convenience foods have resorted to a test marketing procedure prior to large scale commitments for production and marketing \([12]\). This test procedure is subject to a great many variations but basically involves the preparation of a quantity of the product to be marketed, the selection and supplying with this product of relatively small and well defined market areas and, as sales are made, the determination of the market response in terms of product movement, price, promotion, competition, etc. The test may be repeated in one or more additional markets in order to assess market differences. Results from such test marketing serve to guide the marketing organization on the success likely to be had with large-scale production and sale of the product in question.

An experienced and knowledgeable marketing organization will exercise some judgment as to the kind of product likely to succeed, the cost structure needed, etc. As might be expected, different commercial organizations will use different criteria and generalizations on such would not be too meaningful. Therefore, no view will be expressed in this paper as to whether costs for irradiation are likely to be in line with commercial requirements or not. An attempt, however, to estimate these costs will be made.

The approach to making cost estimates involves:

1. An estimation of capital costs for facilities and the translation of such costs to an appropriate part of product costs through a capital cost write-off based on a volume of product over some definite time period.

2. An estimation of operating costs per unit of product.

It should be noted, however, that these two cost items do not constitute the complete cost story, since other variable costs such as selling costs enter into a business operation.
There are many variables in the irradiation process and, at this stage, it is difficult to select those which will apply to a future real situation. Consequently, we will attempt to arrive at a general method which allows narrowing to a particular set of circumstances.

Capital costs

To estimate capital costs, facility design characteristics must be defined to some extent. While generalizations will be made later to provide for a range of conditions, at the start the following will be chosen:

- **Radiation source:** Cobalt-60
- **Capacity:** 4 000 megarad pounds per hour
- **Source efficiency:** 21%
- **Cost of cobalt-60 per curie:** $0.50
- **Dose:** 4.5 megarad
- **6 000 hours per year operation**

Capital costs for this situation are as follows [13]:

<table>
<thead>
<tr>
<th>Item</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Facility</td>
<td>$901 000</td>
</tr>
<tr>
<td>Cobalt-60</td>
<td>865 000</td>
</tr>
<tr>
<td>Liquid nitrogen storage and handling</td>
<td>258 000</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>$2 024 000</td>
</tr>
</tbody>
</table>

A convenient procedure for translating these capital costs to a proper part of the product cost is a method usually referred to as the discounted cash-flow rate-of-return method. In using this technique we will assume the following:

1. **Depreciation life is ten years.**
2. **Depreciation method is a straight line function.**
3. **The same annual net revenue is obtained each year.**

The management of a commercial enterprise will require a rate of return according to its judgment of the risk of the venture, higher rates being required for propositions judged to be more risky. From this is derived the amount of cost assigned to each unit of product.

<table>
<thead>
<tr>
<th>Table II</th>
<th>Sterilization costs - 4 000 megarad pounds per hour</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rate of return on capital (%)</td>
<td>Approximately pay off (years)</td>
</tr>
<tr>
<td>50</td>
<td>1.1</td>
</tr>
<tr>
<td>29</td>
<td>2.0</td>
</tr>
<tr>
<td>13</td>
<td>4.0</td>
</tr>
<tr>
<td>6</td>
<td>6.2</td>
</tr>
</tbody>
</table>
A 50% rate of return requirement would probably indicate that management considers the risk to be quite high. This rate of return would return the capital invested in 1.1 years. A 6% rate of return on the other hand would apply to less risky ventures. It would return capital in about 6.2 years.

Table II shows sterilization capital cost estimates for the chosen conditions specified earlier and for four rates of return on capital invested.

**Operating costs**

For annual operating costs for sterilization, the following are estimated:

<table>
<thead>
<tr>
<th>Direct labor</th>
<th>$50,400</th>
</tr>
</thead>
<tbody>
<tr>
<td>Supervision</td>
<td>38,400</td>
</tr>
<tr>
<td>Maintenance, repairs, utilities</td>
<td>23,200</td>
</tr>
<tr>
<td>Taxes and insurance</td>
<td>34,800</td>
</tr>
<tr>
<td>Source replacement</td>
<td>112,400</td>
</tr>
<tr>
<td>Liquid nitrogen</td>
<td>188,000</td>
</tr>
<tr>
<td>Depreciation</td>
<td>202,400</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>$649,600</strong></td>
</tr>
</tbody>
</table>

Since the annual production is about 5,300,000 pounds, the cost per pound is about 12 cents. Table II also shows the total of capital and operating costs for four rates of return.

One may not always need to irradiate at temperatures requiring liquid nitrogen. Eliminating this would reduce the total cost about 4 cents per pound.

We can extend the estimates to cover some of the variables likely to be encountered, namely

(1) Different capacities.
(2) Different efficiencies of source utilization.
(3) Different cobalt-60 costs.

Using calculation methods similar to that given previously, we arrive at the following for sterilization:

Fig. 1 shows the operating costs in cents per pound of product for cobalt-60 at zero cost and at $0.50 per curie for efficiencies of source utilization of 21 and 35% and over a range of capacities from 2,000 to 5,000 megarad pounds per hour.

Fig. 2 shows the total cost in cents per pound of product as related to cobalt-60 cost from zero to one dollar per curie, at efficiencies of source utilization of 21, 28 and 35%, at a 50% rate of return and at a capacity of 3,000 megarad pounds per hour.

Fig. 3 shows the total cost in cents per pound of product as related to cobalt-60 cost from zero to one dollar per curie, at efficiencies of source utilization of 21, 28 and 35%, at a 50% rate of return and at a capacity of 4,000 megarad pounds per hour. Fig. 4 shows similar information at a 6% rate of return.
Figs 2, 3 and 5 permit comparison of total costs per pound of product, at a 50% rate of return and for efficiencies of source utilization of 21, 28 and 35% for capacities of 3000, 4000 and 5000 megarad pounds per hour.
FIG. 3. Total costs at 50% rate of return and 4000 Mrad lb/h.

FIG. 4. Total costs at 6% rate of return and 4000 Mrad lb/h.

From these calculations we conclude:

(1) A significant reduction of operating costs occurs with increased capacity.

(2) As the cost of cobalt-60 increases, the operating cost becomes more sensitive to different efficiencies of source utilization.
With an adequate scale of operation (at least 4,000 megarad pounds per hour) and with a less severe capital return requirement (ca. 6%) we can reach a cost in the range of 10 to 15 cents per pound for sterilization.

We should add a few comments to these estimates. For sterilized products it is expected that all the costs usually associated with thermal processing covering the preparation of the product, the placing of it in the container, the container itself and associated handling costs would be present. Hence costs to irradiate are extra and are over and above these costs.

Using the information presented in Figs. 1 through 5 one should be able to estimate costs for any specific situation. Should a source other than cobalt-60 be used, such as a machine source, it probably will be necessary to arrive at the costs for both capital and operating costs by appropriate means. However, the same general method should apply. Dose variation can be secured for cobalt-60 facilities by merely dividing the dose into the megarad figures shown and determining the actual capacity at this dose.

Since we are interested in costs for pasteurizing meats and poultry, some index of these can be obtained as follows:

Capital cost, 4,000 megarad pounds per hour

<table>
<thead>
<tr>
<th>Facility</th>
<th>$901,000</th>
<th>21% efficiency</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cobalt-60</td>
<td>$865,000</td>
<td>($0.50 per curie)</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>$1,766,000</strong></td>
<td></td>
</tr>
</tbody>
</table>

Operating costs are assumed to be the same as shown for sterilization, except that no use of liquid nitrogen is involved. Based on
4000 megarad pounds per hour, the annual operating costs are $422,800.

At 0.1 megarad and 6000 hours per year operation, the facility would produce 240,000,000 pounds of product at an operating cost of 0.18 cents per pound. At 0.3 megarad the production would be 80,000,000 pounds at an operating cost of 0.54 cents per pound.

Table III shows both the capital and operating costs for pasteurizing for four rate-of-return requirements.

### Table III

<table>
<thead>
<tr>
<th>Rate of return on capital (%)</th>
<th>0.1 megarad dose</th>
<th>0.3 megarad dose</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Capital (c/lb.)</td>
<td>Total (c/lb.)</td>
</tr>
<tr>
<td>50</td>
<td>.58</td>
<td>.76</td>
</tr>
<tr>
<td>29</td>
<td>.34</td>
<td>.52</td>
</tr>
<tr>
<td>13</td>
<td>.19</td>
<td>.37</td>
</tr>
<tr>
<td>6</td>
<td>.12</td>
<td>.30</td>
</tr>
</tbody>
</table>

If one finds that a business organization believes product quality and characteristics are likely to meet with consumer acceptance and if cost estimates for commercial production are not too high in their judgment, then the next step to be taken would be to test market, as mentioned earlier. To do this with irradiated meats and poultry requires the availability of an irradiation facility of sufficient capacity. The meat irradiator now under consideration in the U.S.A. primarily for the production of sterile meats would be such a unit. Its proposed capacity of one million pounds annually at 4.5 megarad (cobalt-60 radiation) appears adequate for the kind of test marketing which needs to be done.

Until test marketing is undertaken, it will be difficult to know the role irradiation will have in the preservation of meats and poultry—-at least under the marketing conditions in the U.S.A. and countries similarly supplied today with these foods.

### REFERENCES


DISCUSSION

D. MASSA: In my opinion, the use of liquid nitrogen temperatures (-80°C) during irradiation minimizes the off-flavours associated with the radiosterilization of beef and therefore solves the problem of the product's acceptability. The economics of this combined treatment requires further investigation.

W. URBAIN: While the use of liquid nitrogen temperatures during irradiation improves flavour, the D-value for Cl. botulinum is higher, and the increase in dose may offset this advantage. The ideal would appear to be the optimization of flavour, bactericidal action and cost.

G.H. GREEN: Could the acceptability of irradiated meats in your tests involving American troops be ascribed to the meat having been
cooked, any undesirable odours or flavours thereby being eliminated or disguised? Under commercial conditions any off-odour would be recognized and the meat rejected by the housewife in the raw state or during cooking.

W. URBAIN: I have no specific information on this. It is true that the housewife might see some characteristics not observed by the consumer panel, but I do not know whether she would have any objections. Perhaps a certain amount of consumer education will be necessary.

M. de PROOST: Is the construction of an irradiation installation for meat (1 000 000 lb/yr) referred to by you a private venture?

W. URBAIN: The present intention is to operate it privately, but with substantial financial assistance from the United States Government.
RADIATION TREATMENT OF MEAT PRODUCTS AND ANIMAL BY-PRODUCTS

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Abstract — Résumé — Аннотация — Resumen

RADIATION TREATMENT OF MEAT PRODUCTS AND ANIMAL BY-PRODUCTS. Application of radiation in food technology can only be considered as an alternative to existing preservation methods when a higher quality product and/or a cheaper product will result, or in cases where no alternative methods exist.

With this view in mind, work performed at the Danish Meat Research Institute on sliced bacon, canned hams, luncheon meat, and animal feeding stuffs, i.e. meat and bone meal and blood meal, is reviewed and discussed. The conclusion drawn from the experimental results is that the formation of off-flavours in irradiated meat products is a very serious problem and the most important obstacle to a successful application of irradiation in meat processing. It is, therefore, essential that future research should concentrate on finding means to reduce the irradiation flavour.

A number of approaches to solve this problem are mentioned and the Danish work in this field which has been centred mainly on the use of very high dose-rates and of non-equal dose distribution in cans is reviewed, and the concepts briefly described.

TRAITEMENT PAR RAYONNEMENTS DES VIANDES ET DERIVES ET DES SOUS-PRODUITS ANIMAUX. L'application des rayonnements dans l'industrie alimentaire ne saurait être considérée en remplacement des méthodes de conservation actuelles que s'il en résulte un produit de qualité supérieure ou un produit meilleur marché, ou encore lorsqu'on ne peut utiliser aucune méthode de rechange.

Dans cet esprit, l'auteur examine et commente les travaux accomplis par l'Institut danois de recherches sur la viande concernant le lard en tranches, le jambon en conserve, les pâtes de viande en conserve (luncheon meat) et les aliments pour animaux, c'est-à-dire les farines de viande et d'os et la farine de sang. Il conclut des résultats expérimentaux que la formation de goûts indésirables dans les viandes irradiées pose un problème très sérieux et constitue l'obstacle le plus important au succès de l'application des rayonnements à la préparation des viandes. Il importe donc que les futures recherches portent avant tout sur la détermination des moyens permettant d'éliminer le goût dû à l'irradiation.

Le mémoire signale un certain nombre de méthodes destinées à résoudre ce problème. Il passe en revue les travaux accomplis en la matière au Danemark, lesquels ont porté principalement sur le recours à des taux de dose très élevés et sur la distribution inégale des doses dans les boîtes de conserve, et décrit brièvement les divers principes en jeu.

РАДИАЦИОННАЯ ОБРАБОТКА МЯСНЫХ ПРОДУКТОВ И СУБПРОДУКТОВ ЖИВОТНОГО ПРОИСХОЖДЕНИЯ. Применение излучений в технологии пищевых продуктов может рассматриваться только как альтернатива к существующим методам сохранения продуктов питания, если необходимо получить продукт более высокого качества и/или более дешевый или в тех случаях, когда не существует альтернативных методов.

С этой целью в Датском научно-исследовательском институте мясной промышленности проводились работы с беконом, консервированной ветчиной, мясными консервами и животными кормами, как-то: мясная, костная и кровяная мука. Дается обзор и обсуждение этих работ. Выход, сделанный в результате проведенных опытов, заключается в том, что образование неприятных привкусов в облученных продуктах представляет собой весьма серьезную проблему и представляет значительную трудность на пути к успешному применению облучения в обработке мяса. Поэтому важно, чтобы при проведении последующих исследований главное внимание обращалось на изыскание средств для уменьшения привкусов в результате облучения.

Упоминается ряд подходов к разрешению этой проблемы, и дается обзор работ, проведенных в этой области Датским институтом, которые, главным образом, были сконцентрированы на использовании очень мощных доз и неравномерного распределения дозы в консервах. Дается краткое описание существующих концепций.
IRRADIACION DE LA CARNE Y SUS DERIVADOS. En la tecnología de los alimentos, el empleo de las radiaciones en lugar de los actuales métodos de conservación sólo puede considerarse cuando permite obtener productos de mejor calidad o más baratos o cuando no existe ningún otro método utilizable.

Teniendo esto presente, en la memoria se examina la labor que en el Instituto Danés de Investigaciones sobre la Carne se ha realizado con tocino en lonchas, jamón enlatado, pastel de carne en lata y alimentos para los animales, es decir, harina de carne y huesos, y harina de sangre. De los resultados de los experimentos se desprende que la aparición de mal sabor en los productos cárnicos irradiados es un problema muy grave y el obstáculo más importante que se opone a la irradiación de la carne durante su tratamiento. Por tanto, es esencial que en lo sucesivo las investigaciones se concentren en la manera de evitar la alteración del sabor provocada por la irradiación.

En la memoria se mencionan varios métodos para resolver este problema y se informa sobre la labor llevada a cabo en Dinamarca que ha consistido principalmente en exponer latas de conserva a intensidades muy elevadas con una distribución desigual de las dosis. Por último, se examinan algunos aspectos teóricos.

INTRODUCTION

The potential use of irradiation in food processing has been recognized for many years and extensive research has been carried out during the last 15 years to solve the fundamental and technological problems involved. A few years ago, the first irradiated foods were cleared, but although potatoes are now irradiated commercially, it appears that food processors are rather hesitant to use this new technique, and a general breakthrough is still to be seen.

The Danish Meat Research Institute has investigated the possible applications of irradiation within the meat industry for nearly a decade; an attempt is made in this paper to review this work, to give an appraisal of the present situation, and point to lines of future research.

Before reviewing the work, it is essential to define clearly the basic ideas behind the efforts. Although irradiation can be a useful tool in the hands of food technologists as a means of reducing a population of harmful organisms in a food, an irradiation treatment must not be considered as a universal preservation technique which can eventually replace all existing methods for prolonging the useful storage life of food. Irradiation must be taken as an additional preservation technique which can be brought into use:
(a) as an alternative to, or in combination with existing methods when a higher quality product and/or a cheaper product will result; and
(b) in cases where no alternative method exists.

PRODUCTS EXAMINED

Canned hams

The present heat-processing of canned, cured ham leaves a product with considerable heat shrinkage and a rather overcooked surface. The sterilization of cured hams by radiation alone (2.5 to 4.5 Mrad) gives a product with a definite irradiation flavour, and the product will not be shelf stable because of incomplete enzyme inactivation. The effect of dose on off-flavour production in canned cured ham is shown in Fig. 1, and the combination of a mild heat treatment and a low dose of irradiation (less than 1 Mrad) should then result in a ham which is stable at room
temperature and has little shrinkage and off-flavour. Intensive study of combination processing was initiated and has been described in detail earlier [1-3].

The conclusions drawn from these experiments were that it is possible to produce sterile canned hams commercially by the combination of heat treatment, to a centre temperature of 65-70°C, with doses of about 0.5 Mrad. This produces ham with a shrinkage of 6-12%, depending on size, compared to a 25-30% shrinkage in controls normally heat-treated. The irradiated hams had good texture and colour. Some off-flavour arose, and experienced taste panels scored the irradiated hams 1½ - 2 points lower than control hams on an 11-point hedonic scale. The addition of about 500 ppm ascorbate improved the flavour score for irradiated hams by about ½ point.

In order to get an idea of consumer reaction to such a combination-treated product, a consumer-acceptance study was performed [4]. A panel consisting of 150 families, selected in a limited geographical area, about 350 people in all, using a 5-point hedonic scale, compared the flavour of cured, canned ham, which had been given a combination treatment of heat to an instantaneous centre temperature of 70°C, and a 0.5-Mrad dose, to the flavour of cured, canned ham conventionally heat-treated. People were informed in advance that the experiment involved irradiated food, and nearly 80% of those requested to participate showed willingness to do so; it was interesting to note that only four families out of 166 stated that they did not wish to taste irradiated food. In two consecutive weeks they received slices of ham from either an irradiated ham or a control ham, the four possible combinations of irradiated and unirradiated ham being used. By means of test-retest data and check questions the panel was shown not to be inconsistent, and data for identical samples in various groups indicated that randomizing of the panel into different groups had succeeded. A highly significant difference in the flavour of irradiated and control ham was found, the difference in score in groups where direct comparison was possible being higher than 3/4 of a scale point in favour of the control ham; only 20% found a considerable difference between control and irradiated ham.

FIG. 1. Influence of dose on the flavour of canned cured hams. (An 11-point hedonic scale was used with 10 as excellent, 5 neither good nor bad, and 0 as poor)
in favour of the control, 30% were unable to detect any difference, and
10% gave irradiated ham a higher flavour score than the control ham.
The results confirmed the above-mentioned findings of expert taste
panels.

Luncheon meat

Luncheon meat is at present heat-processed with $P_0$ values of the
order of 0.3 to 0.5. Notwithstanding the fact that no botulinum
cook is used, luncheon meat has an excellent public health record.
However, numerous experiments with inoculated packs indicate that heat-
resistant anaerobic spores may survive, germinate, and grow in
commercial products if the initial concentration is high enough, and one
may be inclined to conclude that the safety against *Clostridium* botulinum is, to
a large extent, based on the apparent assumption that this organism is
rather rare in meat products. The risk of botulism deriving from such
products is, therefore, unknown, and the degree of safety against botulism
is considered unsatisfactory by some food microbiologists. A more
severe heat treatment cannot be applied easily, since emulsion stability
in luncheon meat is very delicate and an increase in heating will often
result in more or less complete emulsion breakdown. Therefore, the
best approach to a reduction in the risk of botulism may seem to be the
application of a moderate irradiation dose.

Figure 2 shows results of the irradiation of four different commercial
brands of luncheon meat. It was concluded that the flavour deteriorated
with increasing dose, although the degree of change varied with the brand.
Brand A, a mixed luncheon meat (containing beef), suffered most, whereas
C and D responded most favourably to irradiation, possibly because of a
rather high content of salt and spices, which may have somewhat masked
the irradiation flavour. However, it seems reasonable to assume that
doses up to 1 Mrad can be applied without seriously affecting the organo-
leptic quality of luncheon meat.

Bacon

Attempts to improve the quality of canned bacon by replacing, or
partly substituting, the heat treatment by irradiation are not likely to
succeed. The heating process used at present secures complete inacti-
vation of foot-and-mouth disease virus, if any is present, and is demanded
by several importing countries. A similar degree of inactivation by
irradiation can only be achieved by using high doses of ionizing radiation
(3-5 Mrad [5]).

An advantageous effect of irradiation on the storage life of sliced
vacuum-packed bacon could be anticipated. Off-flavour production in
bacon is moderate and doses of the order of 0.5 - 1.0 Mrad might be
applied without seriously affecting the quality (see Fig. 3). However, the
author's results indicate that the beneficial effect from irradiation on
the bacterial population is counteracted by decreased organoleptic storage
life, due to increased susceptibility to rancidity induced by the action of
the ionizing rays. Therefore, if a prolonged storage life is desired, it
would seem to be more easily obtained by improved hygiene during
processing.
Feedingstuffs of animal origin

The Danish authorities require re-sterilization of imported meat-and-bone meal and similar products. The regulations prescribe heating for at least 45 min at 125°C [6], but this treatment results in severe damage to the nutritive value of the meal. The heat treatment is meant to destroy pathogens which may be present in the imported meals, notably Salmonella species and Bac. antracis, but a similar effect may be achieved by means of irradiation without concurrent damage to the meal.
An irradiation procedure might be applied also with advantage in the production of a wide range of feedingstuffs, to reduce the damaging heat treatment of these. For instance, it would be easy to design a process for the production of sterile blood meal, including spray-drying of the blood, followed by irradiation. Irradiation treatment of animal feeds, particularly in order to eliminate Salmonellae, was recommended by a panel held by the International Atomic Energy Agency in Vienna in 1962 [7].

Dose survival curves for *S. senftenberg*, *S. give* and *S. typhimurium* in meat-and-bone meal are shown in Fig. 4; doses for seven decimal reductions were 0.33, 0.37, and 0.39 Mrad, respectively. Due to the highly infectious character of *Bac. antracis* in a dry material, it was decided to find an organism having the same radiation resistance in phosphate buffer as that of anthrax spores. Figure 5 shows that spores of *Bacillus cereus* No. 5 had the desired characteristics; the dose for a sevenfold reduction of *Bac. cereus* spores in meat-and-bone meal was calculated to be 1.30 Mrad; 2.0 Mrad is the dose used in Australia for ridding goat’s hair of *Bac. antracis*, and the author’s experiments indicate that a dose...
FIG. 5. Dose-survival curves for spores of Bac. cereus No. 5 and Bac. anthracis in physiological NaCl-solution, and for spores of Bac. cereus No. 5 in meat-and-bone-meal (initial spore concentration in solution was approximately $10^7$ organisms per millilitre and in meal approximately $10^6$ organisms per gramme).

of this order will give a high degree of safety against such pathogens in feeds.

Good correlation has been found between the content of available lysine in meals of animal origin and the nutritive value of these [8]; the author has shown that even doses as high as 5 Mrad have no effect on the content of available lysine in meat-and-bone meal or blood meal, whereas re-sterilization by means of heat treatment results in a decrease in available lysine of the order of 10-20%. To confirm these results, a feeding experiment with growing pigs was performed in co-operation with the National Research Institute of Animal Husbandry, Copenhagen [9]. Half a load of imported meat and bone meal and half a load of spray-dried blood were heat-sterilized according to the regulations, whereas the other half of each load was sterilized by means of a 2.0-Mrad dose. Ninety-six pigs, of about 20 kg each, were divided into four equal groups, each of which were fed on rations containing barley and soya meal, supplemented by one of the four different protein meals. The irradiated
meat and bone meal contained 7.5% more available lysine than the heat-sterilized meal, and the corresponding figure for the blood meals was 12%. In the period up to a weight of 50 kg, the pigs fed on rations containing irradiated meals had a significantly lower feed consumption per kilogramme gain than those fed on diets containing the corresponding heat-treated meals, but no such effect was found in the growing period from 50 to 90 kg. It was suggested that the lack of effect in the latter period was due to the fact that the rations given were deficient only in the limiting amino acids during the period when relative growth was fastest (20 to 50 kg) and the demand for essential amino acids was greatest. The pigs were slaughtered on reaching a weight of 90 kg; no significant differences were found in carcass quality or in the organoleptic quality of the bacon in the four different groups. It has thus been shown that the heat treatment used in the production of blood meal, and for the re-sterilization of imported meals, can be substituted by a dose of the order of 2 Mrad, giving a product free from any pathogens and with a higher nutritional value. No harmful effects, due to irradiation treatment, on animals fed on irradiated feeds, are to be expected.

Other products for the meat industry

Natural spices are often heavily contaminated by heat-resistant spores; therefore, spice extracts, or spices treated with ethylene oxide, are usually used in canned goods. The treatment of foodstuffs with ethylene oxide, or similar fumigants, has recently been found to leave persistent toxic chlorohydrines in the products [10]; the flavour profile panel showed that luncheon meat prepared with a number of different brands of spice extracts, or with decontaminated spices, all had off-flavours, or flavours deviating from those of luncheon meat containing natural spices. The use of irradiation for decontamination was indicated, and it was shown that doses of less than 2 Mrad caused complete sterility, even in heavily-contaminated spices (10^7 spores/g). Luncheon meat was prepared, containing one of the following spices: black pepper, white pepper, nutmeg, mace, all-spice or ginger, all of which had been given a 2-Mrad dose. The flavour profile panel was unable to detect any differences between these luncheon meats and luncheon meats prepared with the corresponding non-irradiated spices. Therefore, it appears that irradiation offers the best solution to the problem of decontamination of natural spices.

Imported casings are also often heavily contaminated. They may contain heat-resistant Bacillus spores, notably a Bac. subtilis strain, which spoils sausages by softening, and similarly, heat-resistant Clostridia spores may often be found. Treatment with lactic acid or tartaric acid removes most of the Bacillus spores, but has little effect on Clostridia, whereas irradiation effectively reduces both species. If the objective is an efficient decontamination of casings, this can at present best be achieved by irradiation. High doses of irradiation weaken the casings but the author's experiments have shown that a dose of 0.5 Mrad has no appreciable weakening effect and gives better decontamination than any other known treatment of casings.
It has been established that now, by means of irradiation, it is possible to produce canned hams with little heat shrinkage and a fine texture, botulinum-safe comminuted meats, sterile, sliced vacuum-packed bacon, and high-quality sterile animal feeds. Therefore, it might be asked why commercial irradiation processing of these products has not been established, and why the meat industry still shows a rather reluctant attitude towards food irradiation.

Several reasons for this can be mentioned: Denmark, and most other countries, have no legislation allowing for the consumption of irradiated foods, although research has indicated that no health hazards are involved, and that irradiated foods are wholesome. An international agreement on uniform legislation concerning trade in such commodities is also badly needed. Furthermore, bringing a commercial irradiation process into use means rather large investment; precise knowledge about the general economy of the irradiation processing of foods is still lacking and, what is more, the consumer reaction to irradiated meats, and the acceptability of such products is, to a great extent, unknown. The author's experiments have shown that the irradiation of ham, bacon, and comminuted meats invariably results in the development of unpleasant off-flavours which, with increasing doses, render the products unacceptable. Even doses as low as 0.5 Mrad are easily detected in most of the products tested. This is the core of the problem: the irradiated products which can be offered to industry to-day are simply not good enough; no commercial firm will dare to market a product with this deviating taste. The off-flavour problem is, in the author's opinion, the main obstacle at present to a successful application of irradiation within the meat industry.

However, there are means to reduce the undesirable flavour changes so all hopes need not be abandoned for meat irradiation. Attempts have already been made with some success to incorporate off-flavour reducing processes in the general irradiation procedure, but to obtain substantial gains, much more research is needed. It is therefore essential that future research should be directed towards and concentrated on the development of methods which can effectively minimize the flavour changes induced in the meat by ionizing radiation. A number of general approaches to this problem are mentioned later in this paper together with a brief review of the author's work in this field.

**MEANS OF REDUCING IRRADIATION OFF-FLAVOURS**

Undesirable flavour and odour changes due to irradiation can be reduced in several ways, such as

(a) Dose-modifying processes (the use of free radical acceptors, irradiation at low temperatures, irradiation at very high dose-rates, the exclusion of oxygen during and after irradiation).

(b) Use of odour adsorbants.

(c) A dose reduction (combination treatments, irradiation at high temperatures, use of sensitizers, use of an uneven dose distribution).
Dose-modifying processes

There are two distinct mechanisms by which a chemical change can be brought about by ionizing radiations: (i) By direct action, in which the molecule undergoing a change itself becomes ionized or excited by the passage through it of an electron or any other atomic particle, and (ii) by indirect action, in which the molecule undergoing the change does not absorb the energy but receives this by transfer from another molecule. In animal tissue which has a high water content the main attack on the meat constituents (fat, protein, etc.) will occur by such secondary reactions, whereas the main attack on bacteria is thought to occur by the direct action of ionizing rays. The tissue water molecules will become ionized by direct hits; this leads to the formation of very reactive and consequently short-lived radicals. By trying to direct the subsequent reactions of these, there is a chance of modifying the dose response without changing the bactericidal effect to a similar extent.

Free radical acceptors are substances which react more easily with free radicals than meat constituents do, and they will thus remove the free radicals before these can cause flavour changes. Ascorbic acid is one of the more effective acceptors found but, even so, the protection offered is not large.

A much greater effect has been found by irradiation at low temperatures. Low temperatures immobilize water molecules, the radicals formed are thus trapped and their reaction with the meat constituents suppressed. Kaufman and co-workers [11] have shown that the irradiation flavour in beef which had been given a dose of 6 Mrad can be virtually eliminated by performing the process at the temperature of liquid nitrogen; promising results have also been reported by Coleby et al. [12]. Irradiation at low temperatures caused only small increases in the resistance of bacteria.

When the ionizing rays traverse a medium, a so-called spur of ionizations will occur along the electron track. If the energy input is fast enough, i.e. a sufficiently high dose-rate is used, the spurs will start to overlap, thus causing a very high concentration of free radicals; these will react with each other (recombine) rather than react with the solute. A reduction of the chemical effects is envisaged. To obtain such reduced yield, a very high dose-rate must be used. Taimuty [13] has, on the basis of theoretical calculations, concluded that dose-rate effects in meat are unlikely to occur at rates less than $10^{10}$ to $10^{11}$ rad/sec. Such dose-rates can be obtained today from powerful machine sources on limited sample sizes.

In fats, or fatty tissue, irradiated in the presence of oxygen, a greatly increased rancidity is observed. The exclusion of oxygen reduces the possibility for the production of ozone and other chemically active forms of oxygen which, to a large extent, are responsible for the accelerated autoxidation. The main attack by irradiation on a protein will occur at the peptide and sulphur bonds. Irradiation in the presence or absence of oxygen will basically lead to the same reaction products at the peptide bond, although different mechanisms are involved [14], whereas different products will arise at the sulphur bond in the two cases. Irradiation in oxygen will, preferably, lead to the formation of non-smelling oxidation products, and in inert gas to some reduction to malodorous mercaptans and hydrogen sulphide.
By irradiation of aqueous solutions of the milk protein, \( \beta \)-lactoglobulin, in the presence of oxygen, it was noted that the solutions remained odourless or had a faint sweet smell, whereas anaerobically irradiated solutions had an unpleasant sulphurous smell [15]. Similarly, Coleby et al. [16] found that the irradiation of chicken in oxygen resulted in a better flavour than irradiation in vacuum or nitrogen. Thus, the effects of anoxic irradiation on the off-flavour-and-odour production in the fat and the protein part of meat seem to counteract each other; only in products with a high fat content (e.g. sausages and bacon) is a real advantage of anaerobic irradiation to be expected [17].

(2) Use of odour adsorbants

An attempt has been made to include a small package of activated charcoal in cans with irradiated meat. The activated charcoal has a great surface area and, therefore, a potential for adsorbing gases. During storage of the irradiated meat the charcoal will adsorb some of the volatiles from the meat, but the method has not shown a great deal of promise [18].

(3) Processes involving a dose reduction

The most obvious method for obtaining sterility at a reduced dose is to combine irradiation with another bactericidal treatment, such as heat, curing, antibiotics, etc., and such combination treatments have been applied with some success, cf. the work mentioned on canned, cured hams [1-4].

Lately, irradiation at elevated temperatures has attracted attention. It seems that the lethal effect on bacteria is greater when the ionizing energy is applied simultaneously than when applied consecutively [19], whereas no increase in off-flavour production is to be expected by moderate temperature increases [20]. The theory for the increased radiosensitivity at elevated temperatures is not clear, but it has been suggested that several bonds must be broken in a molecule before it loses its biological configuration and activity. Some of those bonds will be broken by thermal energy and some by ionizing energy. Whereas in the case of consecutive administration a repair of damaged molecules may take place, no such repair mechanism will have time to work in the case of simultaneous application and an enhanced biological effect will result.

The use of sensitizing agents, i.e. compounds which decrease the microbial radioresistance, has received considerable attention in recent years. A wide range of sensitizing agents, notably vitamin \( K_5 \) and related compounds, and sulphhydryl-binding substances, has been investigated, but the actual mechanism behind the sensitizing effect is controversial. Unfortunately, a number of the more effective sensitizers are toxic to man.

The penetration of heat into a block of meat is very slow and, consequently, thermal processing of meat gives a very uneven energy distribution. By the combination of heat and irradiation the process should ideally be designed so that an uneven distribution of the ionizing energy compensates for this. A favourable dose distribution pattern, i.e. a maximum dose in the centre part of the can, may be obtained if the cans are irradiated with electrons of a suitable energy from two or
more sides, or possibly rotated in a narrow beam. A reduction of undesirable flavour changes is achieved if the organoleptic quality of the product is governed not by the flavour changes in the centre, but by an average of the flavour changes throughout the can.

IRRADIATION AT VERY HIGH DOSE-RATES

In a study [21] which was financed through the European Research Office, the influence of dose-rate on a number of systems was investigated: raw pork meat, buffered suspensions of *E. coli* and *Micrococcus radiodurans*, buffered spore suspension of *Bac. cereus*, and *Cl. sporogenes* PA 3679, and finally *Bac. cereus* spores in meat, were irradiated at different dose-rates. Flavour changes in the meat were assessed organoleptically by an experienced taste panel and changes in the microbiological systems were recorded in terms of survival curves.

Three different dose-rates were used: gamma rays from a 60Co source at an average rate of 106 rad/sec, and electrons from a linear accelerator at rates of approximately 2 × 108 and 2 × 1010 rad/sec. An intermediate electron dose-rate was also used for some of the meat irradiations. Irradiations at the linear accelerator were performed using the "straight ahead" beam. Thin glass tubes served as irradiation vessels and were placed directly in front of the beam window on a rig which permitted the sample to be moved to and fro through the beam at right angles to it. Dosimetry was based on a current collection.

The raw, irradiated meat for flavour evaluation was mixed with water, salt was added, and the mixture heated for 5 min at 80°C immediately before serving. An assessment of flavour changes showed that, using this preparation technique, the adverse flavour changes were greatly diminished when dose-rates were increased in the range 2 × 108 to 2 × 1010 rad/sec. A dose of 1.0 Mrad at the high rate seemed to be comparable to a dose of the order of 0.3 to 0.4 Mrad at the low rate.

The bacteriological results are summarized in Fig. 6. No dose-rate effects due to spur overlapping were found on *E. coli* or spores of *Bac. cereus*. However, some rate effects were found on *Cl. sporogenes* PA 3679 and *Micrococcus radiodurans*, the high dose-rate being less effective than the rate of 2 × 108 rad/sec. However, the effects were small, only of the order of 5 to 10%, with the hundredfold increase in rate. The results seem to suggest that the effects of ionizing particles on bacteria are mainly the result of a direct action.

The study led to the conclusion that a substantial gain in the quality of radiation-sterilized meat can be achieved by increasing the dose-rate used for the irradiation process to 1010 to 1011 rad/sec, or preferably to an even higher rate, but a great deal more research in this field is needed, and the practical application of the method is at present hampered by the lack of sufficiently powerful irradiation sources.

IRRADIATIONS WITH UNEVEN DISTRIBUTION OF DOSE

Attempts have been made to obtain favourable dose distributions in square 12 oz cans (46 × 92 × 93 mm) and in round 8 oz cans (71 × 66 mm) using electrons from a linear accelerator: 12 oz cans were irradiated
from opposite sides on the conveyor belt and the 8 oz cans were moved through the beam under rotation. A shielding plate with a 5 mm slit was situated above the rotating cans. The slit was cut in the middle of the plate in the longitudinal direction of the can, so that only the part of the beam directed towards the centre area of the can was used. Dose distributions in the cans were determined by means of strips of a PVC film placed in different positions in cans with agar moulds, essentially using the technique described by Hansen et al. [22]. Electron energies for optimal dose distributions in round and square cans, using the irradiation techniques mentioned, were 12 and 8 MeV, respectively, and both gave doses in the centre which were about twice the dose at the periphery. However, more favourable dose distributions are foreseen, using modified irradiation techniques, and such work is now in progress.

Cans with luncheon meat were irradiated with even and uneven dose distributions and tested by an experienced taste panel of housewives. They judged controls, evenly-irradiated samples, and centre, surface, and average cuts from unevenly-irradiated cans. The dose in the centre was 100% higher than the surface dose but, owing to the definite sizes of the cuts, it was estimated that the average dose for the centre cut was 60-70% higher than the average dose for the surface cut. No single experiment gave significant flavour differences between cuts in unevenly-irradiated cans. However, in each separate experiment there was a tendency that the centre cut received the lowest flavour score, the surface cut the highest score, and the average cut an average score. Table I gives a summary of all flavour scores, the doses and scores quoted being average figures.

![Dose-survival curves at different dose-rates.](image-url)
TABLE I. AVERAGE FLAVOUR SCORES FOR LUNCHEON MEAT AFTER IRRADIATION WITH EVEN AND UNEVEN DOSE DISTRIBUTION

<table>
<thead>
<tr>
<th>Irradiation</th>
<th>Cut</th>
<th>Number of tests</th>
<th>Average dose (Mrad)</th>
<th>Scores (No.)</th>
<th>Average flavour score</th>
</tr>
</thead>
<tbody>
<tr>
<td>None</td>
<td>Average</td>
<td>6</td>
<td>0</td>
<td>46</td>
<td>+ 1.33</td>
</tr>
<tr>
<td>Even</td>
<td>Average</td>
<td>6</td>
<td>0.40</td>
<td>46</td>
<td>+ 0.18</td>
</tr>
<tr>
<td>Uneven</td>
<td>Surface</td>
<td>6</td>
<td>0.45</td>
<td>46</td>
<td>+ 0.18</td>
</tr>
<tr>
<td>Uneven</td>
<td>Average</td>
<td>6</td>
<td>0.60</td>
<td>46</td>
<td>+ 0.04</td>
</tr>
<tr>
<td>Uneven</td>
<td>Centre</td>
<td>6</td>
<td>0.75</td>
<td>46</td>
<td>- 0.39</td>
</tr>
<tr>
<td>Even</td>
<td>Average</td>
<td>6</td>
<td>0.90</td>
<td>46</td>
<td>- 0.74</td>
</tr>
</tbody>
</table>

Score: + 5 = excellent; 0 = neither good nor bad; - 5 = poor.

CONCLUDING REMARKS

It thus appears that several possibilities for solving the off-flavour problem in irradiated meats are in sight. The use of combination treatments, possibly combined with uneven dose application, seems rather feasible, and so does irradiation at low temperatures, taking into account that liquid nitrogen freezing of foods is, in itself, becoming a well-established process. Also, irradiation at high temperatures looks promising, and future developments in electronics may make high dose-rate irradiations feasible. However, no flavour problems exist in the case of animal feeds and, therefore, a first successful application of irradiation may be anticipated in this field, but the possible introduction of rigorous demands for safety against botulinum in products like luncheon meat may, at an early date, force through an irradiation treatment of such products.

SUMMARY

The application of radiation in food technology can only be considered as an alternative to existing preservation methods when a higher quality product and/or a cheaper product will result, or in cases where no alternative methods exist. With this view in mind, work performed at the Danish Meat Research Institute on sliced bacon, canned hams, luncheon meat, and animal feedingstuffs, i.e. meat and bone meal and blood meal, is reviewed and discussed. The conclusion drawn from the experimental results is that the formation of off-flavours in irradiated meat products is a very serious problem, and is the most important obstacle to a successful application of irradiation in meat processing. It is therefore essential that future research should concentrate on finding means to reduce the irradiation flavour.
A number of approaches to solve this problem are mentioned, and the Danish work in this field, which has been centred mainly on the use of very high dose-rates and non-equal dose distribution in cans, is reviewed, and the concepts briefly described.

ACKNOWLEDGMENT

The author is grateful to the Danish Atomic Energy Commission Research Establishment, Risø, for the provision of radiation facilities, and to the staff of the Accelerator Department, Risø, for constructing the experimental kit used for irradiation. Thanks are also due to colleagues at the Danish Meat Research Institute who took part in the research programmes described in the paper.

REFERENCES

DISCUSSION

J. K. MIETTINEN: How much time elapsed between irradiation and
tasting of the ham by the panel?

P. -I. E. HANSEN: About two weeks.

W. HAFFERL: What was the temperature increase in the meat
samples during flash irradiation at a dose-rate of $2 \times 10^{10}$ rad/sec.?

P. -I. E. HANSEN: The temperature increase was 2.5°C/Mrad.

E. JOSEPHSON: Can you reconcile your acceptance data with ours
in the United States? We obtain very acceptable bacon, beef, chicken,
ham, pork and fish when irradiation doses are as high as 5.6 Mrad. Our
data are obtained from highly trained technological panels, from consumer
panels (with acceptance testing carried out by an independent division at
the US Army Natick Laboratories), and from testing with troops at
Fort Lee, Va. The bacon you tasted at the Symposium reception was
irradiated in the dose range 4.5 to 5.6 Mrad at ambient temperature
and stored for 21 months at temperatures ranging between $20^\circ$C and $38^\circ$C.
If you could visit us at Natick, we would demonstrate how we get such
good irradiated products.

P. -I. E. HANSEN: I can only assume that there is some difference
in palate between people in the United States and Denmark. In any case
I would be very interested to visit the US Army Natick Laboratories and
try your products.

M. INGRAM: I have often commented on the difference in criteria
of organoleptic acceptability apparent on opposite sides of the Atlantic.
In this case, Mr. Hansen has dealt with a very sensitive product of
delicate flavour, normally eaten without further preparation and finally
intended for normal sale on the civilian market. I am sure that the
irradiated bacon we tasted at the Symposium reception would not be
regarded by the Danes as suitable for this purpose, though it represents
a remarkable technical achievement.
IRRADIATION OF POULTRY AND EGG PRODUCTS

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Abstract — Résumé — Аннотация — Resumen

IRRADIATION OF POULTRY AND EGG PRODUCTS. Poultry and egg products may be treated advantageously with various kinds of irradiation process, in different circumstances.

Where contamination with Salmonella is a problem, 'radicidation' may be carried out with doses of the order of 0.5 Mrad. This is particularly valuable for frozen products, such as whole egg and some kinds of poultry, especially duck. Dried-egg products may be treated also in this way. This application is described in detail by other authors (Ley, Mossel [2,3]).

The treatment of poultry carcasses so that they can be stored indefinitely, or 'radappertization', can be achieved by doses of 4.5 Mrad. However, other processes must be associated with the irradiation, to prevent undesirable off-flavours. These can include pre-heating to inactivate enzymes, irradiation in the frozen state, in vacuum or nitrogen packs, or with activated charcoal included in the pack, and particular methods of cooking are sometimes recommended. These methods are of interest for army use, and have been extensively studied for the research programme of the United States Army.

The 'radurization' process for poultry, i.e. increase in storage life by inactivation of most of the spoilage microorganisms, is of interest for commercial use. Doses ranging from 0.15 to 0.25 Mrad may be used without adverse effects on flavour, and will extend the period before microbial spoilage by 1.5- to 3-fold. Storage at chill temperatures (5°C or below) is necessary, and changes in flavour during storage may limit the extension of this period, so that 20 days at 1°C is about the most obtainable without quality deterioration. The mechanism of these changes is not understood, but they are not due to microbial spoilage or to the irradiation.

The eventual microbial spoilage of irradiated chickens at chill temperatures is due to 'non-pathogenic bacteria, which are normally present in the spoilage flora, though sometimes the proportions of different kinds of these bacteria may be altered, giving rather different 'off' odours.

The application of this process to British conditions for production and distribution of broiler chickens has been studied, and a joint investigation by the United States Atomic Energy Commission, the Atomic Energy of Canada Ltd., and the United States Army Material Command's Natick Laboratories is now in progress. This will cover economic needs and advantages, wholesomeness, product development, packaging and consumer acceptance.

IRRADIATION DE LA VOLAILLE ET DES ŒUFS ET DERIVES. La volaille et les œufs et dérivés peuvent être avantageusement traités par divers procédés d'irradiation, selon les circonstances.

S'il s'agit de contamination par Salmonella, on peut recourir à la radicidation à des doses de l'ordre de 0,5 Mrad. Ce procédé est particulièrement intéressant pour le traitement de produits congelés, tels les œufs entiers et certaines volailles, notamment le canard. Les dérivés déshydratés de l'œuf peuvent également être traités de cette façon. Cette application est exposée en détail par d'autres auteurs (Ley et Mossel [2,3]).

Le traitement de volailles entières en vue de leur conservation indéfinie (radappertisation) peut être effectué à des doses de 4,5 Mrad. Pour prévenir certaines altérations du goût, il faut cependant combiner l'irradiation à d'autres procédés, par exemple: traitement thermique préalable pour inactiver les enzymes, irradiation à l'état congelé, en emballage sous vide ou contenant une atmosphère d'azote ou du charbon de bois activé; en outre, certains modes de cuisson sont quelquefois recommandés. Ces méthodes sont intéressantes pour les usages de l'armée et ont été longuement expérimentées pour le programme de recherche de l'Armée des États-Unis.

La radurisation de la volaille, destinée à prolonger la durée de conservation par l'inactivation de la plupart des micro-organismes corrupteurs, est commercialement intéressante. On peut utiliser des doses
de 0,15 a 0,25 Mrad sans provoquer d'altérations désagréables du goût, tout en retardant de 1,5 à 3 fois la corruption microbienne. La conservation sous réfrigération (5°C ou au-dessous) est nécessaire, et cette durée peut être ahéée par l'altération du goût, de telle sorte que 20 jours à 1°C est à peu près le maximum que l'on puisse obtenir sans altération de la qualité. Le mécanisme de ces changements reste inexpliqué, mais on sait qu'ils ne sont pas dus à des agents microbiens ni à l'irradiation.

La corruption par les microbes de poulets irradiés sous réfrigération est due à des bactéries non pathogènes normalement présentes dans la flore corruptrice; toutefois, les proportions des différentes sortes de bactéries peuvent varier, donnant ainsi différentes altérations de l'odeur.


ОБЛУЧЕНИЕ ДОМАШНЕЙ ПТИЦЫ, ЯИЦ И ИЗДЕЛИЙ ИЗ НИХ. Домашняя птица, яйца и изделия из них могут успешно обрабатываться с помощью различных процессов облучения в различных условиях.

Когда речь идет о заражении Salmonella, может осуществляться "радиодеструкция" с дозами порядка 0,5 мегарад. Это особенно эффективно в отношении замороженных продуктов, таких как яйца и некоторые виды домашней птицы, особенно утки. Таким же образом могут обрабатываться сухие яичные продукты. Данный метод детально описан другими авторами (Лей, Моссел).

Обработка тушек домашней птицы с тем, чтобы они могли храниться в течение продолжительного времени, или "радаппертизация", может быть достигнута с помощью доз в 4,5 М рад. Однако наряду с облучением при этом должны применяться другие процессы для предотвращения нежелательных привкусов. Эти процессы могут заключаться в предварительном нагревании для инактивации ферментов, облучении в замороженном состоянии, в вакуумных или азотных упаковках или с активированным древесным углем в упаковке, и иногда рекомендуется отдельные методы упаковки. Эти методы представляют интерес для вооружённых сил и широко изучаются в рамках программы исследований армии США.

Процесс "радуризации" в отношении домашней птицы, т. е. увеличение срока хранения путем инактивации большей части микроорганизмов, вызывающих порчу продуктов, представляет интерес для коммерческого использования. Дозы в диапазоне 0,15 – 0,25 мегарад могут использоваться без неблагоприятного воздействия на вкус продуктов и увеличивают период хранения без порчи, вызываемой микроорганизмами, в полтора – три раза. Необходимым является хранение при низких температурах (5°C или ниже), и изменение вкусовых качеств в период хранения может ограничить продолжительность данного периода, так что 20 дней при 1°C является примерно наиболее подходящим сроком без ухудшения качества. Механизм этих изменений еще не понят, однако они имеют место не из-за микробиологической порчи или облучения.

Возможная микробиологическая порча облученных кур при низких температурах вызывается непатогенными бактериями, которые обычно имеют в микробиологической флоре, вызывающей порчу продуктов, хотя иногда соотношение этих видов этих бактерий может меняться, что приводит к появлению различных "дополнительных" запасов.

Применение этого процесса изучалось в Англии в отношении производства и распределения яичных продуктов и в настоящее время осуществляется совместное исследование Комиссией по атомной энергии США, организацией Атомик Энерджи оф Канада лимитед и Натикскими лабораториями интендантского управления армии США. Оно охватывает экономические потребности и преимущества, целостность, подготовку продукта, упаковку и одобрение потребителями.

IRRADIACION DE VOLATERIA, HUEVOS Y PRODUCTOS DERIVADOS. La volatería, los huevos y sus derivados pueden someterse eficazmente a diferentes procesos de irradiación, según las circunstancias.

Cuando el problema consiste en la contaminación por Salmonella, puede practicarse la «radicidación» con dosis del orden de 0,5 Mrad. Éste es particularmente útil cuando se trata de productos congelados, tales como huevos enteros y algunas variedades de aves, en particular patos. Los huevos desecados y sus derivados pueden también tratarse por este procedimiento. Otros autores (Ley, Mossel [2,3]) describen detalladamente esta aplicación.

El tratamiento de aves sacrificadas para poder almacenarlas durante tiempo indefinido (<radapertura>) puede efectuarse con dosis de 4,5 Mrad. De todas formas, la irradiación debe combinarse con otros procesos para evitar sabores desagradables; por ejemplo, puede recurrirse al calenta-
miento previo para inactivar las enzimas y a la irradiación de los artículos congelados, en envases al vacío o con atmósfera de nitrógeno, o en envases con aditivo de carbón vegetal activado; se recomiendan a veces procedimientos culinarios especiales. Estos son particularmente interesantes para el Ejército y son objeto de amplios estudios en el programa de investigación de las fuerzas armadas de los Estados Unidos.

La «radurización» de la volatería, es decir, la prolongación del período de almacenamiento por inactivación de la mayor parte de los microorganismos causantes de la descomposición, presenta interés comercial. Pueden administrarse dosis de 0,15 a 0,25 Mrad, que no tienen efectos perjudiciales sobre el sabor y permiten un período de conservación de 1,5 a 3 veces mayor que el habitual. Es preciso guardar los productos a baja temperatura (5°C o inferior); las alteraciones del sabor durante el almacenamiento pueden limitar el período de conservación, de forma que el máximo que se puede conseguir sin detrimento de la calidad suele ser de 20 días a 1°C. Estas alteraciones, cuyo mecanismo se desconoce, no se deben a la acción de los microbios ni a la irradiación.

El deterioro eventual por acción microbiana de los pollos irradiados conservados a baja temperatura se debe a bacterias no patógenas normalmente presentes en la flora causante de la descomposición, aunque a veces las proporciones de las diferentes especies de estas bacterias varían, produciendo malos olores también distintos.

Se ha estudiado la aplicación de este procedimiento en Inglaterra para la producción y distribución de pollos cebados de asar, y se ha emprendido una investigación en la que participan la US Atomic Energy Commission, la Atomic Energy of Canada Ltd. y los US Army Material Command’s Natick Laboratories, en la que se estudiarán las necesidades y ventajas económicas, la comestibilidad, la preparación de productos, su envasado y su aceptación por los consumidores.

Radiation can be applied to the treatment of poultry and egg products, with several different aims in view. The first of these concerns the elimination of Salmonellae, where these are known to be causing a public health problem; this is now known as Salmonella radicidation [1] and may be achieved with doses of the order of 0.5 Mrad. Other authors have dealt with this subject in some detail [2, 3] so it is only necessary to emphasize the importance of the process in relation to poultry and egg products.

Infection with Salmonellae of various serotypes is widespread among poultry, much of it being derived from the feedingstuffs used. Eggs are infected from the poultry, and the bulked egg products are particularly important in transmitting the infection to humans because they are often lightly, or partially cooked, or may pass on the infection to other uncooked products in the bakery (see review by Granville [4]). A large part of bulk egg production is stabilized by either freezing or drying, so that microbial spoilage is not a problem; only Salmonella removal is necessary.

The technical aspects of the radicidation of frozen egg have been thoroughly studied, and it has proved to be a perfectly feasible process [5, 6, 7]. It is now a question of the legal and economic aspects which will determine its eventual use. As far as legislation is concerned, the United Kingdom has recently passed a regulation making the heat pasteurization of liquid or frozen egg compulsory [8], so there seems to be little prospect for the introduction of an irradiation process here. Other countries, such as Canada and the United States, have regulations requiring the absence of Salmonellae in egg products, without specifying the method of removal. Provided irradiation in itself is sanctioned by the appropriate government agencies, it could be applied for this purpose.

An economic study [9], prepared by Arthur D. Little, Inc. on behalf of the United States Atomic Energy Commission, concludes that heat pasteurization of egg is much cheaper than radiation processing (0.12 $/lb for heat, compared with 0.75 to 1.17 $/lb for gamma rays, depending on
the size of plant) but the heat treatment has technical difficulties since the
temperature of Salmonella inactivation is very near to that of coagulation
of the egg.

If the product is already frozen, irradiation can be done without
thawing, and this may give an economic advantage over heating [5]. This
could be useful for the treatment of infected products at the port of entry.
Irradiation has also been considered as a means of improving the
prospects of export from Thailand of egg products contaminated with
Salmonellae [10].

The use of irradiation on liquid egg has not been considered feasible,
because of off-flavours produced, but a recent development shows some
promise of improvement. Licciardello [11] has shown that Salmonellae in
egg become more sensitive to radiation with increasing temperature, and
that a sharp increase takes place above 110°F (43°C), at which lethal
effects due to heat alone begin to operate. Flavour changes produced by
irradiation do not vary with temperature, over the same range [12]. This
means that a lower dose of radiation could be used in combination with
moderate heating, and such a process might be a useful alternative to heat
pasteurization.

The inactivation of Salmonellae on frozen poultry, using doses of
0.4 or 0.5 Mrad, has recently been described by Mossel and de Groot [13]
and by Tanasugarn [10] and could be especially useful for ducks, where
Salmonella contamination is particularly important. This application has
been described by Mossel [3].

In the United States and Canada, a two-year research programme on
the radicidation of chicken has been undertaken jointly by the United States
Atomic Energy Commission, the Atomic Energy of Canada Ltd. and the
United States Army Material Command's Natick Laboratories, and is now
in progress. This is described by other authors.

To turn to processes with the aim of prolonging storage life, rather
than removal of pathogenic bacteria, the first of these is radiation
sterilization, or radappertization [1], which has the object of providing
indefinite storage life at room temperature.

The generally accepted sterilizing dose of 4.5 Mrad produces severe
organoleptic changes in raw chicken, as in other raw meats, both im­
mEDIATELY after irradiation and during storage at 20°C or above, when
further deterioration takes place. A large amount of research, mostly on
behalf of the United States Army, has been devoted to methods of minimiz­
ing these changes in meats, and the most recent developments regarding
poultry are the work of the Western Regional Research Laboratories
[14, 15]. A brief summary of their conclusions follows.

To inactivate autolytic enzymes responsible for the deterioration in
flavour during storage, pre-irradiation heating to 74 to 80°C was neces­
sary. This also decreased, but did not completely eliminate, a red colour
which appeared during anaerobic storage after irradiation.

Conditions during irradiation were of great importance, and generally
included packaging under vacuum, or in nitrogen. Irradiation in the frozen
state at or below -20°C gave much reduced off-flavours immediately after
irradiation; indeed the product was sometimes indistinguishable from the
control. However, the product irradiated at room temperature improved
more during storage at 21 or 38°C, so the difference became less with
storage. The reports of improved flavour during storage differ from
earlier results, in which bitter flavours developed [16], and this was thought to be due to incomplete enzyme inactivation in the earlier experiments. Another method was to irradiate, and store with activated charcoal included in the pack; this was reported by Lineweaver and colleagues to minimize irradiation flavour at least as effectively as irradiation at sub-freezing temperatures. Reports of the same treatment with other meats had shown conflicting results.

As shown previously [17, 18], cooking methods affected the taste panel’s ability to detect irradiation flavours, which were least apparent after deep fat frying.

The main problem unsolved was that of texture changes during storage. These included the exudation of liquid, and production of a soft, disintegrated texture and dryness in the meat. Variations in the enzyme inactivation process, and the injection of adrenalin before slaughter, were tried, but did not give a satisfactory result [14].

Such a complex process as this is mainly of interest for military application. Of more general commercial interest is the lower dose treatment of chicken, known as radiation pasteurization or radurization [1]. Doses in the range 0.1 to 0.5 Mrad may be used for this, and organoleptic changes do not present such a serious problem.

The delay in microbial spoilage obtained with various doses and temperatures is shown in Table I, and varies from a 1.5-fold to a 3-fold increase (except for the highest temperatures used). Data of both authors [18, 19] show that, for any given dose, the extension is proportionally greater at lower temperatures. At the highest temperature tested by McGill et al. [19], 14.4°C (58°F), no extension of storage was obtained, even by the higher dose of radiation, 0.415 Mrad. This illustrates the importance of holding the product under refrigeration, which is also necessary to avoid any possible risk from the development of pathogens. For instance, Clostridium botulinum or perfringens in the spore form might not be killed by the radiation doses used, and could give rise to toxins if held at higher temperatures, above about 10°C for the types likely to occur on chicken.

The detailed microbiology of the process has been studied in a few cases [20, 21]. Figure 1 relates to chickens produced by large-scale factory processing and shows that, after 0.25 Mrad, the viable count was reduced by a factor of 10³, and that an additional 0.25 Mrad (making a total of 0.5 Mrad) only gave a further tenfold reduction. This non-exponential curve reflects the variation in resistance of the initial microflora. When the percentage composition was examined (Table II), most of the mixed organisms present on the control had been reduced to undetectable levels by 0.25 Mrad, leaving the more resistant yeasts and Achromobacter strains.

The spoilage of control chickens under aerobic conditions at chill temperatures is largely due to pseudomonads, with smaller numbers of Achromobacter and coliform organisms [20]. These give the usual putrid smells on spoilage. In the experiment shown, the same kind of microflora, with pseudomonads predominant, had developed on the irradiated carcasses when these eventually spoiled, in spite of the selective inactivation of these organisms by the irradiation. It seems that the effectiveness of the process is due to the high radiation sensitivity of the
TABLE I. EXTENSION OF STORAGE LIFE AT VARIOUS TEMPERATURES OBTAINED BY RADURIZATION OF WHOLE EVISCERATED CHICKENS WITH GAMMA RAYS

<table>
<thead>
<tr>
<th>Source</th>
<th>Dose (Mrad)</th>
<th>Mean storage life (d) at various temperatures (°C)</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cobalt-60</td>
<td>-18</td>
<td>1.1 4.4 10</td>
<td>[19]</td>
</tr>
<tr>
<td>0</td>
<td>&gt; 20</td>
<td>11 11 6</td>
<td></td>
</tr>
<tr>
<td>0.083</td>
<td>&gt; 20</td>
<td>20 16 11</td>
<td></td>
</tr>
<tr>
<td>0.415</td>
<td>&gt; 20</td>
<td>&gt; 20 16 11</td>
<td></td>
</tr>
<tr>
<td></td>
<td>(R11)b</td>
<td>(R16)</td>
<td></td>
</tr>
<tr>
<td>Fuel elements</td>
<td>-18</td>
<td>1.1 4.4 14.4</td>
<td>[19]</td>
</tr>
<tr>
<td>0</td>
<td>&gt; 20</td>
<td>11 6 6</td>
<td></td>
</tr>
<tr>
<td>0.083</td>
<td>&gt; 20</td>
<td>20 11 6</td>
<td></td>
</tr>
<tr>
<td>0.415</td>
<td>&gt; 20</td>
<td>&gt; 20 15 6</td>
<td></td>
</tr>
<tr>
<td></td>
<td>(R10)</td>
<td>(R15)</td>
<td></td>
</tr>
<tr>
<td>Cobalt-60</td>
<td>1</td>
<td>3 5 10</td>
<td>[18]</td>
</tr>
<tr>
<td>0</td>
<td>10</td>
<td>7 - -</td>
<td></td>
</tr>
<tr>
<td>0.125</td>
<td>-</td>
<td>11 - -</td>
<td></td>
</tr>
<tr>
<td>0.25</td>
<td>24</td>
<td>15 - -</td>
<td></td>
</tr>
<tr>
<td>0.5</td>
<td>34</td>
<td>21 - -</td>
<td></td>
</tr>
<tr>
<td>0.8</td>
<td>71</td>
<td>- 18c 14c</td>
<td></td>
</tr>
</tbody>
</table>

a Values quoted in rep have been converted to rads: rep \( \times \frac{83}{100} \) = rad.

b R, time to appearance of rancid odour.
c +3 days at 0°C before irradiation.

FIG. 1. Effect of irradiation with cobalt-60 on survival of microorganisms on whole eviscerated chicken [20].
TABLE II. THE EFFECT OF IRRADIATION WITH COBALT-60 GAMMA RAYS, AND STORAGE AT 1°C ON THE PERCENTAGE COMPOSITION OF THE PSYCHROPHILIC MICROFLORA OF CHICKEN CARCASSES [21]

<table>
<thead>
<tr>
<th></th>
<th>Percentage colonies on 1°C plates for:</th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Initial samples</td>
<td>Spooled samples</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Control 0.25 Mrad 0.5 Mrad</td>
<td>Control 0.25 Mrad</td>
<td>Control 0.5 Mrad</td>
<td>Control 0.825 Mrad</td>
<td></td>
</tr>
<tr>
<td>Pigmented Pseudomonas</td>
<td>27 - -</td>
<td>7 11 3 22</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Non-pigmented Pseudomonas</td>
<td>- - -</td>
<td>64 52 77 71</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Achromobacter</td>
<td>41 11 -</td>
<td>18 37 20 -</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Gram-negative gas-producers</td>
<td>9 - -</td>
<td>11 - - -</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Other Gram-negative bacteria</td>
<td>9 - -</td>
<td>11 - - -</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Gram-positive bacteria</td>
<td>14 - -</td>
<td>- - - - -</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Yeastsa</td>
<td>89 100 -</td>
<td>- - - - -</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Number of strains studied</td>
<td>22 19 23</td>
<td>28 27 31 24</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

a Some picked also from 20°C plates.

pseudomonads, which was reported in earlier work on meat irradiation [22], and has been confirmed in experiments with pure cultures [23].

In some early experiments which gave different results [21] chickens prepared on a farm scale with hand evisceration showed the predominance of Achromobacter strains, giving sweetish, fruity smells, on spoilage after irradiation. This difference was probably due to a different initial microflora, and shows that any change in processing conditions may affect the result. In particular, anaerobic conditions during irradiation and storage would be expected to alter the microbiological picture considerably, since both pseudomonads and Achromobacter are strongly aerobic.

The possibility that microbial growth may be delayed by irradiation products in chicken meat has been investigated by Solberg and Nickerson [24, 25], who found inhibitory effects on unirradiated cells of Staph. aureus growing on chicken irradiated with 3 Mrad. Although doses used in radurization are much lower than this, it is possible that some similar effect may take place with poultry spoilage organisms. In Fig. 2, the counts on irradiated chickens stored at 0°C are shown, and the slow rate of increase on chickens which had received 0.3 Mrad may be due to this kind of effect.

To turn to organoleptic changes, slight alterations in odour and colour may be detected after radiation doses as low as 0.1 Mrad, but are not likely to be objectionable [18, 15]. Changes in flavour were also detected after 0.1 Mrad by Hanson et al. [15], and after 0.125 Mrad by Coleby et al. [18] when the product was cooked by steaming. After the roasting of whole
FIG. 2. Number of microorganisms present on chickens during storage at 0°C after treatment with 20 ppm of chlortetracycline or irradiation [27]

Control + CTC

○ 0.3 Mrad △ 0.6 Mrad

Counts at 20°C

Counts at 0°C

FIG. 3. Decline in average hedonic score of chicken carcasses which had been treated with 20 ppm of chlortetracycline or radiation and stored at 0°C [27]. (20 tastes were made on each carcass). 0°C control (frozen) + CTC △ 0.3 Mrad □ 0.6 Mrad

chickens those which had received doses up to 0.8 Mrad could not be distinguished from controls [18].

A deterioration in flavour during storage was noted by Proctor et al. [26], for chickens irradiated with $0.8 \times 10^6$ rep and stored at 36 - 40°F (2.2 to 4.4°C). McGill et al. [19] described a rancid odour appearing during storage at low temperatures in carcasses which had received 0.415 Mrad (Table 1). This observation was not confirmed by Coleby et al. They found a decline in flavour during storage, but this was worse with nitrogen-packed than air-packed chickens, so could not have been due to rancidity. The change was the same after 0.3 Mrad as after antibiotic treatment (Fig. 3), so it was not primarily due to the irradiation, although it seemed to be accelerated by the higher dose of 0.6 Mrad [27]. It could not have been caused by microbial spoilage, as can be seen from the low viable counts in the irradiated samples after storage (Fig. 2). The change consisted of a loss of the attractive flavour of fresh chicken rather than a
development of unpleasant flavours, and its mechanism is not yet understood [28]. However, this process limits the useful extension of storage life to a time of about 20 d at 1°C, after which the decline in flavour becomes marked, although microbial spoilage can be delayed for much longer than this.

Rhodes [28] has described a process suitable for the conditions in the United Kingdom. At present, much of the poultry is distributed in the frozen state, and the aim of this irradiation process is to avoid the necessity for freezing. This involves irradiation, within 24 h of slaughter, with 0.15 Mrad, which ensures a storage life of 6 d at 5°C and one day at 15°C. Six days is thought to be the maximum needed for distribution, and one day is allowed for handling by the consumer. Control carcasses were showing signs of spoilage after 4 d at 5°C and 1 d at 15°C, and were putrid after 6 + 1 d, whereas the irradiated carcasses had no signs of spoilage after 6 + 1 d (Table III); another test indicated that their maximum storage life was about 10 d at 5°C + 1 d at 15°C. Tasting tests of roasted chickens after irradiation and storage in air for 6 d at 5°C + 1 d at 15°C showed them to be indistinguishable from frozen controls. Processing costs were reasonable, being estimated at 0.28d/lb (0.33 $/lb) for a cobalt-60 facility with a throughput of 7600 ton/yr. So far, trials have only been made on a small scale, although chickens from four different processing plants were included, and testing on a much larger scale would be necessary. However, the prospects for processes such as this in Great Britain depend on the passage of legislation which is necessary before any application of radiation to foods can be considered for approval.

It appears that processes for radurization of poultry may be useful in countries with large-scale processing plant and with refrigeration facilities. It is difficult to envisage applications for this kind of irradiation treatment in underdeveloped countries, which would probably lack refrigeration facilities even if large-scale processing were possible.

<table>
<thead>
<tr>
<th>TABLE III. APPEARANCE AND ODOUR OF IRRADIATED CHICKEN AFTER COMPOSITE STORAGE AT 5°C AND 15°C. THREE CARCASSES AT EACH EXAMINATION [28]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Radiation dose (Mrad)</td>
</tr>
<tr>
<td>----------------------</td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td>0</td>
</tr>
<tr>
<td>0.15</td>
</tr>
<tr>
<td>0.30</td>
</tr>
<tr>
<td>0.60</td>
</tr>
<tr>
<td></td>
</tr>
</tbody>
</table>

a In one carcass a very slight odour, possibly typical of irradiation, was noted.
None of the applications of radiation to poultry or eggs is at present legally approved in any country.

In the United States, a petition concerning radiation-sterilized chicken is to be submitted to the Food and Drug Administration by the Army, during this year, and a petition on pasteurized chicken, based on data collected in the joint United States and Canadian study mentioned above, will be submitted in 1968.

There is no doubt that legal clearance for these products will provide a great stimulus for the development of commercial processes.

ACKNOWLEDGEMENT

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DISCUSSION

J. MORRE: Were your experiments carried out on completely eviscerated chickens, or on birds from which the intestines are removed via the anus? This is the industrial method employed in France and it leads to less contamination of the carcass.

M. J. THORNLEY: The chickens were completely eviscerated, and irradiation of partially or non-eviscerated chickens has not been tried. However, spoilage in our experiments was due predominantly to pseudomonads, which have been shown to contaminate the carcasses during washing and chilling processes. The presence or absence of intestinal organisms would probably not offset the process, since they are mostly unable to multiply at chill temperatures. However, a different process, from which the washing and chilling procedure was omitted, would alter the microbiological result.

A. S. KOVACS: Do you have any evidence regarding the comparative effects of irradiation and, e.g., heat treatment, on the rheological properties of egg-white?

M. J. THORNLEY: Perhaps Mr. Ley can answer this question.

F. J. LEY: Our investigations at Wantage Research Laboratory have so far been concerned only with establishing the dose required for Salmonella elimination; studies of effects on the rheological properties of egg-white have not yet been carried out. Some results are available in the United States.

S. A. GOLDBLITH: In reply to Mr. Kovacs, I may add that we recently presented a paper on this question at the 26th Annual Meeting of the Institute of Food Technologists, held at Portland, Oregon, from 22 to 26 May. We have found that for a 3 log-cycle reduction of S. typhi-murium in irradiated whole-egg magma there is no difference in foam characteristics or baking quality when the magma is used for sponge cake.
STUDY OF COMBINED TREATMENT FOR DAMP-HARVESTED MAIZE: GAMMA IRRADIATION AND DRYING BY CONTROLLED VENTILATION. The purpose of combining the effects of gamma irradiation from $^{60}$Co and of slow drying by cool ventilation (10-25°C) in storage chambers is to replace the standard technique of rapid drying with high temperature air by a treatment which is less likely to damage the grain and also disinfects at the microbiological level. In France, one million tons of damp maize are involved (1964); the problem is to be regarded as one of increasing importance both in Europe and in tropical countries.

The authors first study the direct effect of gamma radiation on the yield and technical characteristics of the starch. The latter is extracted from the maize by a laboratory method which faithfully and accurately reproduces industrial conditions. Radiation doses of less than 500 krad are found to have no effect on the extraction yield, whereas drying at 74°C lowers the yield by about 4% because of the partial coagulation of the protein network and the bursting of starch granules. The slight changes in structure of the irradiated starch are in most cases advantageous from the viewpoint of further treatment of the product. They may lead to the development of a test to ascertain whether the starch or the maize have been irradiated.

Microbiological analysis techniques suitable for defining the optimum conditions for radiopasteurization of maize in relation to the environment were developed.

Armed with these data, the authors attacked the problem of combined irradiation-ventilation treatment on a laboratory scale under experimental conditions easy to transpose to the industrial level. They studied the microbiological and biochemical changes occurring in the fraction of moist grains reached last by the drying air flow, which corresponds to the most unfavourable case. From a quantitative point of view, it appears that in this zone the depressive effect of radiation on the mycoflora persists even after 26 days, and the effect on bacteria is even more pronounced. From the qualitative point of view, the mycoflora which regenerates first is specifically sensitive to the dry air flow which will reach it.

Industrial applications are envisaged, but before going on to the pilot stage, which is indispensable for establishing costs, the biochemical investigations must be taken further. The public health aspect must also be studied in case the process finds a use in the field of animal or human feeding.
qui reproduit de manière fidèle et précise les conditions industrielles. On trouve qu’un dose d’irradiation inférieure à 500 krad est sans influence sur le rendement d’extraction, alors qu’un séchage à la température de 74°C diminue déjà ce rendement d’environ 4%, en raison de la coagulation partielle de la trame protéique et de l’éclatement de granules d’amidon. Les faibles modifications de structure de l’amidon irradié sont dans la plupart des cas favorables du point de vue du traitement ultérieur du produit. Elles peuvent conduire à la mise au point d’un test permettant de savoir si l’amidon ou le maïs ont été irradiés.

Des techniques d’analyses microbiologiques ont été mises au point dans le but de définir, en fonction du milieu, les conditions optimales de la radiopasteurisation du maïs.

En possession de ces données les auteurs abordent à l’échelle du laboratoire le problème du traitement combiné irradiation-ventilation, dans des conditions expérimentales faciles à transposer sur le plan industriel. Ils étudient les modifications microbiologiques et biochimiques qui se produisent dans la fraction des grains humides atteinte en dernier par le flux d’air sèchante, ce qui correspond au cas le plus défavorable. D’un point de vue quantitatif, il apparaît dans cette zone que l’effet dépressif de l’irradiation sur la mycoflore persiste même après 26 jours; cet effet est encore plus important sur les bactéries. D’un point de vue qualitatif, on observe la régénération prioritaire d’une mycoflore précisément sensible au flux d’air sec qui doit l’atteindre.

Des applications industrielles sont en vue; mais, avant de passer au stade pilote, phase indispensable à l’établissement d’un prix de revient, il est nécessaire de mener plus avant des investigations biochimiques. De même, le point de vue de la santé publique ne devra pas être négligé pour le cas où le procédé trouverait une application dans le domaine de l’alimentation animale ou humaine.
maíz húmedo (1964) y cobrará cada vez más importancia tanto en Europa como en los países de la zona tropical.

Los autores estudian primero la influencia directa de las radiaciones gamma sobre el rendimiento y las características técnicas del almidón. Este se extrae del maíz por un método de laboratorio que reproduce de manera fiel y precisa las condiciones industriales. Se observa que una dosis de irradiación inferior a 500 krad no influye en el rendimiento de extracción, mientras que un secado a la temperatura de 74°C reduce dicho rendimiento en un 4%, debido a la coagulación parcial de la estructura proteica y a la rotura de los gránulos de almidón. Las ligeras modificaciones de la estructura del almidón irradiado son, en la mayor parte de los casos, favorables desde el punto de vista del tratamiento ulterior del producto. Tal vez sea posible idear, basándose en ellas, una prueba que permita saber si el almidón o el maíz han sido irradiados.

Se han elaborado técnicas de análisis microbiológico para definir, en función del medio, las condiciones óptimas de radiopasteurización del maíz.

Conociendo estos datos, los autores abordan el estudio en laboratorio del problema del tratamiento combinado por irradiación-ventilación, en condiciones experimentales fácilmente adaptables a la industria. Estudian las modificaciones microbiológicas y bioquímicas que se producen en la fracción de grano húmedo que es la última en ser alcanzada por el flujo de aire seco, lo que corresponde al caso más desfavorable. Desde el punto de vista cuantitativo, parece que en esta zona el efecto restrictivo de la irradiación sobre la microflora persiste incluso al cabo de 26 días; este efecto es aún más importante sobre las bacterias. Desde el punto de vista cualitativo, se observa la regeneración prioritaria de la microflora precisamente sensible al flujo de aire seco a que va a estar sometida.

Se prevén aplicaciones industriales, pero antes de pasar a la fase experimental, indispensable para determinar el precio de costo, es preciso profundizar más en las investigaciones bioquímicas. Asimismo, conviene no descuidar el punto de vista de la sanidad pública para el caso en que el procedimiento pudiese aplicarse a la alimentación animal o humana.

I. Introduction : Le problème du maïs humide


En France, la production de maïs est très fluctuante et en accroissement constant depuis une quinzaine d'années : 0,5 million de tonnes en 1950, 2 en 1960 et 2,8 en 1965, soit le dixième de la production céréalière française. Pendant cette même période l'évolution de la collecte, part de la production livrée aux organismes stockeurs, est encore plus spectaculaire : insignifiante en 1950 elle s'est élevée à 1 million de tonnes en 1960 et près de 2 en 1965. En 1970 la Communauté Economique Européenne devra faire face, selon les prévisions des spécialistes, à un déficit en maïs de l'ordre de 9 millions de tonnes, en sorte que cette culture va sans doute progresser en France et dans toute l'Europe pendant les années à venir.

Or la moitié du maïs français est récolté humide, état de choses lié à une évolution de la culture qui se manifeste depuis 20 ans. Ensemencé dans des régions plus septentrionales qu'autrefois, avec des variétés tardives à haut rendement, le maïs est à présent soumis aux impératifs de la
récolte mécanisée. On peut de moins en moins laisser sécher les épis sur pied, ou les stocker dans les cribs. Cette technique artisanale est en régression dans les régions de culture traditionnelle du Sud-Ouest et ne peut guère se propager dans les zones de grande culture. Par suite le grain collecté a souvent une humidité de 40 %, et il se pose un sérieux problème de conservation pour 1 million de tonnes de maïs d'une valeur de 400 millions de Francs. Il est indispensable que, dans un laps de temps très court, ce maïs soit ramené à un taux d'humidité assez bas pour éviter le développement de la microflore superficielle des grains et les dégradations enzymatiques.

Actuellement les organismes de stockage pratiquent un séchage rapide en insufflant de l'air très chaud (80 à 120°C). Il faut signaler que le maïs soumis à un tel traitement n'est pas accepté par les industriels de l'amidonnerie qui se trouvent amenés à importer une part non négligeable des 0,4 million de tonnes qu'ils traitent annuellement. C'est précisément sur le maïs d'amidonnerie, dont une fraction importante n'est pas destinée à l'alimentation humaine, que va porter à court terme notre étude.

Pour limiter les inconvénients d'une prolifération de la microflore, on propose d'utiliser l'effet pasteurisant des rayons gamma du cobalt-60. De très fortes doses d'irradiation permettraient sans doute d'aboutir à une stérilisation totale. Mais le procédé serait trop coûteux; et comme il ne supprime pas l'activité enzymatique l'obligation de sécher les grains demeure entière. La solution du problème réside ici, comme cela est souvent en usage lorsqu'on veut appliquer les techniques nucléaires à la conservation des aliments [1], dans l'association de l'irradiation avec un traitement classique : la ventilation à l'air ambiant. Plus lente qu'un séchage à l'air chaud, cette technique va mettre à profit le gain de temps obtenu par une irradiation aussi modérée que possible et à l'issue de laquelle le grain évoluera moins rapidement.

La pasteurisation des céréales est un sujet peu abordé. Seul MILNER [2] a examiné, dans une perspective plutôt fondamentale, les conséquences d'une irradiation gamma du blé humide en se bornant à quelques critères biochimiques simples. À l'opposé, de nombreux travaux [cf 3, 4, 5] ont été effectués à propos de l'effet de fortes doses d'irradiation sur l'amidon à l'état sec. L'objectif est dans ce cas plus technologique; l'application demeure limitée par le coût du traitement. En comparaison, notre propre démarche, qui est une étude aussi complète - et par conséquent aussi fondamentale - que possible des effets sur le maïs humide de l'irradiation associée à la ventilation, est caractérisée par le souci de dégager des conditions où le procédé conserve une chance économique.

C'est pourquoi on va examiner en premier lieu les effets de l'irradiation sur le maïs d'amidonnerie en vue de définir une dose limite compatible avec les exigences technologiques particulières à cette industrie. On analysera ensuite dans ce domaine de doses l'influence de l'irradiation sur la
microflore contaminante, avant de présenter les résultats acquis lors des deux dernières campagnes sur le traitement combiné irradiation - ventilation. On dressera pour conclure un premier bilan exprimé en termes de programme de travail et de perspectives économiques.

II. Irradiation gamma et maïs d'amidonnerie : bilan technologique

Le maïs à destination industrielle est surtout considéré comme une source d'amidon. Celui-ci extrait du grain avec un rendement compris entre 60 et 70 %, est une véritable matière première, transformée dans 80 % des cas en produits de grande valeur : sorbitol, glucose, dextrines, etc.

Les autres constituants donnent des sous-produits, commercialisés par exemple sous forme de poudre de gluten, huile, drêches, etc..., et-représentent une part relativement moins intéressante quoique non négligeable (15 à 20%) du bilan économique : leur étude n'est pas abordée dans ce mémoire.

La qualité première du maïs industriel étant définie par son rendement en amidon, le problème consiste à comparer dans ce domaine les effets d'une irradiation gamma à ceux du séchage avec de l'air ambiant ou avec de l'air chaud. Pour effectuer une telle comparaison à l'échelle du laboratoire, il a fallu mettre au point une méthode d'extraction dérivée de la technique industrielle qui conduise à la prédétermination du rendement d'extraction sur un petit échantillon, sans pour autant modifier les caractéristiques physico-chimiques de l'amidon obtenu. Cette méthode a fait l'objet d'une récente publication [6].

Pour les besoins de l'expérimentation la variété INRA 640 récoltée à une teneur en eau de 35 %, puis séchée jusqu'à 12 % avec de l'air ambiant dans les conditions idéales d'une ventilation très rapide (5000 m3/h par m3 pendant 24 heures) a servi de témoin. Des échantillons de cette même variété ont été séchés dès la récolte avec de l'air porté à 74°C, ou bien irradiés à des doses comprises entre 100 et 1000 krads avant d'être conditionnés comme le témoin.

Les moyennes des rendements nets obtenus sont mentionnées sur la figure 1. On voit que par rapport au séchage à l'air ambiant (maïs témoin) l'irradiation a sur le rendement d'extraction un effet dépressif, croissant avec la dose : 1,9 % à 200 krads, 2,7 % à 400 krads, 4,7 % à 1000 krads. En réalité une partie de cette diminution est artificielle car elle se trouve liée à la technique de laboratoire dans la mesure où celle-ci, forcément discontinue, n'utilise pas comme en industrie, pour l'opération de trempage, les eaux de recyclage (overflow) riches en bactéries lactiques. On remédie à cette situation en ajoutant
à l'eau de trempe un levain lactique dont l'emploi, sans influence significative sur le maïs témoin (témoin + 0), se traduit par un effet positif notable sur les échantillons irradiés (x krad + 0). Les taux d'extraction obtenus après correction sont les suivants : 62,2 % (témoin + 0), 62,1 % (200 krad + 0), 61,6 % (400 krad + 0), 60,0 % (1000 krad + 0). Compte tenu de la précision de la méthode qui est de l'ordre de 1 % c'est seulement au-delà de 400 krad que la baisse de rendement observée est significative. Jusqu'à cette dose la pasteurisation induite par l'irradiation était donc pratiquement seule en cause. Au contraire le séchage du maïs avec de l'air à 74°C entraîne une diminution importante et irréversible : le rendement net est de 59,4 % contre 62 % pour l'échantillon témoin (0,2 %). Dans ce cas l'effet microbicidaire du traitement thermique est mineur comparé à la coagulation partielle de la trame protétique et à l'éclatement des granules d'amidon, altérations qui sont causes de freinées d'autant plus importantes que la température est plus élevée. Ce résultat est confirmé par l'observation microscopique de l'amidon en présence d'iode à la température ordinaire : les granules provenant de maïs irradié sont absolument intacts alors que ceux extraits de maïs séché à 74°C se trouvent lésés dans 10 % des cas.

Il reste à apprécier l'incidence de ces traitements sur la qualité industrielle de l'amidon, essentiellement définie par sa viscosité au cours de l'empesage. Cette étude effectuée à l'aide d'un viscosographe "Brabender" sur les échantillons précédemment extraits montre que l'irradiation provoque une dépolymerisation partielle d'autant plus importante que la dose est plus élevée. À 300 krad la viscosité maximum de l'empois est de 25 % inférieure à celle du témoin et comparable à celle de l'échantillon séché avec de l'air chaud. Sur les amidons irradiés la chute de viscosité s'accompagne d'un abaissement de la température de début de formation de l'empois, phénomène confirmé par l'observation microscopique, en lumière polarisée ou en présence de rouge congo, de granules d'amidon au cours d'une gélatinisation contrôlée. Sur le montage photographique N° 1, il apparaît qu'à la même température le processus est plus avancé sur l'échantillon irradié que sur le témoin ; les granules sont d'un diamètre plus important, un plus grand
nombre se sont colorés ou ne présentent plus la croix de bi-réfringence.

Compte tenu des techniques de transformation de cette matière première, qui dans la plupart des cas font appel à une dépolymérisation (hydrolyse, dextrinification, hydrogénation catalytique etc...), la diminution de viscosité et l'abaissement de température de début de formation de l'empois représentent généralement pour les industriels un avantage, et parfois un inconvénient facile à corriger mais rarement irrémédiable.

C'est dans cette perspective orientée vers le maïs d'amidonnerie que le traitement combiné irradiation - ventilation risqué de trouver à court terme une application puisqu'il aboutit du point de vue du rendement d'extraction à un grain d'une qualité comparable à celle obtenue par un séchage rapide avec de l'air ambiant et nettement supérieure à celle obtenue par un séchage avec de l'air chaud. Cette étude montre aussi que la pasteurisation du maïs pourra être effectuée si nécessaire à une dose de 400 krad sans pour cela être la cause d'altérations profondes du grain.
Les recherches microbiologiques ont été entreprises simultanément dans deux directions : détermination globale pour diverses conditions de milieu de la dose nécessaire à une pasteurisation suffisante du maïs, étude plus particulière sur la radiosensibilité des spores de moisissures en vue de minimaliser cette dose dans les limites qui viennent d'être définies (400 krads).

La microflore du maïs est surtout composée de bactéries et de moisissures. Ces dernières sont les plus redoutables et représentent une menace potentielle pour la conservation des grains car elles survivent aux très basses teneurs en eau. Elles peuvent être classées en mycoflore champêtre (Cladosporium, Céphalosporium ...) et mycoflore de stockage (Penicillium, Aspergillus ...). La répartition de cette flore varie avec l'anée, les conditions climatiques, l'époque et le lieu de la récolte ce qui rend l'étude du phénomène global extrêmement complexe. Celle-ci a requis la mise au point d'une méthode originale de détermination quantitative et qualitative de la population microbienne. Basée sur la technique des dilutions elle comporte les opérations suivantes : broyage aseptique à température constante et en présence d'un diluant à base de Tween 80, dilutions, culture sur milieux révélant au mieux bactéries et germes fongiques même en présence de Mucorinées.

Les résultats obtenus ont permis de vérifier ou d'établir que la dose d'irradiation nécessaire à une pasteurisation suffisante du maïs dépend d'un certain nombre de facteurs, en particulier :

- Importance numérique, état physiologique et nature de la microflore.
  En 1963, sur du maïs très humide et fraîchement récolté, le classement des principales espèces fongiques en fonction de leur radiosensibilité, exprimée en terme de dose de réduction centésimale, était le suivant : Céphalosporium (100 krads), Cladosporium (200 à 300 krads), Penicillium et Aspergillus (350 à 450 krads). Les bactéries étaient très radiosensibles (100 krads) tandis que leurs formes sporulées se sont révélées les plus radiorésistantes (400 à 500 krads).

- Teneur en eau des grains : les résultats mentionnés sur la figure 2 montrent que la dose requise est d'autant plus faible que l'humidité du grain est plus élevée. Par exemple, pour que la population fongique du grain soit réduite, immédiatement après l'irradiation, à une dizaine de germes par gramme il a suffi pour un maïs à 30,5 % d'humidité d'une dose de 100 krads contre 300 krads pour un maïs à une teneur en eau de 15,4 %.

Un enquête plus approfondie a été entreprise sur spores d'Aspergillus flavus, moisissure de stockage très résistante dont certaines espèces sont toxinogènes, à l'aide d'une technique nouvelle de détermination de leur pouvoir germinatif fai-
sant appel à un compteur "Coulter". L'étude de la radiosensibilité de l'Aspergillus a été effectuée dans les directions suivantes :

- **État physiologique des spores et en particulier leur âge.**
  Les spores conservées sur milieu nutritif ont une radiorésistance maximum au bout de 3 mois, les plus âgées et surtout les plus jeunes étant très radiosensibles. Cette sensibilité est exacerbée au cours de leur germination.

- **Conditions de milieu.** L'humidité a la même influence que celle constatée dans l'étude globale; la teneur en eau qui correspond à la radiorésistance maximum varie avec la dose appliquée. Divers traitements des spores avant irradiation : dégazage, balayage avec de l'air enrichi en O₂ ou en CO₂, se sont révélés sans influence sur la radiosensibilité alors qu'un traitement thermique de moins de cinquante minutes à une température inférieure à 50°C a un effet dépressif dont l'importance reste à déterminer. Des recherches sont en cours sur l'action du SO₂.

- **Mode d'irradiation.**
  L'efficacité de l'irradiation à dose égale a été étudiée en fonction du débit de dose et de son mode d'intervention continu ou discontinu. Seule une série d'irradianations séparées par des temps de repos allant de 24 heures à quelques jours s'est révélée
plus efficace qu'une exposition continue, mais pas assez pour conduire à un procédé économiquement valable.

En résumé les deux types de démarche montrent qu'une dose d'irradiation de 100 à 300 krad assainit convenablement le grain à condition que sa teneur en eau soit élevée, ce qui est précisément le domaine qui nous intéresse ; la dose optimale est d'autant plus difficile à préciser qu'elle dépend du comportement de la flore résiduelle au cours du temps requis par le séchage associé à l'irradiation.

IV. Étude de la combinaison irradiation - ventilation

Il s'agit d'une étude saisonnière, effectuée sur du grain humide fraîchement récolté puis irradié à des doses comprises entre 100 et 300 krad. On a vu que dans ce domaine de doses l'irradiation exerce une action dépressive notable sur la population bactérienne et fongique de surface sans perturber la qualité industrielle du maïs. Débarrassé de la majeure partie de sa microflore, ce dernier n'est pas pour autant soustrait à l'activité enzymatique. C'est alors qu'intervient le séchage par ventilation dont les caractéristiques dépendront de la vitesse de multiplication de la flore résiduelle, et par suite de la dose d'irradiation.

Pour définir le meilleur point de fonctionnement on étudie l'évolution dans le temps de la population microbienne et des constituants biochimiques du grain en fonction de la dose d'irradiation et des caractéristiques de la ventilation associée. Les expériences sont effectuées au laboratoire sur des échantillons de 2 à 3 kgs de maïs récolté à Cadarache à une teneur en eau de 38 à 40 %, placés dans des dispositifs (photographie N° 2) où ils sont ventilés à des débits correspondant à ceux qui seraient utilisés dans la pratique. L'air est filtré, saturé et porté à une température comprise entre 10 et 20°C. Il correspond alors à celui qui atteint la dernière couche de grains d'un silo en cours de séchage par ventilation avec de l'air ambiant ou faiblement réchauffé, ce qui représente les conditions les plus défavorables. L'évolution des différents lots est suivie grâce à des contrôles microbiologiques et biochimiques simultanés qui interviennent dès la récolte, puis immédiatement après l'irradiation, et enfin à intervalles réguliers au cours de la ventilation.

En 1964 les essais ont été réalisés sur du maïs irradié à une dose de 300 krad et ventilé pendant 3 à 9 jours avec un flux d'air saturé à une température de 13°C (vitesse 144 cm sec⁻¹). Sur la récolte 1965 des expériences plus nombreuses ont été effectuées à des doses de 100 et 300 krad avec une ventilation moins rapide (vitesse max. 16 cm sec⁻¹) à des températures de 13, 15 et 18°C et pendant des durées pouvant atteindre 26 jours. Trois dispositifs ont été construits pour traiter de façon identique un témoin et deux échantillons irradiés à des doses différentes.
Les déterminations biochimiques effectuées en 1964 n'ont pas permis de déceler des variations importantes de la qualité, car les caractéristiques de l'air ventilé étaient trop éloignées d'un cas réel (température trop basse). Cependant il est possible d'affirmer que la dépolymerisation de l'amidon par le rayonnement gamma ne crée pas un substrat plus favorable à l'action des amylases et que, parfois, l'activité α amylasique est moins grande sur les lots irradiés et ventilés que sur le témoin placé dans les mêmes conditions. L'étude des échantillons de la récolte 1965 est en cours, et porte soit sur l'amidon extrait (rheologie, gonflement et solubilité, sensibilité à l'amylase) soit sur le grain (activité α et β amylasique, chromatographie des sucres et acides aminés, dosage électrophorétique de l'acide γ amino - butyrique).

Les déterminations microbiologiques se rapportent aux bactéries mais surtout aux moisissures, tant d'un point de vue qualitatif que quantitatif. En 1964, pendant la durée des expériences, la population microbienne des échantillons irradiés est restée nettement plus faible que celle des témoins ventilés de façon identique, et presque toujours inférieure à celle du maïs au moment de la récolte. Les essais effectués au cours de la dernière campagne montrent que l'effet dépressif de l'irradiation est plus important sur les bactéries que sur les fongiques (à 200 krad, $10^{-3}$ au lieu de $10^{-1}$ à $10^{-2}$). On retrouve cette différence dans la vitesse de multiplication de la flore résiduelle au cours de la ventilation (fig. 3 et 4).

Le processus, beaucoup plus rapide qu'en 1964, est difficile à interpréter en fonction de la dose d'irradiation et de la température, car malgré les précautions prises la teneur en eau des échantillons n'a pas pu être maintenue à un niveau comparable. Cependant ces expériences permettent d'affirmer que dans tous les cas, quelles que soient la dose, la température et la durée de ventilation (26 jours maximum), la population microbienne des grains irradiés est toujours inférieure à celle des témoins, d'un facteur 10 pour les bactéries et 4 pour les moisissures. Toutefois le phénomène le plus important ressort de la radiosélection fongique dont l'effet persiste de façon très nette même après 19 jours de ventilation (fig. 5 et 6).

Les Pénicilliums, en petite quantité au moment de la récolte, constituent une des espèces caractéristiques de la flore de stockage résistant aux faibles teneurs en eau. Ils n'apparaissent de façon notable sur les échantillons irradiés qu'au bout de 12 à 14 jours de ventilation alors qu'ils représentent déjà plus de 80 % de la mycoflore de l'échantillon témoin à la même date. Ce résultat est du plus grand intérêt : après le séchage du grain irradié seule une faible partie de la mycoflore survivra, alors qu'une très grande proportion persistera sur le témoin. De tels résultats devront être confirmés au cours de la campagne 1966.

L'étude du traitement combiné irradiation - ventilation est extrêmement complexe en raison de la fluctuation des caractéristiques chimiques et microbiologiques du grain au m-
PHOT. 2. Dispositifs expérimentaux - Chacun d'eux comporte : à droite les régulations de débit et de température, à gauche trois cellules en série (les deux premières servent au conditionnement de l'air, la troisième renferme le grain)

FIG. 3. Evolution des populations bactériennes d'un maïs irradié à différentes doses au cours d'une ventilation avec de l'air saturé à une température de 18°C
FIG. 4. Évolution des populations fongiques d'un maïs irradié à différentes doses au cours d'une ventilation avec de l'air saturé à une température de 18°C

FIG. 5. Répartition des principales espèces fongiques d'un maïs irradié à différentes doses au cours d'une ventilation avec de l'air saturé à une température de 13°C

ment de la récolte. Toutefois les premiers résultats acquis montrent que des doses d'irradiation inférieures à 400 krad pourront être associées à un séchage d'une durée de plusieurs jours; les déterminations biochimiques en cours préciseront ces deux paramètres essentiels.
V. Perspectives d'avvenir

Après avoir dressé le bilan de nos études sur la radio-pasteurisation du maïs humide, il est opportun de présenter les perspectives d'avenir. Si quelques résultats encourageants ont été déjà obtenus, un gros travail reste à accomplir au laboratoire avant que soit envisagée une application industrielle qui, dans tous les cas, devrait être précédée par des essais à une échelle intermédiaire.

Sur le plan microbiologique, où la difficulté réside dans l'hétérogénéité de la flore, on se propose d'étudier séparément sur chaque espèce l'effet du rayonnement gamma en utilisant, comme support des micro-organismes, soit un modèle artificiel (billes de verre) soit des grains préalablement stérilisés. Les recherches biochimiques se sont limitées jusqu'ici aux composés, généralement glucidiques, que les traitements mis en comparaison modifient le plus rapidement ou le plus profondément. L'emploi de dispositifs automatiques permettra d'effectuer ce genre d'analyses avec plus de précision et dans des délais plus courts. Un effort particulier sera tenté dans le sens de la mise au point d'un test caractéristique de l'amidon irradié. L'aspect technologique du problème continura d'être étudié au laboratoire, où l'on réalisera sur petit volume le cycle complet du procédé combiné irradiation - ventilation, afin de mieux connaître la relation qui existe entre le débit de renouvellement de l'air employé et ses caractéristiques de température et d'humidité.

L'expérimentation à l'échelle pilote, étape nécessaire avant l'application industrielle, aura un double objectif. Il s'agit en premier lieu de mieux définir les caractéristiques des traitements à mettre en œuvre dans les conditions pratiques, c'est-à-dire avec un maïs aussi voisin que possible de celui qui est récolté dans les régions septentrionales, et en
particulier contaminé par la microflore typique de ces régions. Ceci implique de réaliser l'opération par exemple dans le Bassin Parisien, en faisant appel aux services d'un irradiateur semi-industriel déjà en place (IRMA de Saint-Gobain techniques nouvelles) et au concours des organismes agricoles directement concernés. Cet essai pilote est prévu en 1967.

Le deuxième objectif est l'établissement d'un prix de revient. Une estimation préliminaire permet de situer le problème. Le prix du séchage à l'air chaud est d'environ 4,5 Frs par quintal. D'autre part selon les plus récentes évaluations [7] le coût de l'irradiation s'élève à 2 Frs pour une dose de 100 krads, à quoi il faut ajouter les frais de ventilation estimés à 0,5 Frs pour l'énergie, et à un chiffre compris entre 1,4 et 4,5 Frs pour l'amortissement du matériel, selon les valeurs finalement retenues pour la vitesse et la température de l'air soufflé. Sachant que la dose effectivement utilisée sera comprise entre 100 et 300 krads, le coût global de la combinaison irradiation - ventilation se situe dans la fourchette 4-11 Frs. Pareille estimation laisse une chance non négligeable au procédé surtout si l'on rappelle que le gain de 4% obtenu sur le rendement d'extraction de l'amidon se traduit par un bénéfice de 3,2 Frs par quintal de maïs. Ce genre de calcul démontre bien la nécessité de déterminer avec plus de précision au laboratoire et de contrôler à l'échelle pilote le point optimum de fonctionnement.

Une fois reconnues les chances - techniques et économiques - du procédé, et à plus forte raison dans une perspective à long terme qui débordera le cadre du maïs d'amidonnerie, ce sont les problèmes de compostabilité et d'innocuité qu'il faudra résoudre avant toute commercialisation du produit irradié. On notera tout d'abord au bilan de l'irradiation une action positive d'assainissement. Les insectes, qui pullulent certaines années se trouveront détruits sans qu'il soit nécessaire de faire intervenir des substances toxiques. La diminution de la flore bactérienne et fongique, et plus particulièrement de sa fraction toxinogène, représente un avantage certain. Cependant il convient d'apporter la preuve de l'innocuité d'une irradiation du maïs aux doses finalement utilisées. Un programme de recherches orienté dans cette direction est en cours d'examen. Sa mise en œuvre apparaît comme une condition indispensable au développement du procédé même limité aux applications industrielles.

REMERCIEMENTS

Nous remercions Mme Poisson (INRA) de sa contribution efficace à l'étude microbiologique et M. Khau van Kien (CEA) de son aimable collaboration au cours de l'étude microscopique de l'amidon.

REFERENCES

DISCUSSION

A. R. DESCHREIDER: Could Mr. Pelegrin or Mr. Saint-Lebe tell me whether the gamma irradiation of maize advocated by them causes changes in the transformation products, particularly sorbitol and glucose?

L. SAINT-LEBE: No, it does not. The changes occur at the level of the 1-4 $\alpha$ bonds of the glucosidic chain and not in the glucose units. The manufacturing technology of sorbitol and glucose is favoured by the depolymerization of the starch, and there is no change in these transformation products.
STATUS OF IRRADIATION CONTROL OF INSECTS IN GRAIN

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Abstract — Résumé — Аннотация — Resumen

STATUS OF IRRADIATION CONTROL OF INSECTS IN GRAIN. Research into the uses of ionizing radiations for the control of insects infesting stored foodstuffs has demonstrated the technical feasibility of irradiation for the treatment of grain. Studies in radiation entomology have established the susceptibilities of the principal grain storage insects and the extent to which environmental factors may modify the efficacy of treatment. Investigations into chemical and physical properties of irradiated grain have shown no adverse effects on organoleptic and manufacturing properties at the dose level required for disinfestation. Work on the wholesomeness of irradiated grain has shown no loss in nutritional adequacy, with the result that clearance has been given in the United States for the human consumption of irradiated wheat and wheat products. Engineering considerations suggest that irradiation is an economic competitor to chemical methods for the treatment of grain at large exporting or collecting centres.

With bulk storage and automated conveying systems now established as the most expedient method of handling grain between producers and consumers, it can be wisely predicted that implementation of radiation disinfestation into the grain handling industry will follow in the foreseeable future.

Information on infestation problems and the grain-handling industries of various countries is used to illustrate the likely future potential of irradiation for the treatment of grain on an international scale.
Radiation disinfestation of grain is adaptable to the treatment of large bulks of grain during handling and storage at large collecting centres and port installations. It will not replace the use of chemical sprays, dusts or fumigants, but can provide an alternative where conditions are favourable for its application.

The technology of grain irradiation has now reached a stage whereby the information necessary for practical application has been acquired. The future of the method depends on stimulating the grain handling industries of the world to look at radiation processing as being applicable within the large cereal producing countries. Competitive in cost with fumigation, the irradiation of grain in large tonnages is ripe for commercial exploitation.

Our present knowledge of the technical feasibility of controlling insects in grain by irradiation derives from studies in radiation entomology, the chemical and physical properties of irradiated grain, wholesomeness and engineering. The purpose of this paper is to review this knowledge and to suggest where grain irradiation might be considered for practical application.
Lethal and sterilizing doses on insects

The severity of radiation damage to reproductive and somatic tissues varies with dose. Complete and immediate kill of insects is obtained at 300,000 to 500,000 rad, complete kill a few days after irradiation, at about 100,000 rad, and complete reproductive sterilization followed by death a few weeks after irradiation at 10,000 to 20,000 rad. On economic grounds, radiation disinestation of grain makes use of a sterilizing dose to inhibit reproduction and cause death some days later. The minimum effective dose for sterilizing pupae and adults of the grain weevil (S. granarius) is 16,000 rad, death occurring 2-3 weeks after treatment. All eggs and larvae are prevented from maturing, and thus from reproducing, by 5,000 rad. When infested grains containing all developmental stages are irradiated with 16,000 rad, only those containing late pupae are able to produce adults, these being sterile, and dying soon after emergence. Any measure of overdosing above that required for effective treatment constitutes wasted energy and a consequent increase in operating costs. Irradiation treatment cannot ensure that all grains receive the minimum effective dose without some measure of overdosing. It is therefore pertinent to ask what degree of control can be achieved with treatment of a high proportion of grains at the required dose and the remainder at substerilizing doses.

Substerilizing doses

Substerilizing doses of ionizing radiation cause deleterious effects in the gametes, which keep weevil populations suppressed to a low level for many months; results of tests have shown that with 10,000 and 12,000 rad, populations of S. granarius rise to only 6% and 0.2%, respectively, after seven months. With small populations, doses of 10,000 and 12,000 rad can give complete control and, if processing follows shortly after irradiation, these doses are also adequate for suppressing populations of up to 1 million adult weevils. The cost of irradiation is thus appreciably reduced. Evidence with the grain weevil has also indicated that the reproductive potential of insects treated at 6000 rad (i.e. 40% of the minimum effective dose) is further reduced by one-third when outnumbered by sterile insects at a ratio of 5:1.

Partial protection against reinfestation

Sterilized adults can also provide partial protection to grain against reinfestation when the number of sterile insects is large compared with the number of insects reinfesting the commodity. The protection is afforded by the insemination of fertile females with sterilized sperm while the irradiated population remains alive. The sterile sperm of grain weevils remains competitive with fertile sperm within the female for at least four months. If irradiation is carried out so as to allow a proportion of sterile insects to remain alive for a longer period, the reproductive potential of contaminants can be further reduced. This "biological" protection afforded by irradiation is a distinct advantage over fumigation, particularly where storage conditions in warm climates are physically inadequate to combat reinfestation.
Susceptibility of insect species

A considerable number of insect species which attack cereals have been tested for susceptibility to irradiation. Most show a very high level of sterility even at doses as low as 6000 rad. The grain and rice weevils (S. granarius and S. oryzae), the flour beetle (T. confusum), and the lesser grain borer (R. dominica), are completely sterilized by 16 000 rad. The fertility of the saw-toothed grain beetle (O. surinamensis) is reduced to 0.1%. Grain and rice weevils are killed (100%) by 16 000 rad, but 2% of adult R. dominica, 4% of O. surinamensis and 10% of adult T. castaneum survive. Grain and rice weevils are among species most rapidly killed by irradiation. Moth species are more resistant than beetles to sterilization and killing by irradiation; a dose of 16 000 rad is recommended for industrial application and is effective for control of the Khapra beetle (T. granarium).

Susceptibility of insect strains

Strains of insects, of the same species, taken from infested storage vary considerably in susceptibility to killing by irradiation; 16 000 rad has proved effective against 30 wild strains of S. granarius from various parts of the world; strains of weevil and flour beetle collected from Australian storage are also controlled by this dose. There is no evidence at present to suggest that strains of insects resistant to insecticides are more tolerant of irradiation.

Effect of rearing medium on insect susceptibility

The chemical composition of the cereal on which an infestation develops influences the rate of development of a number of insect species. In tests with the flour beetle (T. confusum) rapidly developing beetles were more quickly killed by irradiation, but work with this insect and the grain weevil indicate that the type of cereal supporting the infestation is unlikely to influence the efficacy of the irradiation process.

Effect of dose-rate

Chronic irradiation is less effective than acute and this has its implications on the dose-rate of an industrial process; adult S. granarius, T. confusum and O. surinamensis are more readily killed by dose-rates at the higher end of the range, 1500 - 4700 rad/h. The fertility of adult O. surinamensis is also similarly modified. At very high dose-rates radiation sterilization of pupae of S. granarius is in small measure reduced by treatment with accelerated electrons (peak dose-rate 5.8 x 10⁸ rad/h) compared with cobalt-60 gamma radiation (75 000 rad/h). In studies, from which results must be treated with reserve, high dose-rate electrons were also inferior to gamma radiation in killing and sterilizing adult S. granarius. It is postulated that the optimal dose-rate for radiation disinfection of grain lies between 10⁴ - 10⁶ rad/h: this suggestion requires confirmation, since it may have a significant influence on the choice of plant and handling rate for an industrial process. American
studies report no difference in the insecticidal efficiency of electrons, gamma and X-rays.

Effect of temperature on insect susceptibility

High temperatures before irradiation (30°C) sensitize grain weevils to killing by irradiation. High temperatures (30°C) during irradiation increase resistance to killing. High temperatures after irradiation accelerate the rate of mortality only. Temperature does not modify the susceptibility of the grain weevil to sterilization. Responses to temperature, dose fractionation and dose-rate are closely associated with the ability of the insect's tissues to recover from radiation damage. Temperatures experienced in grain storage practice are unlikely to influence the efficacy of irradiation for the control of grain weevils, but other species require investigation of temperature effects. Low temperatures after irradiation may retard rate of death, but feeding activity is also much reduced. Cornwell [2] has shown that grain weevils treated with 16 000 rad ingest approximately half the amount of food compared with untreated adults.

Effect of metabolic heat on insect susceptibility

Temperatures above 26°C, induced by metabolic heat of larval populations, increase susceptibility of adult S. granarius to killing by irradiation, but again have no effect on susceptibility to sterilization. The rearing conditions under which these laboratory results were obtained were equivalent to the worst conditions likely to be encountered in commercial practice, where "hot'spots" of infestation occur as a result of prolonged storage: no loss is envisaged in the efficacy of the process at insect densities normally encountered in commercial storage.

Effect of oxygen tension at irradiation

A low oxygen tension at irradiation, sufficient to anaesthetize adult grain weevils in 30 min, increases their resistance to killing and sterilization by irradiation. Russian work [3] to compare the effects of X-rays and gamma radiation, under normal oxygen conditions (21%) and hypoxia (0%), shows that the ratio of damage (kill) for the two types of radiations whose ionization densities are comparatively close were 1: 2 and 1: 2.6, respectively. Since conditions of low oxygen are unlikely to be encountered in grain storage practice, particularly with movement of the grain during irradiation, the efficacy of the process is not likely to be jeopardized.

Effect of dose fractionation

In practice, irradiation of grain could be carried out in a series of interrupted treatments to accommodate high rates of grain handling at terminal intake: a light treatment followed by the completion of treatment some time later. Fractionated treatments of radiation allow the repair of tissues to radiation damage and increase survival; 16 000 rad may, however, be given to S. granarius in at least four fractions over a maximum period of five days without modifying susceptibility to killing. The
level of sterility in adults afforded by fractionated treatment with intervals of up to one day is also equal to that with continuous doses.

Efficacy of treatment against large insect populations

With an infestation rate of 0.1% (one adult per 1000 grains) a typical terminal silo bin, holding 200 tons of grain (the capacity of a bin) contains 5 million adults. (An infestation rate of three insects per 1000 grains is unacceptable for milling). A population of 10 million S. granarius, in all stages of development, has been effectively sterilized and killed by 16 000 rad in experimental bulk storage containing 6 tons. Considerable confidence can therefore be attached to the use of 16 000 rad for radiation disinfection of grain for an industrial process. Populations ranging from one thousand to one million adults treated with 14 500 rad in 400 pounds of grain showed some redevelopment of infestation five to eight months after irradiation.

EFFECTS OF RADIATION ON GRAIN

It is a prerequisite of radiation processing that the dose level applied must produce no adverse effects on the quality of the grain, or on its acceptability to the consumer; there must be no reduction in its nutritional adequacy, or production of toxic compounds. Before health clearance may be given, long-term animal feeding studies are therefore essential. A variety of animals have been used to examine the nutritive value and possible toxicity of irradiated grain: these include rats, mice, dogs, poultry, guinea pigs and some insects. Entomological research has shown that 16 000 rad can be accepted as a reliable dose for radiation disinfection and in certain circumstances it may be more than adequate. Nevertheless, many tests of wholesomeness have been made at doses considerably higher, particularly in the United States, where treatments with 2.79 Mrad and 5.58 Mrad have been used in a programme concerned with food sterilization and the elimination of bacteria.

Acute and chronic toxicity

In studies of the possible toxicity of irradiated grain, tests of acute toxicity have been carried out on food consumption and growth over periods of 8 to 12 weeks. Chronic toxicity has been assessed over several generations using the parameters of food consumption, growth, longevity, reproduction and tumour incidence. Histopathological tests have been made at the end of short and long feeding periods, and tests for carcinogenicity have usually been made with mice after feeding for 80 weeks. In the United States, feeding tests have also been extended to human subjects, but only for restricted periods. Following such extensive testing clearance for human consumption has been given to the process in the United States.

Nutritive value

In studies to investigate the effects of irradiation on nutritive value, carbohydrates have been found unaffected nutritionally even at high doses.
of radiation. The biological value of maize protein and wheat gluten is unaffected by treatment with 2.8 Mrad but the digestibility of maize protein is lowered by 5% at 9.3 Mrad. Experiments with rats, carried out in support of the entomological studies in the United Kingdom, confirm that the biological value of wheat protein is unchanged up to 1 Mrad.

Radiation has little effect on the B complex vitamins in Manitoba wheat. Microbiological assay could detect no change at 20 000 rad and only slight losses of nicotinic and pantothenic acids at 200 000 rad. Resistance of B vitamins to radiation damage in wheat and other cereals has also been found by other workers; Russian data, however, indicate that thiamine is sensitive in white flour with a 10% loss reported at 50 000 rad and 65% loss at 150 000 rad. On the other hand, chemical assays of thiamine in Pearl barley and Buckwheat also carried out in the Soviet Union, indicate an increase in this vitamin at 50 000 rad. Fat-soluble vitamin E is normally regarded as radiosensitive, but chemical assays in the United Kingdom have shown little destruction at 20 000 rad and 200 000 rad.

**Legislation**

Legislation is an important consideration in the establishment of pilot plant operations. In the Federal Republic of Germany, ionizing radiation for the treatment of foodstuffs is forbidden. With this exception, the current legislative regulations of the majority of countries make no specific reference to irradiation processing of foods; since they prohibit any treatment which renders food injurious to health, control of new processes is regarded as adequate. At an international meeting in Brussels in 1961 [4], in which all aspects of the wholesomeness of irradiated foods were reviewed, it was concluded that "while it is premature to give health clearance for the irradiation of food in general, sufficient evidence has been accumulated on the treatment of certain food items to allow their appraisal by appropriate authorities". In France, draft regulations for the radiation processing of foods have already been prepared. In the United States, submission to the Food and Drug Administration for clearance for human consumption of wheat and wheat products treated with gamma radiation from sources with a maximum energy not exceeding 2.2 MeV, and to provide an absorbed dose from 20 000 to 50 000 rad, was approved in August 1963. A similar submission, incorporating full experimental data, is shortly to be made in the United Kingdom; there is now sufficient evidence to support the conclusion that treatment of cereals with the low doses required for disinfestation does not give rise to toxic, or carcinogenic compounds, and that nutritional damage is negligible. These findings are also supported by data obtained and still being accumulated on other foods treated at very much higher doses. Such findings were the basis for discussions on the technical basis for legislation on irradiated food by a Committee of Experts in April 1964, [5]1.

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1 Jointly convened by the Food and Agriculture Organization of the United Nations, the International Atomic Energy Agency and the World Health Organization.
Chemical and physical properties

A further aspect of the effects of irradiation on grain concerns its acceptability to the milling trade and the consumer. A number of studies have been made on the effects of irradiation on hard and soft wheat, flours, cereal products and wheat gluten with respect to physical properties, induced biochemical changes and the behaviour of doughs. Studies have also been made on the cooking and brewing properties of rice. Most of these studies have been carried out at very high doses, adverse effects being consistently observed at doses of 1 Mrad and above, but few studies have been carried out at dose levels of economic interest for insect control. The studies of Milner and Yen, for example, are concerned with the effects on bread-making of doses required for the destruction of microflora responsible for the heating and biochemical deterioration of grain stored at high moisture contents, while some of the European investigators have been concerned with the possible improvement of flours by irradiation.

Extensive tests [1] have been carried out at Wantage, (UKAEA), in collaboration with four United Kingdom cereal laboratories, into the effects of gamma radiation on English wheat treated at 20 000, 125 000, 500 000 and 1 000 000 rad. It was held in bulk storage for periods of up to one year and milled to 60%, 70% and 80% extraction. No changes were obtained at 20 000 rad, with the exception of a slight darkening of the flour. Treatment at 125 000 rad increased the water absorption of the flour to an extent comparable with a change in moisture content of 0.5%. The same dose caused a measurable decrease in viscosity, but only a very slight increase in maltose value. Only three of the four cereal laboratories were able to show statistically perceptible changes in dough properties at 125 000 rad, and these were a little more marked at the higher levels of extraction. With the exception of modifications in viscosity, irradiation at 125 000 and 500 000 rad produced only minor changes in the grain, comparable with relatively small changes in the extraction rate. In most cases, alterations in the physical properties of the dough by irradiation at doses up to 500 000 rad were less severe than can be obtained with heat conditioning, the use of flour improvers, or which result from 6 to 12 months' storage. It is clear that doses many times higher than that proposed for the disinfestation of grain may be used without causing changes of commercial significance, with the reservation that they might be sufficient to influence the trade against wheat which had been treated, if given a choice. The slight toughening of the gluten may be desirable when irradiated soft wheats are admixed with imported varieties.

Organoleptic appraisal

In studies to investigate the effect of irradiation on the taste of irradiated wheat 11 000 assessments were made by staff of the Wantage Research Laboratory (UKAEA). It can be confidently concluded from this work, designed to study such variables as storage period, extraction rate and the making of treated wheat into bread and biscuits, that 16 000 rad is well below the dose level which causes organoleptic changes.
### TABLE I. GRAIN EXPORT TERMINALS IN THE MAJOR PRODUCING COUNTRIES

<table>
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<tr>
<th>Port</th>
<th>Storage capacity in silos (thousand tons)</th>
<th>Port</th>
<th>Storage capacity in silos (thousand tons)</th>
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*The annual throughput of an export terminal averages 5 to 10 times the storage capacity.*

**Germination tests**

One further aspect of the acceptability of irradiated cereals which remains to be considered is the effect of treatment on germination. It is customary in most countries to retain locally on farms that grain which is intended for seed; it does not usually enter the same channel as the bulk of cereals destined for storage or marketing and is therefore most unlikely to experience treatment by irradiation. Nevertheless, a
A number of studies on irradiated cereals have included a test on germination and there is a considerable body of literature devoted to the effects of ionizing radiations on the production of chromosomal aberrations and the consequent effect upon inheritance. Doses of 10,000 to 200,000 rad do not prevent the germination of wheat treated with high-energy electrons, but doses of 40,000 to 200,000 rad, not only markedly reduce the number of embryos reaching the surface of the soil, but completely check their continued growth. The possible effects of radiation on barley intended for malting are therefore of significance. Work on the biochemical effects of irradiation on a medium-grade malting barley has shown that germination is only seriously reduced at 500,000 rad, although shoot production is impaired by 8000 rad and plumules completely stunted at about 50,000 rad. Since a uniform germination is essential for the production of good quality malt, this factor might well prejudice the use of irradiation for disinfestation, where the level of infestation is only slight.

INTEGRATION OF SOURCES FOR GRAIN DISINFESTATION

Cobalt-60 sources and electron machines are both adaptable to the treatment of grain for disinfestation. Practical and economic considerations suggest that gamma radiation is applicable to grain handling rates up to 100 tons/h and electrons for the range 100-400 tons/h.

Use of cobalt-60

Fabrications involving gravity feed undoubtedly provide the optimum method for maximum radiation utilization; the unique flowing properties of grain are exploited to achieve movement at high densities, without absorbing the radiation with unnecessary metal. Plants of this type can be expected to utilize up to about 70% of emitted radiation.

When installing irradiation facilities in a grain terminal it is important to arrange to treat the grain as soon as possible after arrival. The intake capacities of modern grain terminals are, however, such that immediate treatment of the grain on arrival may be impossible. Under these circumstances the grain should be directed to holding bins until it can be treated, and thereafter distributed to storage bins. For irradiation by 60Co, these holding bins should be adequate to provide storage for one to two days' intake. The grain should then be fed directly to the irradiation unit, ensuring that it is supplied with an even flow of material. Because of the shielding requirement and its weight it is desirable to locate the plant at or below ground level, where adequate foundation can be provided. Because of this low location it is impossible to arrange bin space below the unit, so that an elevator must be used to take the treated grain from the irradiation source continuously.

Use of electron plant

In the past, electron machines have been criticized as unreliable sources of radiation for industrial processing, and the cost of processing has been high. During the last few years, however, considerable advances
have been made in the development of insulated core transformers and radio-frequency cascade rectifiers; direct current power outputs of the electron beam are available up to 30 kW and at energies up to 3 MeV. In the present state of technology these two machines provide the cheapest form of electron processing. To achieve good uniformity of irradiation a machine of 20-kW beam power at 3 MeV is necessary to treat grain with 16,000 rad at 200 tons/h, using 50% of the incident radiation.

Penetration of electrons of 3 MeV or less is small; grain must therefore be treated in a thin uniform layer, and if large throughputs are required, either the grain velocity must be high or the layer very broad. As with an isotope plant, not all the radiation can be absorbed, particularly if a low ratio of maximum to minimum dose is required. With electron irradiation it is necessary to treat a falling stream of grain from both sides in order to ensure uniformity of dose.

ECONOMICS OF GRAIN IRRADIATION

Information on the economics of grain irradiation is analysed in detail in a separate paper by Baines and Mosely and therefore will not be considered here. For the economic operation of irradiation plant the following principles apply: to be competitive with fumigation, cobalt sources must operate continuously to give 24-h utilization; in contrast, electron machines can be integrated to normal handling shifts. Neither method of treatment is likely to compete with fumigation at annual throughputs of less than about 100,000 tons/yr.

COMPARISON OF FUMIGATION TREATMENT WITH RADIATION PROCESSING

<table>
<thead>
<tr>
<th>Fumigation treatment</th>
<th>Radiation processing</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Mode of action</td>
<td></td>
</tr>
<tr>
<td>Adequate treatment gives immediate kill of all grain-infesting species. There is no further damage to the product. Adults are not always at the most resistant stage.</td>
<td>Immediate reproductive sterilization. Adult weevils die within two to three weeks of treatment with 16,000 rad. Damage to the product is not immediately arrested. Present evidence indicates that a dose evaluated for the control of grain weevils would give good control of most other grain-infesting insects. Adults are at the most resistant stage.</td>
</tr>
</tbody>
</table>
2. Re-infestation

No protection against re-infestation.

3. Versatility

Fumigants are transported for the treatment of grain in situ. The method is versatile and equally suited for the disinfestation of bulk storage in port silos, small bins, boat holds, barges and warehouses. Also for the treatment of bagged grain under gas-proof sheets. The silo bin or barge is also disinfested.

4. Efficacy

Adequate penetration of fumigant may be difficult to obtain in bulk grain and allow a residual population to survive. At present, treatment is considered reasonably successful but a higher level of control may well be required with the adoption of purity standards: 100% control can be obtained if proper fumigation techniques are used.

5. Commercial acceptance

Techniques are well established with fumigation plant installed in some existing large port silos.

6. Effect of seasonal demand

Relatively unaffected by seasonal crop production.

Delayed death of irradiated insects, afford partial protection against re-infestation, through sterile sperm in an over-abundance of live, sterile males, reducing the reproductive potential of smaller numbers of contaminants of the same species.

Likely to involve at least one extra handling step in conveying grain to or from the irradiation source, or in its circulation between bins if the source is of low capacity. Incompatible with small scale storage. Treatment does not disinfest the storage facilities (although sterile sperm reduces the reproductive potential of resident insects).

Penetrating gamma radiation delivered at a uniform dose-rate can afford 100% control.

Acceptance of radiation treatment may involve some reorganization of bulk grain conveyer systems. The design of any established grain terminal will determine the ease of integration.

Seasonal and annual changes in crop production considerably affect the economic operation of a gamma source, but less so with electron machines.
7. Economics

Moderate capital expenditure for plant. Cost per treated ton by methyl bromide circulatory fumigation, 1/-s. to 2/-s. per ton, or higher for certain fumigants.

Capital expenditure high, depending on required throughput. 24-h treatment of bulk grain is estimated at 2/-s. per ton for an annual throughput of 200,000 tons.

8. Residues, health and effect on manufacturing properties

Effect on the product varies with fumigant and dose. Extensive work has been necessary to determine nature and safety of residues. Official tolerances for residues of methyl bromide and other fumigants established.

The dose level for grain disinfestation (16,000 rad) does not adversely affect the milling, baking or organoleptic properties of wheat. These properties are not affected by treatment with several times this dose. No loss in nutritional adequacy. No induced toxicity. No residue problem. Clearance of wheat for human consumption in the United States of America.

9. Resistance

Very little evidence that resistance is likely to develop to fumigants, but is known to be increasing with contact insecticides.

Radiation-induced resistance is suggested as being likely, but at present there is no evidence that it may occur.

10. Safety

Low concentrations of fumigant are often difficult to detect and some residues may remain. Operator hazard potentially present, depending on training and experience. Dosaging subject to human error.

Foolproof systems ensuring no radiation hazards are in operation. Automated treatment.

11. Dwell-time for treatment

Varies with fumigant and type of treatment. Usually 24-48 h, plus a period of airing-off.

Instantaneous. Sources of high capacity (electron plant) can accommodate treatment at currently used conveyor loadings. More leisurely treatment desirable with gamma plant to keep facility in operation for the maximum period.

INDUSTRIAL EXPLOITATION

"Radiation disinfestation of grain has reached the stage where pilot plant studies are not only feasible but to be encouraged". This conclusion,
reached in 1961 by the International Atomic Energy Agency (IAEA) as a result of reviewing all aspects of grain disinfestation by irradiation, was confirmed by a panel of experts held in Vienna in May 1962. The panel laid down certain recommendations as to the form pilot studies should take and these are now being implemented by the Joint IAEA/FAO\textsuperscript{2} Division of Agriculture, with the appropriation of funds to put grain disinfestation by irradiation to practical test. Pilot plant evaluation (and demonstration) is recognized as an essential prerequisite to industrial acceptance of grain irradiation.

Assuming that these pilot operations prove the practical and economic feasibility of grain irradiation, where can commercial exploitation be expected to follow? There are six guiding principles:

1. **A pest problem must exist**

   A new technique, such as irradiation, will be afforded greatest opportunity for acceptance if it can provide more effective control over a pest problem than existing methods. Khapra beetle (*Trogoderma granarium*) is the most difficult insect of stored cereals to control by methyl bromide fumigation. It is now present in all of Asia, from India westwards, including Israel and Turkey, and most of Africa. It is not known from Australasia or South America, and its distribution in Europe is very restricted.

2. **Losses and purity considerations**

   Despite the importance of Khapra beetle, the cereal industry is vitally concerned with all grain-infesting species. These too are candidates for radiation control. Suffice to say that a need for disinfestation must exist, irrespective of species, and that this requirement is most applicable to (1) tropical and sub-tropical areas, to reduce losses, and (2) to the more temperate climates to provide the required freedom from contamination.

3. **Degree of grain-handling development versus "losses and purity"**

   Unfortunately, many of the countries experiencing the heaviest losses to stored cereals are those without the primary requirement of good bulk storage and modern mechanical handling. Thus, although India and Pakistan qualify for improved methods of insect control, irradiation is not applicable at this time.

   It is not surprising, on the other hand, that the largest grain producing countries, upon which the greatest demands are being made for high purity of consignments, are those with the most developed facilities for grain storage, and handling. These countries are Canada, the United States, Australia and South America. All these countries could assimilate irradiation relatively easily and at the present time. The storage capacities of export silos in these countries are given in Table I.

\textsuperscript{2} International Atomic Energy Agency/Food and Agriculture Organization of the United Nations.
4. **Integration of irradiation into new constructions**

The integration of irradiation into grain handling can be achieved most easily "on the drawing board". In this context, five port silos are planned for India (total capacity 300,000 tons) and five for import requirements in Pakistan (325,000 tons). Another is being considered for Beirut, Lebanon (50,000 tons) and six are planned for Saudi Arabia. All these proposed installations fall within the distribution range of Khapra beetle.

5. **Duration of storage and quantity**

In many countries, e.g., the United Kingdom, which import grain throughout the year, the storage period of the grain, before processing and consumption, is relatively short. In temperate climates insects present in grain multiply relatively slowly and with milling following soon after import the need for disinfestation is often avoided. Apart from the considerations of climate, prophylactic treatment offers greatest reward if grain is to be stored for long periods.

In the producing countries the storage period averages 6 to 12 months, but in exceptionally good years, and with a poor overseas market, the storage period may be extended through to the next season. In this regard grain disinfection is more applicable to producing/exporting countries than to importing countries, particularly as the exporting country is equipped to handle large tonnages from up-country installations to shipping.

6. **International trade and wholesomeness approval**

Until there is "international approval" of irradiated grain for human consumption, supposed health hazards will act as a depressant on the exploitation of irradiation for the treatment of grain. Thus, acceptance of the technique is most likely in (1) those producing countries consuming most of the grain internally; (2) those countries importing grain for internal consumption; and (3) least likely in those countries exporting grain in international trade.

**SUMMARY**

1. Sufficient research information has now been obtained to justify pilot plant studies in grain disinfestation by irradiation. This information is reviewed. It derives from research in radiation entomology, the effects of irradiation on grain, and studies in engineering and grain handling.

2. A comparison is made between irradiation and fumigation. The principal advantages of irradiation are that it provides homogenous treatment, the design of plant is compatible with 100% insect control, the process is automatic and there is no human error or operator prejudice. Plant can be designed to be completely hazard-proof; nothing is added to the grain (cf. chemical control) and treatment is instantaneous.

3. Principles underlying the likely industrial exploitation of grain irradiation are discussed. They include the importance of Khapra beetle as a cereal pest, the need to reduce losses in tropical climates, the importance
of grain purity in temperate regions and the need for well-developed grain storage and handling as a prerequisite for irradiation. Also, the relative ease of introducing irradiation into new terminal constructions, the period of grain storage and quantity available for irradiation, and the need for "international approval" of grain irradiation before exporting countries can adopt the process.

REFERENCES


DISCUSSION

S. JEFFERSON: Mr. Cornwell stated that rice is difficult to treat because it is a bagged product. I should like to mention that recent developments in gamma-radiation plant design make the irradiation of bagged products economically feasible.

A. SREENIVASAN: Mr. Cornwell referred to the possibility of applying radiation disinfestation procedures in countries like India. We are fully aware of this possibility and have carried out extensive studies on the lethal gamma doses required for various prevalent grain pests. We are now in the process of using these data in our feasibility trials with a portable 60Co irradiator under the various conditions peculiar to the application of irradiation procedures for grain disinfestation in India.

I also would like to comment on Mr. Cornwell's observation that radiation disinfestation of rice will pose problems because rice is stored not in bulk but in bags. Considerable work has been done in India to achieve easy and inexpensive treatment of bags, so that the re-infestation of disinfested grains can be minimized, if not eliminated.

P. PESSON: Mr. Cornwell mentioned that irradiation-sterilized insects that survive for some time in the irradiated grain may help to inhibit subsequent infestation. This is an important advantage of irradiation over fumigation; grain containing irradiation-sterilized males is less easily invaded by new insect populations than grain that has been completely disinfested.

P.B. CORNWELL: This is indeed an exciting possibility. However, there is bound to be opposition to the presence of live insects — even if they are sterile and present in the grain for only a short time.

N.W. HOLM: Why do you think that an accelerator facility should be designed to cope with the peak season throughput of a grain-handling terminal, while a 60Co facility need only be capable of treating the average throughput? I should have thought that in both cases capacity need be related only to average throughput.
I also feel that irradiation ought to be carried out as early as possible in order to prevent insect reproduction; this is a strong argument for machine irradiation.

In your presentation you offered a choice between a $^{60}$Co facility and irradiation from two sides with 3-MeV electrons. However, most people concerned with radiation technology consider that two-side irradiation is a poor solution in view of the problems of dose homogeneity; due to the steepness of the two dose absorption curves, which have to be added together, a very small change in the thickness of the layer of material for irradiation can cause the dose at the centre to vary from zero to more than twice the surface dose. I would therefore suggest irradiating a thinner flow of material or using an accelerator that provides electrons of higher energy.

P.B. CORNWELL: Our ideal is the instantaneous treatment of the grain arriving at the terminal on any day. This implies that a machine facility must be capable of coping with the peak season throughput.

We aim to provide a facility for irradiating throughputs of the order of 400 ton/h. In order to achieve this, while at the same time keeping the electron energy at a reasonable level, one must irradiate from two sides.
RADIATION DISINFESTATION OF GRAIN AND SEEDS

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Abstract — Résumé — Аннотация — Resumen

RADIATION DISINFESTATION OF GRAIN AND SEEDS. Current interest in radiation treatment of
grain and seeds mainly revolves about its efficacy for control of insect infestations in these products.
The recent literature on this subject is reviewed and gaps still existing in the fundamental and practical
knowledge of radiation disinfestation are pointed out. Research programmes in the United States
Department of Agriculture that are under way, or planned for the immediate future, are discussed in
detail. Current studies are being directed toward establishing minimum effective doses for sexual
sterilization and mortality, influence of environmental factors on dose requirements, and potential for
the development of biological resistance. In May 1966 the scope of the work expanded as a new grain
products irradiator became operative and applied studies were initiated.

An integral part of this research is a study of the effect of irradiation on the quality of food and
feed grains and on cereal products, at the doses for both insect control and fungal disinfection. This
paper examines critically the results of research in this area and estimates future research needs.

RADIODESINSECTION DES CEREALES ET DES SEMENCES. A l'heure actuelle, l'intérêt que suscite
le traitement par les rayonnements des céréales et des semences est dû avant tout à son efficacité pour
la désinsection. Les auteurs analysent les récentes publications dans ce domaine et signalent les lacunes,
qui subsistent encore dans les connaissances fondamentales ou pratiques relatives à la radiodésinsection.
Ils examinent en détail les programmes de recherches du Département de l'agriculture des États-Unis qui
sont actuellement mis en œuvre ou projetés pour l'avenir immédiat. Les études actuelles concernent la
détermination de la dose minimum nécessaire pour la stérilisation sexuelle et de la dose mortelle,
il'influence des facteurs ambiants sur les doses requises, et les possibilités de développement de la
résistance biologique. En mai 1966, les travaux se sont élargis à la suite de la mise en service d'une
nouvelle installation d'irradiation des céréales qui permet d'entreprendre des études appliquées.

Ce programme comprend l'étude des effets de l'irradiation aux doses insecticides et fongicides sur
la qualité des céréales destinées à la consommation humaine et animale et sur celle des produits dérivés.
Le mémoire procède à un examen critique des résultats des recherches entreprises et évalue les besoins
futurs à cet égard.

ОБЕЗЗАРАЖИВАНИЕ ЗЕРНА И СЕМЯН С ПОМОЩЬЮ ОБЛУЧЕНИЯ. В настоящее время
обработка зерна и семян с помощью облучения представляет интерес главным образом с точки
зрения определения ее эффективности в деле обеспечения контроля за заражением этих про-
dуктов паразитами. Рассматривается современная литература по этому вопросу и указыва-
ются все еще существующие проблемы в области фундаментальных и практических знаний о
способах обеззараживания с помощью облучения. Подробно рассматриваются научно-иссле-
dовательские программы министерства сельского хозяйства США, которые находятся в стадии
выполнения или планируются на ближайшее будущее. Проводимые в настоящее время исследо-
вания направлены на установление минимальных эффективных доз для половой стерилизации
и смертности, влияния окружающих факторов на дозовые потребности и возможность для раз-
вития биологической сопротивляемости. В мае 1966 года объем работ будет расширен, так
как будет введена в эксплуатацию новая установка по облучению зерновых продуктов и начнит-
ся прикладные исследования.

Составной частью этих научно-исследовательских работ является изучение влияния
облучения на качество пищи и фуража, а также продуктов из злебных злаков при дозах, обес-
печивающих контроль за паразитами и уничтожение грибков. В данном докладе критически
рассматриваются результаты научно-исследовательской работы в этой области и определя-
ются потребности в научных исследованиях в будущем.
DESINFESTACION DE GRANOS Y SEMILLAS POR IRRADIAICION. El interés que suscita el tratamiento de granos y semillas por irradiación radica principalmente en su eficacia en la lucha contra la infestación de esos productos por insectos. Los autores examinan las publicaciones más recientes sobre esta cuestión y señalan las lagunas que todavía existen en los conocimientos básicos y prácticos de la radiodesinfestación. Exponen detenidamente los programas de investigación del Departamento de Agricultura de los Estados Unidos que se están ejecutando o que se proyecta ejecutar en un futuro inmediato. Los estudios actuales están orientados hacia el establecimiento de valores mínimos de dosis eficaces para la esterilización sexual y para provocar la muerte de los insectos, la influencia de los factores ambientales sobre las dosis necesarias y las posibilidades de desarrollo de una resistencia biológica. En mayo de 1966 se amplió el alcance de estos trabajos con la entrada en servicio de una nueva instalación de cereales y derivados y se iniciaron estudios de aplicación.

Como parte integrante de esas investigaciones se lleva a cabo un estudio de los efectos de la irradiación sobre la calidad del grano destinado a la alimentación humana o utilizado como pienso, y sobre los productos derivados de los cereales. Esa irradiación se efectúa con las dosis que se precisan en la lucha contra los insectos y con las empleadas para la eliminación de hongos. Los autores hacen un estudio crítico de los resultados de las investigaciones que se realizan en este sector y evalúan las futuras necesidades en materia de investigación.

I. Introduction

The practical approach to the radiation disinfestation of foods began more than fifty years ago with the abortive attempt by Morgan and Runner (1) to control the cigarette beetle, Lasioderma serricorne, in packaged cigars by means of X-radiation. Although it was later shown (2) that high doses could kill eggs, larvae, and adults of Lasioderma, the earlier failure had a dampening effect on the exploration of control applications of radiation. Nevertheless, over the intervening decades, basic studies on this subject continued, and a wealth of data has been accumulated on lethal effects of radiation on insects (3).

Current research on the radiation treatment of grain, oilseeds, and other agricultural seeds in the United States is directed primarily to the practical objective of controlling insect infestation, in order to prevent storage losses and extend storage life. Since storage fungi are the second most important factor in storage losses and deterioration of grain, radiation effects on this particular group of microorganisms are also receiving attention. Emphasis here is on the reactions of insects and molds when normally associated with the grain bulk instead of in an unnatural isolated condition. The quality of grain as simultaneously affected by such radiation treatments is also being examined in detail. Current quality studies relate mainly to wheat but will expand to other grains when a new pilot-scale grain irradiator goes into operation in 1966. This review will summarize the present status of these developments.

II. Irradiation for control of stored-product insects and mites

1. Proposed systems for disinfestation of grain by radiation

Various systems for irradiating grain have been proposed (4). Although most proposals suggest radioisotopic sources using penetrating gamma radiation from Cobalt-60 or Cesium-137, electron accelerators with high grain flow rates and low penetrating powers have been suggested. Several ideas have appeared in the literature for mobile irradiation facilities in trucks, railcars, and ships.

For a pilot-scale bulk grain irradiator in the United States, a gamma Co60 radioisotopic system was selected. The facility is currently under
construction at our Stored-Product Insects Research and Development Laboratory, Savannah, Georgia. The United States Atomic Energy Commission is making it available to the Department of Agriculture for research purposes. Through unique design this facility also will be capable of radiating packaged processed foods. At present, disinfestation of packaged foods by radiation appears to be more feasible commercially than disinfestation of bulk grain. The United States Atomic Energy Commission has plans for an electron machine bulk grain irradiator that may be located at Savannah, Georgia, to supplement the gamma irradiator, or located at an industry site (5).

Cornwell and Bull (6) believe commercial use of gamma radiation for the disinfestation of grain is discouraged by expense. They suggest that recent advances in electron machines would enable them to treat grain at 200 tons per hour, operating at 50% efficiency. They believe such machines could be installed in terminal elevators. Machines of still greater power have been designed, and their estimated cost is not prohibitive. The limited penetration of electrons would require that the grain flow be in a uniform thin layer. These authors state that research has shown that electrons and gamma radiation are equivalent in their lethal and sterilizing properties against stored-product insects, and that improvements of electron machines are a major step toward commercial radiation disinfestation of grain.

Conclusions on the most efficient and practical system require further research and pilot-scale studies.

2. Present status of knowledge on radiation effects on stored-product insects

Although many observations have been made of the effect of radiation on stored-product insects, the data have not been integrated into an easily identifiable pattern. Different kinds of radiation and times of exposure were used, and often the dosage was not precisely controlled. Also, methods of treatment and handling of insects before and after the irradiation were not standardized. It is now known that many of these procedures affect the insects' susceptibility to radiation. Other factors, such as the age of the insect and its metamorphic stage, have a considerable effect on sensitivity to radiation and chances of recovery. Some important effects are not immediately apparent, but show up later as death or injury in succeeding stages or even to progeny.

The most complete summary of the action of ionizing radiations on insects is by Hilchey (3) who tabulated the information up to 1957. This summary includes data for several species of stored-product insects. Effects of radiation on insects include mortality, arrested development, inhibited or prevented reproduction, reduced longevity, and affected physiological processes. All of these effects are of general interest in the control of stored-product insects, but of greatest immediate interest to the disinfestation of grain and grain products are the effects on mortality, development, and reproduction.

Two generalities Hilchey makes about the effects of ionizing radiations on insects are: lethal radiation doses for insects are high compared with lethal doses for warm blooded animals that have been tested, and lethal doses among the insects vary extensively according to species. In addition to species differences, there are great differences in the lethal doses within a species according to the developmental stage exposed. For example, the dose required to kill adults may be many times that required to kill
the immature stages. Also, the insect's age within the developmental stage is related to its susceptibility to radiation, so that newly emerged larvae, pupae, or adults are more susceptible than older ones.

Radiation may have a short-term or a long-term effect on insect development. For example, a larva may fail to develop from an irradiated egg, or an adult may fail to develop from an irradiated pupae. Long-term effects may be observed in a stage succeeding the one exposed to radiation. For example, Proctor et al. (7) showed that larvae of Oryzaephilus, Rhyzopertha, and Tribolium from eggs exposed to radiation died shortly after emergence. These same authors showed also that adults of Rhyzopertha and Tribolium died soon after emergence from pupae exposed to radiation.

Radiation may affect insect reproduction by interfering with the development of reproductive organs or by directly influencing the gametes in the adult body. In addition, radiation can so influence behavioral patterns that adults do not mate.

Numerous contributions to the knowledge of the effects of radiation on stored-product insects have been made since Hilchey's review of 1957. Cornwell et al. (8) showed that different species of Laemophloeus vary considerably in response to radiation. The same has been shown for species of Sitophilus by Van den Brul and Bollaerts (9) and for Tribolium by Park et al. (10) and Erdman (11). Differences in responses to radiation by male and female kharpa beetles, Trogoderma granarium Everts, were shown by Carney (12) and Kansu (13). Varying susceptibilities to radiation according to insect age and stage were demonstrated by Peredel'ski (14). Considerable evidence is available to show that, within any given insect stage, older insects are more resistant to radiation than are newly emerged ones (6). Jefferies and Cornwell (15), using Calandra granaria (Sitophilus granarius (L.)), reported that radiation applied in fractions was less effective than continuous exposure of equal dosage. Later Jefferies (16) showed that dosages applied in fractions did not reduce the amount of reproduction from exposed adults. Kumyantsev and Ratanova (17) showed that radiation dosages of X-rays required for mortality of the mite, Tyrophagus putrescentiae (Schrank), were 20 to 30 times greater than dosages required to produce the same effect on stored-product insects.

Recent studies by Tilton et al. (18, 19, 20, and 21) using a mobile irradiator housed in a semitrailer truck, contributed significantly to the knowledge of the effects of gamma radiation on stored-product insects. Insects were exposed to a 40,000 Ci Co^60 source to develop information on the dosages of gamma radiation required to arrest insect development, and to produce sterility.

The information on the effect on insect development presented by these authors is summarized in Table I. The important conclusions to be made from this information appear to be the following:

a. For most insects tested, very high dosages (40 to 100 krads or higher) of gamma radiation were required to prevent at least a few larvae developing from exposed eggs, a few pupae developing from exposed larvae, or a few adults developing from exposed pupae. Low dosages (13.2 krads) did prevent pupae of two species of dermestid beetles from developing from exposed larvae.

b. Low dosages (13.2 to 25 krads) of gamma radiation allowed some development of exposed eggs and larvae but prevented them from reaching the adult stage.
Table 1. Minimum dosage of gamma radiation completely arresting development of stored-product insects and a mite

<table>
<thead>
<tr>
<th>Organism</th>
<th>Stage observed</th>
<th>Dosage - krad</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>exposed</td>
<td></td>
</tr>
<tr>
<td></td>
<td>for effect</td>
<td>13.2</td>
</tr>
</tbody>
</table>

### LEPIDOPTERA

**Plodia interpunctella**
- Egg: Larva
- Egg: Adult
- Larva: Pupa
- Larva: Adult
- Pupa: Adult

**Sitotroga cerealella**
- Egg: Larva
- Egg: Adult
- Larva: Adult
- Pupa: Adult

### COLEOPTERA

**Tribolium confusum**
- Egg: Larva
- Larva: Larva a/
- Larva: Pupa
- Larva: Adult
- Pupa: Adult

**Lasioderma serricorne**
- Egg: Larva
- Larva: Larva a/
- Larva: Pupa
- Larva: Adult
- Pupa: Adult

**Rhyzopertha dominica**
- Egg: Larva
- Larva: Pupa
- Larva: Adult
- Pupa: Adult

**Attagenus piceus**
- Egg: Larva
- Larva: Larva a/
- Larva: Pupa
- Larva: Adult
- Pupa: Adult

**Trogoderma glabrum**
- Egg: Larva
- Larva: Larva a/
- Larva: Pupa
- Larva: Adult
- Pupa: Adult

### ACARIÑA

**Acarus siro**
- Egg: Larva
- Larva: Adult
- Hypopus: Adult

---

*a/ Based on data obtained 21 days after exposure.
*b/ One survivor after exposure of 45 krad.
*c/ One survivor after exposure of 100 krad.
*d/ One survivor after exposure of 45 krad.

**c.** In general, dermestids were more susceptible to gamma radiation than were flour and grain beetles and moths.

**d.** The mite, *Acarus siro*, showed relatively high resistance to gamma radiation.

**e.** *Tribolium* larvae were more susceptible to gamma radiation than were larvae of the other species of beetles exposed.
Table II. Minimum dosage of gamma radiation producing sterility in 100% exposed adult stored-product insects and a mite

<table>
<thead>
<tr>
<th>Organism</th>
<th>Sex exposed</th>
<th>Dosage - krad</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>13.2</td>
</tr>
</tbody>
</table>

LEPIDOPTERA

<table>
<thead>
<tr>
<th>Plodia interpunctella</th>
<th>Male</th>
<th>&gt;X</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Female</td>
<td>&gt;X</td>
</tr>
<tr>
<td>Sitotroga cerealella</td>
<td>Male</td>
<td>&gt;X</td>
</tr>
<tr>
<td></td>
<td>Female</td>
<td>X---X</td>
</tr>
</tbody>
</table>

COLEOPTERA

<table>
<thead>
<tr>
<th>Tribolium confusum</th>
<th>Male &amp; female</th>
<th>X-----X</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lasioderma serricorne</td>
<td>Male &amp; female</td>
<td>X-----X</td>
</tr>
<tr>
<td>Attagenus piceus</td>
<td>Male</td>
<td>X-----X</td>
</tr>
<tr>
<td></td>
<td>Female</td>
<td>X-----X</td>
</tr>
<tr>
<td>Trogoderma glabrum</td>
<td>Male</td>
<td>X-----X</td>
</tr>
<tr>
<td></td>
<td>Female</td>
<td>X</td>
</tr>
</tbody>
</table>

ACARINA

<table>
<thead>
<tr>
<th>Acarus siro</th>
<th>Male &amp; female</th>
<th>X-----X</th>
</tr>
</thead>
</table>

In summary, this information indicates that fairly low dosages of gamma radiation could be used on commodities such as bulk grain in which some infestation by insect stages beyond the stage irradiated could be tolerated, but that high dosages of radiation would be required on products such as packaged foods where 100% mortality must be obtained.

Information on the minimum dosage of gamma radiation required to produce sterility in stored-product insects is summarized in Table II. The important conclusions that appear to be shown by this information include:

a. Very high dosages (45 to 100 krads or higher) of gamma radiation were required to sterilize stored-product moths, compared with the dosages required to sterilize stored-product beetles.

b. In most species the female was more susceptible to radiation than was the male.

c. Comparatively high dosages (25 to 45 krads) of gamma radiation were required to sterilize the mite Acarus siro.
In summary, this information indicates that smaller dosages of gamma radiation would control stored-product beetles than would control stored-product moths and mites.

3. Pilot grain irradiator--design

The design of the bulk grain irradiator (Figure 1) was discussed by Laudani et al. (22) and in "Radiation Preservation of Food," published by the United States Department of Commerce (5). The design was based on a study conducted by Vitro Engineering Company, New York City, for the Brookhaven National Laboratory (23).

The facility will be located beside a paved railroad spur permitting both rail and truck traffic. A series of grain storage bins will be located next to the irradiator. Bulk grain will enter an outside hopper and be conveyed to the irradiation chamber. The inlet to the chamber is offset to reduce radiation streaming. The grain will flow continuously by gravity through a horizontal source rod configuration located in the center of the chamber. The radiation chamber and parts of the grain inlet and outlet will be enclosed in a concrete shielded cell. When in operation, the radiation chamber will be continuously filled with grain. After exposure, the grain will be moved from the bottom of the irradiation chamber by pressurized air. It will be possible to vary the grain flow rate from 2,500 to 10,000 pounds per hour, thus varying the radiation dose. For example, a flow rate of
<table>
<thead>
<tr>
<th>Item</th>
<th>Specification</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Source energy</td>
<td>About 26,000 Ci</td>
</tr>
<tr>
<td>2. Source design</td>
<td>Doubly encapsulated strips of Cobalt-60</td>
</tr>
<tr>
<td>3. Source array in irradiation chamber</td>
<td>Thirteen tubes in single row spaced 4 inches on center in a horizontal plane in center of chamber</td>
</tr>
<tr>
<td>4. Minimum grain capacity specified</td>
<td>About 5,000 lb/hr at minimum dose of 25,000 rad (about 80 bu/hr) a/</td>
</tr>
<tr>
<td>5. Grain flow rate variability</td>
<td>From 2,500 to 10,000 lb/hr, with proportionately higher to lower dose</td>
</tr>
<tr>
<td>6. Maximum-minimum dose ratio</td>
<td>1.65. Minimum dose for design specifications = 25,000 rad; maximum should not exceed 41,500 rad</td>
</tr>
<tr>
<td>7. Packaged food capacity</td>
<td>About 2,000 lb/hr for most products, based on 100 lb/package carrier</td>
</tr>
</tbody>
</table>

a/ If dose analysis data are confirmed by experimental results when the facility becomes operable, an initial loading of 26,000 curies and a minimum dose of 25,000 rad would provide a throughput of 6,800 lb/hr with an efficiency of about 56 percent. At the end of 1 year’s operation, throughput for the same dose would be 6,000 lb/hr, and after 2 years would be 5,200 lb/hr.

5,000 pounds of grain per hour will allow an estimated dose of 25,000 rads to the grain. Lower or higher flow rates will produce proportionately higher or lower dosages (Table III).

The radiation source consists of 13 doubly encapsulated strips of Co⁶⁰, four feet in length, each mounted in an aluminum carrier. When not in use, the source in its carriers will be housed in a lead cask mounted in the concrete cell wall. When irradiating grain, the source carriers will be withdrawn from the cask into the irradiation chamber. The carriers will move through a single row of 13 square tubes located in a horizontal plane at the center of the chamber. Grain flow will be perpendicular to the horizontal array of tubes, which will span the full width of the four-foot-square chamber. The grain at all positions across the width of the chamber will move at a uniform speed past the source (a plug flow pattern). Initial total source activity will be about 26,000 Ci. The bulk of the grain that surrounds the source during operation absorbs a high proportion of the radiation and results in a calculated efficiency of about 56%. To make the radiation dosages more nearly uniform at all positions across the chamber, the outer ends of each source strip and the entire length of the two outer
strips are more strongly radioactive than the source strips at the center of the array. This provides a maximum-to-minimum dose ratio of 1.65.

In addition to bulk grain irradiation, the design provides for irradiation of a variety of packaged products in textile and paper bags, shipping cases, and cartons. The same source used for bulk grain will be used for packaged foods. The source strips will be extended through the tubes past the grain irradiation chamber to the package irradiation area. The packages will enter the irradiator through a conveyor and move in a series of short movements followed by several relatively long dwell times across the top of the array of tubes. Then the packages will move down to a position below the tubes and follow a similar pattern on the return. The packages will be removed from the irradiator by means of a shielded shuttle.

Dose rates for packaged foods were estimated by several computer runs. One computation was made for each area of the source array having a different activity level, and the dose rates computed for each part of the array were summed for various positions inside the food package. The minimum dose should be received at the center plane of the food product in a package that has a dwell period over and under the corners of the source array. The maximum dose should be received by the top and bottom surface of the food product in a package that passes over and under the central part of the source array. Dose will vary depending on the density of the food product and the number of packages placed in each package carrier. For most products a maximum-to-minimum dose ratio of 1.65 or less should be achieved. In order to keep dosages uniform, it will be necessary to fill the empty space in each carrier with material of a density similar to that of the food product. The residence time of the food package in each of eight dwell positions to achieve a minimum dose of 25,000 rads will be from 2.7 to 3 minutes for most food products. Based on a typical product loading of 100 pounds per carrier, the product throughput will be 2,000 pounds per hour, with an efficiency of about 18.6%. When the product can be packed to a greater weight per carrier while maintaining the required maximum-to-minimum dose, the efficiency will be increased.

Some of the important performance data for the irradiator are summarized in Table III.

4. Pilot grain irradiator--research program

Laudani et al. (22) described the research program that will be carried out when the bulk grain irradiator becomes available. Basic and applied studies will be conducted to determine the unknowns about the use of gamma radiation for the disinfestation of free flowing grain. Basic studies will be made on biological and physiological problems of stored-product insects. Some of the earliest studies will be to determine the levels of gamma irradiation required to produce sterility and mortality in the various metamorphic stages. Although much of the information about required dose is available for "naked" insects, it must be determined whether different dose requirements are needed for external and internal infestation in grain moving through a radiation source array. Tests will be made to evaluate the hypothesis that some degree of protection to irradiated grain might be obtained from infestation by sterile adults. It has been proposed that reinfestation of grain containing sterile insects would be less than reinfestation of grain containing a normal population.

Infested bulk quantities of commodities will be treated at various dosage levels to determine the gamma ray attenuation, to develop a commer-
cially acceptable method of gamma radiation for insect control, and to compare irradiation and chemical control for effectiveness and cost. Effective dosages for the bulk treatment of various commodities will be determined and direct comparisons made with conventional control methods.

Basic studies on stored-product insects will include determining the influence of various ecological factors on the dosage required to control an existing insect infestation under normal storage conditions. Such factors as temperature, humidity, and composition of the air in the grain space will be included in these studies. The effects of gamma radiation on the population dynamics of the major species will be studied. The effects of sex, age, developmental stage, and pre- and post-irradiation treatments will be determined. Changes in physiology, behavior, and genetic characteristics will be investigated. Successive generations of insects will be exposed to substerilizing doses of radiation to observe whether radioresistant strains develop. The effect of different dose rates and dose fractionation will be determined.

The effects of gamma radiation on quality factors of various agricultural commodities will be determined through cooperative studies with the Field Crops and Animal Products Research Branch of the Market Quality Research Division, the Human Nutrition Research Division, and with various grain milling and processing industries. These studies will include various grains, peanuts, legumes, coffee, cocoa, and different formulations of animal feeds.

There will be four primary lines of investigation in the studies on the development of gamma radiation for the control of stored-product insects in packaged foods. First, the dosage levels of radiation necessary to produce mortality to 100% of exposed eggs and newly emerged larvae of the more important species of stored-product insects will be determined. Second, the gamma-ray attenuation coefficient will be determined for pertinent food products and packaging materials. The influence on gamma radiation penetration will be studied for such factors as the density of the commodity, packaging materials, etc. Third, the effects of the lethal dosages of gamma radiation on various quality factors of the treated commodities and the packaging materials will be determined. Quality studies on processed foods will be performed by the same groups doing the studies on raw commodities. Packaging materials will be studied for possible changes in physical characteristics, such as loss in tensile strength, flexibility, color, adhesive failure, etc. Fourth, the feasibility of the use of gamma radiation on packaging lines for processed foods and feeds will be studied. The commodities to be included in these four lines of research are wheat flour, cornmeal and other processed corn products, milled rice, breakfast cereals, cake mixes, dried fruits, nut meats, dry legumes, spices, and dry animal feeds.

Throughout the research program the feasibility and economics of the use of gamma radiation for the disinfestation of grain on a commercial scale will be continuously examined. This will be one of the major objectives of the pilot-scale program. The pilot grain irradiator was designed for possible scale-up to commercial size. There have been several suggestions for construction of a commercial-scale grain irradiator. We believe, however, that there are now too many unknowns in requirements for dosimetry and practical handling to proceed with drawing up construction and performance specifications on a commercial scale. It is hoped that the proposed research and pilot-scale studies will eliminate these unknowns.
Seeds in storage are subject to deterioration by microorganisms. Under certain storage conditions, fungi are capable of destroying large quantities of seeds unless prevented by physical or chemical means. The use of fungicides or chemical sterilants to control storage fungi has met with only limited success. Ionizing radiation, which has the potential of being economical and comparatively simple to use, can destroy fungi. Bridges et al. (24) found that cathode-ray radiation over a range of 0.22 to 0.36 megareps (235 to 385 krads) was lethal to spores of seven species of Aspergillus. Kafer (25) reported that survival of conidia from two diploid strains of Aspergillus nidulans was slightly less than 1% at 50 kr (45.45 krads). By irradiating suspensions of spores and mycelia of eight phytopathogenic fungi on agar, with a Co$^{60}$ source, Kijacic (26) found that the lethal dose varied from $2 \times 10^3 \text{ r}$ to $1 \times 10^6 \text{ r}$ ($1.82 \times 10^4 \text{ rads}$ to $0.91 \times 10^6 \text{ rads}$).

According to Terui and Harada (27), dose rate as well as the dose in irradiation is one of the factors in determining the fungistatic effect of gamma radiation. They found that the mycelia of Penicillium expansum irradiated with a dose of $80 \times 10^4 \text{ rads}$ at a high dose rate (approximately $100 \times 10^4 \text{ rad/hr}$) were almost completely killed, while the samples irradiated with the same dose at a low dose rate (approximately $2 \times 10^4 \text{ rad/hr}$) resumed mycelial growth.

Only a few studies have reported the use of radiation to kill fungi associated with seeds. Using cathode rays, Lambou et al. (28) found that radiation levels that were lethal to the microflora of cottonseeds also injured the seeds. Cropsey et al. (29) used cathode rays in a comprehensive study of wheat which included the effect of these rays on surface borne fungi. They reported that the general mold population of wheat was significantly reduced at 500 kcps (535 krads), especially in grain of high moisture content that was irradiated on two sides. Kulik and Justice (30) explored the feasibility of using gamma radiation to destroy or retard the growth of seed storage fungi without seriously damaging the host seeds. Seeds of onion (Allium cepa L.), radish (Raphanus sativus L.), Kentucky bluegrass (Poa pratensis L.) crimson clover (Trifolium incarnatum L.), sorghum (Sorghum vulgare Pers.), wheat (Triticum aestivum L.), and corn (Zea mays L.) were inoculated with spores of the common storage fungus Aspergillus amstelodami prior to irradiation. Peanuts (Arachis hypogaea L.) were inoculated with spores of A. flavus before they were irradiated. Inoculated and noninoculated seeds were exposed to doses of $0, 5, 10, 20, 40,$ or $80 \text{ krads}$ of gamma radiation from a Co$^{60}$ source. Some destruction of A. amstelodami and A. flavus apparently occurred at $80 \text{ krads}$. At this exposure, however, the seedling production potential of all crop species, with the possible exception of crimson clover and radish, was greatly reduced. In general, the fungi were found to be more resistant to radiation injury than were the seeds. Storage of inoculated, irradiated seeds under conditions favorable to the growth of storage fungi yielded no clear-cut picture of the effect of gamma radiation on the subsequent behavior of A. amstelodami (or A. flavus on peanuts) in stored seeds.

Although some questions still remain, Kulik and Justice conclude that gamma radiation as used in their study does not appear to be a practical method of controlling or destroying storage fungi of seeds intended for planting purposes.

This conclusion is confirmed by the recent work of Fifield and Columbic (31), who found that germination of hard red winter wheat was seriously
reduced by radiation levels as low as 50,000 rads. Treatment at levels of 125 and 175 krads completely eliminated seed viability. This generally agrees with the observations of Milner and Yen (32). At the 175-krad level, externally borne populations of storage fungi and both external and internal field fungi were reduced. Changes in internal storage fungi were too small to measure.

IV. Effect of radiation treatment on quality of food and feed grains

1. Wheat

A critical review of the literature on this subject by Milner (33) led him to state "earlier conclusions that the low irradiation levels required for deinfestation of wheat (25,000 to 50,000 rep) may not alter the desirable characteristics of the flour, are not considered reliable since no storage studies were performed to determine whether delayed or slowly cumulative reactions, characteristic of only somewhat higher treatment levels, may occur at the lower levels as well."

The recent study by Fife and Golumbic (31) helps to resolve this question of changes in irradiated wheat while in storage. Gamma radiation (Co$^{60}$ source) in dosages of 10, 25, 50, 125, and 175 krads was applied to hard red winter wheat, which was subsequently stored for one year at 75°F (24°C). Quality tests were made immediately after treatment and every three months thereafter on the stored samples.

The various dosages of radiation had no immediate effect on such milling criteria as test weight, flour yield, and pearling index of the samples when initially treated, as compared to the control, and none of these indices showed a significant change during 12 months of storage. Power consumption required for milling was not checked, but according to a report mentioned in Milner's review (33) this factor decreases after irradiation. This interesting and economically important effect requires confirmation.

Other indices, such as fat acidity, wheat and flour proteins, flour ash, diastatic activity (maltose content), glutamic acid decarboxylase activity, capacitance-resistance measurements, nitrogen solubility in NaCl and alcohol solutions, and rheological properties of the doughs were unchanged by treatment at any of the radiation levels.

All breads made from the flours, even those from grain treated at the highest level, were of remarkably good quality (Figure 2). Loaf volume, absorption, and internal bread characteristics were not altered by increasing initial dosages of radiation. However, absorption increased somewhat with time of storage. Also, there were no significant changes in the loaf volumes or the crumb grain of the loaves during the year that the wheat was stored. Crumb color of the loaves, however, decreased significantly after wheat had been stored nine months.

Bread from wheat treated at 125 and 175 krads had a definite scorched or burned odor when removed from the oven. After the bread cooled to room temperature, however, systematic taste panel studies, initially and after nine and twelve-month storage, detected no differences in odor or flavor of bread from irradiated wheat as compared with bread from untreated wheat.

2. Other grains

Brown rice showed very marked changes when subjected to gas plasma irradiation according to Deobald (34); milled rice was nearly unaffected.
The development of free fatty acids during storage of brown rice was definitely inhibited. The oil in the bran became much more insoluble. Irradiated fresh bran showed a marked inhibition in free fatty acid formation, less hexane extractable oil, lowered iodine number, and increased molecular weight.

Tipples and Norris (35) studied the effects of irradiation and post-irradiation storage on the malting properties of barley that had been irradiated at levels from 8 to 500 kilorads. Irradiation up to 50 kilorads produced only small effects on the malting properties. Barley malt can be effectively pasteurized with gamma irradiation of 0.112 krads (36).

Gamma irradiation of corn at 2.8 megarads does not result in nutritional damage to its protein, and no off flavors and odors are produced (37). An irradiation dose of 300 000 rads does not impede the swelling process of the grain (38). Chmyr et al. (39) studied the effect of doses of 2.5 megareps on the fat content and iodine value in dry and moist corn held in storage for 360 and 105 days respectively. No change in fat content in either sample was observed but the iodine number decreased in the moist seed.

Gamma irradiation doses of 50 to 1000 krads apparently had little or no effect on oats (40). Other than a slight flavor change, there was no evidence of significant difference between treated and untreated oats as judged by storage performance of products made from them.

V. Conclusion

These scattered and incomplete reports on the quality effects of irradiation of different grains reflect the paucity of information on the subject. Not all questions on organoleptic and processing quality have been answered. With pilot-plant-scale tests in prospect, providing the opportunity for ample quantities of material for investigation, it should be possible to close this gap in existing knowledge of the subject.
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(3) HIlchey, J. D., "Action of ionizing radiations on insects," Ch. 25, Radiation Preservation of Food, USQC, PB 151493 (1957).


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DISCUSSION

A. SREENIVASAN: Would you care to comment on the possibility of using gamma radiation to control Aspergillus flavus, which is responsible for aflatoxin in peanuts?
C. GOLUMBIC: As part of our studies on the irradiation of storage fungi associated with seeds, we have in fact irradiated groundnuts (peanuts) infested with A. flavus. We found that this fungus was as resistant to radiation as other storage fungi and that the host seed was killed before there was appreciable reduction in A. flavus.
Present Status and Future Prospects of Irradiation Preservation for Fish

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Torry Research Station, Aberdeen, Scotland, United Kingdom

Abstract — Résumé — Аннотация — Resumen

Present Status and Future Prospects of Irradiation Preservation for Fish. All the present evidence seems to show that radiation sterilization of almost all kinds of sea foods is not a practical proposition owing to the production of undesirable organoleptic changes, mainly in flavour and odour, of the cooked product. On the other hand, a variety of sea foods (including about 30 species of fish and shellfish) can withstand pasteurizing doses of from 0.3 to 0.5 Mrad without any such organoleptic changes being detectable. Moreover, the shelf life of such irradiated products, in terms of good commercial quality, can be extended by factors of approximately 1½ and 2 times at storage temperatures of 40° and 32°F respectively. Thus, newly-caught cod and haddock which remain of good quality for a shelf life of 9 and 12 days at 40° and 32°F can, after irradiation at 0.3 Mrad, still have similar qualities after storage at these temperatures for approximately 14 and 24 days, respectively. To obtain the maximum extension of storage life, irradiation on board the fishing vessel would be the most appropriate, but the technical difficulties of such a task are formidable. Most of the white fish, such as cod and haddock, are not landed immediately after catching but may be anything from a few hours old up to the limit of edibility, viz. about 17 days for well-iced cod at 32°F at landing. Accordingly, the longer the fish have been stored in the fishing vessel before landing the shorter the remaining life on shore. Taking the storage limit of good commercial quality cod and haddock as being 9 and 12 days at 40° and 32°F respectively, experiment has shown that the remaining shelf life of such species on landing can be extended by factors of approximately 1½ and 2 at 40° and 32°F. Thus, cod or haddock stored for six days at 32°F before landing would have their subsequent storage life of six days at landing extended to twelve if irradiated.

Feasibility studies in Britain, and elsewhere, have indicated that the radiation pasteurization of fillets of fish and of other sea foods in the packaged form is most likely to be immediately commercially successful. Wholesomeness studies, and of bacterial hazards, particularly from Clostridium botulinum Type E, in the production and marketing of such packaged products, are now under way, and the present position of some of these and other aspects of the irradiation of such products are discussed in detail in the full paper.

État Actuel et Perspectives de la Radioconservation du Poisson. Il semble, d'après les données actuellement disponibles, que la radiostérilisation de presque toutes les espèces d"aliments d'origine marine n'est pas une méthode très pratique, étant donné l'apparition d'altérations organoleptiques indésirables, notamment dans le goût et l'odeur des produits soumis à la cuisson. Divers produits de la mer (une trentaine d'espèces de poissons et de crustacés ou mollusques) sont cependant capables de résister à des doses de pasteurisation allant de 0,3 à 0,5 Mrad sans altérations organoleptiques décelables. De plus, la durée de conservation de ces produits irradiés sans altération de leur qualité commerciale peut être prolongée d'environ une fois et demie à deux fois à des températures de 4,4 et 0°C respectivement. Ainsi, la morue et l'aiglefin qui viennent d'être pêchés et qui conservent leur bonne qualité pendant 9 et 12 jours respectivement aux températures de 4,4 et 0°C pourraient gagner, après irradiation à 0,3 Mrad, des qualités analogues lorsqu'ils sont conservés à ces températures pendant environ 14 et 24 jours respectivement. La plus grande prolongation possible de la durée de stockage serait obtenue le plus facilement par une irradiation à bord du bateau de pêche, mais les difficultés techniques auxquelles on se heurte dans ce cas sont énormes. La plupart des poissons à chair blanche, tels la morue et l'aiglefin, ne sont pas amenés à terre aussitôt pêchés ; il s'écoule normalement un délai pouvant aller de plusieurs heures jusqu'à la limite de la comestibilité, soit environ 17 jours pour la morue bien réfrigérée à 0°C. En conséquence, plus le poisson aura séjourné à bord avant son déchargement, plus courte sera sa durée de conservation à terre. En supposant que la limite de conservation de la morue et de l'aiglefin de bonne qualité commerciale soit de 9 et 12 jours à 4,4 et 0°C respectivement, l'expérience montre que la durée de conservation à terre de ces espèces peut être prolongée d'environ une fois et demie et deux fois aux températures de 4,4 et 0°C.
Ainsi, la durée de conservation à terre de la morue ou de l'aiglefin conservés sur le bateau pendant 6 jours à 0°C pourrait être portée de 6 à 12 jours après irradiation.

Des études sur les possibilités de réalisation effectuées en Grande-Bretagne et ailleurs indiquent que la radiopasteurisation des filets de poisson et d'autres produits marins après conditionnement pour la vente a les plus grandes chances de remporter un succès immédiat sur le plan commercial. Des études sur la comestibilité et sur l'inocuité bactérienne - notamment en ce qui concerne Clostridium botulinum - dans le cycle de production et de commercialisation de ces produits conditionnés pour la vente se poursuivent à l'heure actuelle; le mémoire examine en détail ces divers aspects, et d'autres encore, de l'irradiation des produits en question.

NATIÓNALSEE POLOJENIE I PERSEPÉNTIY SÀ BUDUÊSHEE B STERILIZĀCII RÝBÝ PÝTÈM OBŁÜČENIÁ. Vše imejúce sia v naštejšie vême dôkazateľstva, káže, soobrat o tom, že sterilizácia posredstvom obľúčenia počíť všetkých vias pišuvých produktov mora ne je také praktickým meria, kázavá pojavom nejelatelných organo­lepitichých zmenien hlavným obrazom vo wкусových a aromatičnych kachetách prígotov­ lených produktov. С другой стороны, многие вид пищевых продуктов моря (включая около 30 видов рыб и моллюсков) могут выдерживать при пастеризации дозы облучения от 0,3 до 0,5 Мрад без каких-либо заметных органолептических изменений. Более того, срок хранения облученных таким образом продуктов с точки зрения хорошего коммерческого качества мо­ жет быть увеличен в 1,5 и 2 раза при температуре хранения соответственно 40° и 32° по Фаренгейту.

Таким образом, только что выловленная треска и пикша, сохраняющие хорошее качество в период сохранения в течение 9 и 12 дней при температурах 40° и 32° по Фа­ renгейту, могут после облучения дозой в 0,3 Мрад сохранять аналогичные качества после хранения в этих температурах в течение, приблизительно, 14 и 24 дней соответственно. Для получения максимального срока хранения наиболее подходящим было бы облучение на борту рыболовного судна, но технические трудности такого мероприятия весьма значительны. Большинство бельых рыб, такой как треска и пикша, не доставляется на берег немедленно после вылова, а может покасть туда в пределах от нескольких часов до периода сохранения ею съедобности, который для хорошо замороженной трески составляет около 17 дней при температуре 32° по Фаренгейту. Соответственно, чем дольше рыба хранилась на рыболов­ном судне перед разгрузкой на берег, тем короче срок возможного хранения ее на берегу.

Ввеливо внимание то, что предел хранения трески и пикши с сохранением их хорошего коммерческого качества составляет 9 и 12 дней при температуре соответственно 40° и 32° по Фаренгейту, эксперименты показали, что срок хранения таких видов после доставки на берег может быть увеличен, приблизительно, в 1,5 и 2 раза при температурах 40° и 32° по Фаренгейту. Таким образом, срок хранения некоторых видов после облучения может быть увеличен примерно на 1,5 и 2 раза при температуре 40° и 32° по Фаренгейту. Кроме того, в случае облучения срок последующего хранения трески и пик­ ши, хранившихся в течение 6 дней при температуре 32° по Фаренгейту до достижении на берег, увеличился бы с момента разгрузки с 6 до 12 дней.

Проведенные как в Англии, так и в других местах исследования показали, что пастериза­ция посредством облучения рыбного филе и других пищевых продуктов в упакованном виде, очевидно, будет иметь немаленький коммерческий успех. Исследования, касающиеся па­ тентовальных и вкусовых качеств, а также бактериологических опасностей, в частности, от Clostridium botulinum вида E, при производстве и сбыте таких упакованных продуктов, проводится в настоящее время и температурное положение с облучением таких продуктов с этой и других точек зрения подробно рассматривается в полном докладе.

ESTADO ACTUAL Y PERSPECTIVAS DE LA CONSERVACION DE PESCADO POR IRRADIACION. Hasta ahora todo parece indicar que para la inmensa mayorfa de las especies de peces y mariscos comestibles la radioesterilización es una solución poco práctica, puesto que produce cambios organolépticos indeseables, sobre todo en el sabor y en el aroma del producto condimentado. Muchos de esos alimentos (unas 30 especies de peces y crustáceos) pueden no obstante resistir dosis de pasteurización de 0,3 a 0,5 Mrad sin sufrir cambios organolépticos apreciables. Además, el período de conservación en buen estado de estos alimentos irradiados puede prolongarse en un 50 o un 100% a temperaturas de almacenamiento de 40 y 32°F, respectivamente. En efecto, el bacalao y el róbalo recién pescados, que se conservan en buen estado durante 9 y 12 días a 40 y 32°F, respectivamente, pueden llegar a conservarse hasta 14 y 24 días, a esas temperaturas si se someten a una irradiación de 0,3 Mrad. Para prolongar al máximo el período de almacenamiento, lo más indicado sería irradiar el pescado a bordo de los barcos pesqueros, pero esto supone enormes dificultades técnicas. La mayor parte de los pescados blancos, como el bacalao y el róbalo, no se descargan inmediatamente después de su captura, sino al cabo de períodos que pueden variar entre unas horas y el límite de comestibilidad, es decir, unos 17 días, en el caso del bacalao bien congelado, a 32°F en el momento de la descarga. En consecuencia, cuanto más tiempo haya permanecido almacenado en el barco pesquero, tanto menor será el tiempo en que el pescado se conservará en buen
estado una vez descargado. Admitiendo que el período de almacenamiento del bacalao y del róbalo de buena calidad sea de 9 y 12 días a 40 y 32°F, respectivamente; los experimentos demuestran que el tiempo de conservación en buen estado de estas especies, después de la descarga, puede prolongarse aproximadamente en un 50 y 100%, a 40 y 32°F. Es decir, una vez descargados, el bacalao y el róbalo almacenados a bordo durante 6 días a 32°F tendrían, si se irradiaran, un período de almacenamiento de 12 días en lugar de 6.

Los estudios realizados en Gran Bretaña y en otros países muestran que la radiopasteurización de filetes de pescado y de otros alimentos de origen marino empaquetados es el procedimiento que más probabrador ofrece de éxito comercial inmediato. Se están realizando estudios sobre compatibilidad y riesgos de tipo bacteriológico sobre todo los debidos al Cl. botulinum tipo E para la producción y comercialización de dichos artículos empaquetados. La memoria trata con detalle del estado actual de estos y otros aspectos de la irradiación.

INTRODUCTION

It was early recognized from laboratory experiments that many fish and fishery products were among the more successful of the foodstuffs that could be preserved by irradiation and it is not surprising, therefore, that much of the work designed at the ultimate commercial exploitation of this method of preservation should be concerned with fish and other sea foods. However, despite the large amount of work that has been done on irradiation preservation, no fish or fishery product is yet available commercially to the general consumer. Moreover, even a cursory glance at the various reports now available would indicate that future prospects of them ever being available range from genuine optimism to extreme pessimism.

In this paper the author surveys the acknowledged accomplishments of this alternative method of preservation, relates these to possible commercial uses, and compares any overall advantages with other more well-established preservation processes, such as icing and freezing.

RADIATION STERILIZATION

It was early recognized that complete sterilization of fish and fishery products, requiring doses of the order of 10^6 rad, so altered the products organoleptically that they would be quite unacceptable to the ordinary consumer [16]. However, if sterilization could be accomplished, either by the straight suppression of the undesirable chemical and other changes that occur, or by some combination process, such as the use of antibiotics, which would sensitize the more resistant spore-bearing microorganisms, and in particular Cl. botulinum, to irradiation, then the usefulness of the method would be considerably enhanced and it could then be a much more serious rival to other preservation methods than it is at present.

RADIATION PASTERURIZATION

Most of the work is now being carried out on radiation pasteurization. To date, results indicate that some 30 to 40 species of fish, including the commoner commercial species and other sea foods, can be successfully preserved by this method [12, 23, 28, 29, 30, 32]. For most species doses
beyond 0.3 to 0.5 Mrad produce discolouration and undesirable off-flavours, usually described as "burnt", or "burnt feather-like", so that the majority of workers employ pasteurizing levels at or just below these levels (Table I).

It seems to be generally agreed that with this order of irradiation the extension of shelf life at chill temperatures of most species is two to three times that of the controls [4, 12, 32, 36, 39] (Table II), although even greater extensions have been claimed. In many cases this has been adjudged as the point where the product becomes inedible. However, since the article has to compete, quality-wise, with products preserved by other methods, such as chilling and freezing, it seems logical that a higher level of quality, described as "a good acceptance level", should be the criterion used. In these circumstances, extensions of two to three times that of the non-irradiated control can be safely claimed. Using the same criterion, it can be claimed also that the shelf life extension of some shellfish products (Table II) is even greater than that of fish, and this is one area where exploitation of the method seems to be well worth while.

### Table I. Some Examples of Dose Levels for Unchanged Acceptability as Measured by Cooked Flavour (after Rhodes and others)

<table>
<thead>
<tr>
<th>Species</th>
<th>Irradiation dose (Mrd)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cod</td>
<td>0.5 -1.0</td>
</tr>
<tr>
<td>Haddock</td>
<td>0.6 -0.70</td>
</tr>
<tr>
<td>Sole</td>
<td>0.5</td>
</tr>
<tr>
<td>Flounder</td>
<td>0.75</td>
</tr>
<tr>
<td>Halibut</td>
<td>0.50</td>
</tr>
<tr>
<td>Whiting</td>
<td>0.23-0.25</td>
</tr>
<tr>
<td>Herring</td>
<td>0.5</td>
</tr>
<tr>
<td>Smoked cod</td>
<td>0.3</td>
</tr>
<tr>
<td>Smoked haddock</td>
<td>0.5</td>
</tr>
<tr>
<td>Salmon</td>
<td>&lt; 0.1</td>
</tr>
<tr>
<td>Smoked salmon</td>
<td>0.1</td>
</tr>
<tr>
<td>Crab meat</td>
<td>0.2</td>
</tr>
<tr>
<td>Raw shrimp</td>
<td>0.15</td>
</tr>
<tr>
<td>Cooked shrimp</td>
<td>0.15</td>
</tr>
</tbody>
</table>

### Possible Commercial Exploitation of Pasteurization

Having accepted the fact that shelf life, to a reasonable acceptance level, can be extended by two to three times at chill temperatures by radiation pasteurization, the questions to be answered are: how feasible is irradiation as a preservation process; and is it one which would compete both technologically and commercially with the more established processes, such as drying, salting, chilling, canning and freezing? The answer to some of these questions will depend to a large extent on the stage of development of some of the processes in the various countries.
TABLE II. SOME DATA ON STORAGE LIFE OF IRRADIATED PRODUCTS AT CHILL TEMPERATURES (from various sources)

<table>
<thead>
<tr>
<th>Species</th>
<th>Irradiation dose (Mrad)</th>
<th>Extension of storage life (days °F)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Haddock</td>
<td>0.75</td>
<td>39-49 36-40</td>
</tr>
<tr>
<td>Cod</td>
<td>0.25</td>
<td>45 32</td>
</tr>
<tr>
<td>Pacific cod</td>
<td>0.25</td>
<td>56 32</td>
</tr>
<tr>
<td>Pollack</td>
<td>0.25</td>
<td>21 35</td>
</tr>
<tr>
<td>Sole</td>
<td>0.25</td>
<td>35 35</td>
</tr>
<tr>
<td>Halibut</td>
<td>0.2</td>
<td>25 33</td>
</tr>
<tr>
<td>Lobster meat (boiled)</td>
<td>0.25</td>
<td>166 35</td>
</tr>
<tr>
<td>Blue crab (cooked)</td>
<td>0.75</td>
<td>90 35</td>
</tr>
<tr>
<td>Oysters (raw shucked)</td>
<td>0.0</td>
<td>90 35</td>
</tr>
<tr>
<td>King crab meat</td>
<td>0.2</td>
<td>23-28 33</td>
</tr>
<tr>
<td>Raw shrimp (shelled)</td>
<td>0.15</td>
<td>10-15 33</td>
</tr>
<tr>
<td>Shrimp (cooked)</td>
<td>0.15</td>
<td>10-15 33</td>
</tr>
<tr>
<td>Clams (soft shelled)</td>
<td>0.5</td>
<td>119 35</td>
</tr>
</tbody>
</table>

For example, in Britain, with its well-established cold chain, the economic advantages of changing over, even partially, to a new technique such as irradiation, might be less attractive than in a country like India. In the United Kingdom a major problem of the fishing industry is the increasing distances which many of the fishing vessels have to go to fish, with subsequent loss in quality by present-day preservation methods, such as icing, while in the United States the large distances from the port to the inland consumer cause major loss in quality. Among the advantages claimed for fish irradiation are the following [20, 21]: expansion of the marketing area; improvement in quality control; stabilization of the market; reduction in spoilage losses; facilitation in distribution; reduction of transportation and handling costs; and improvement in merchandizing methods.

All these advantages could be claimed equally for some of the other preservation methods: such as freezing, so that irradiation must have other advantages, economic or otherwise, if it is to be a successful competitor.

Many housewives insist on fresh fish for a variety of reasons. In the United Kingdom some of these are due to the poor quality of frozen fish that was often sold; but with greater knowledge of the frozen fish technology in the industry and, in particular, the insistence of good-quality fish before freezing, and proper low-temperature storage after freezing until sale, the quality of frozen fish now available is steadily improving. Even so some consumers prefer fresh fish. It is more convenient, requires no defrosting and is more versatile for cooking. In areas where refrigeration is not available, and salted or canned fish are the only alternatives, a steady supply of fresh fish would be a welcome addition to the diet. Therefore, it might be profitable to examine in some detail the possible
advantages of irradiation to the fish industry in, for example, the United Kingdom, since many of the conclusions likely to be drawn would be relevant to several other countries.

PATTERN OF THE FISHING INDUSTRY IN THE UNITED KINGDOM

(a) Production

Before 1960 the bulk of the fish caught by fishing vessels was iced at sea. For the last five years the total quantity of fish landed in the United Kingdom has amounted to approximately 800,000 tons (Table III). Of this, about half comes from the near, middle and inshore fishing grounds; the remainder from distant waters. The latter involves the vessel in anything from 5 to 7 days' journey from the home port, with 10 days on the fishing grounds and a further 5 to 7 days on the homeward journey. In other words, each fishing trip requires from 20 to 23 days, the average trip now being about 21 days. It is well known that ice, the main means of preservation on board ship, even when used to best advantage, can keep fish (like cod and haddock, the main species caught on these distant water grounds) really fresh for about 5 to 7 days, and in a reasonably fresh condition for a further 5 to 6 days, after which they rapidly deteriorate; by the 17th day of storage they are so poor that they are usually condemned by the Public Health inspectors at the market [35].

Various methods have been tried to extend the usefulness of ice, and the introduction of antibiotic ice into the major distant water ports is said to be responsible for the considerable decline, over the past three or four years, in the amount of condemned fish [17]. Super-chilling, by which the fish are kept at just below the freezing temperature (-1.2°C for cod and haddock) is not yet in commercial use in the United Kingdom. It has definite possibilities, however, in extending the usefulness of ice storage which are now being investigated [24]. Even so, it was recognized by many in the industry that better alternatives would have to be found if the distant-water fishing was to continue to be economically reliable. The obvious method was to freeze the catch at sea and, as early as 1954, at least one factory-type ship, the "Fairtry I" was successfully operating this method. Two sister ships joined "Fairtry I" in 1959 and 1960.

In the trawler, "Lord Nelson", which came into operation in 1961, the first part of the catch was frozen at sea, the remainder being iced in the conventional manner. The number of freezer trawlers has steadily increased since then, so that during 1966-67, 30 such vessels should be operating in the distant-water fishing grounds. In 1965 approximately 1.0% of the distant-water landings in the United Kingdom were frozen at sea and undoubtedly this percentage will increase substantially over the next decade or so (Table IV). Irradiation could also presumably effectively extend the storage life of the first caught fish and in this connection the results of the United States experiments with the irradiator on board the fishing vessel are awaited with much interest [22].

(b) Treatment on-shore and distribution

The catch from the conventional icing trawler is normally auctioned on the market, and after further processing, such as filleting, by the port
### TABLE III. SEA-FISH PRODUCTION IN THE UNITED KINGDOM
Landings of fish for the past four years (tons)

<table>
<thead>
<tr>
<th></th>
<th>1961</th>
<th>1962</th>
<th>1963</th>
<th>1964</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>BRITISH CAUGHT</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Distant-water vessels</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>England and Wales</td>
<td>348,983</td>
<td>388,333</td>
<td>355,929</td>
<td>324,489</td>
</tr>
<tr>
<td>Scotland</td>
<td>10,517</td>
<td>11,068</td>
<td>9,605</td>
<td>11,897</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>359,500</td>
<td>399,401</td>
<td>365,584</td>
<td>336,386</td>
</tr>
<tr>
<td>Near and middle waters</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>England and Wales</td>
<td>105,605</td>
<td>93,056</td>
<td>104,457</td>
<td>113,982</td>
</tr>
<tr>
<td>Scotland</td>
<td>94,346</td>
<td>92,446</td>
<td>100,521</td>
<td>112,442</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>199,951</td>
<td>185,502</td>
<td>204,978</td>
<td>226,424</td>
</tr>
<tr>
<td>Inshore vessels</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>England and Wales</td>
<td>25,878</td>
<td>29,268</td>
<td>27,451</td>
<td>41,699</td>
</tr>
<tr>
<td>Scotland</td>
<td>67,732</td>
<td>76,471</td>
<td>104,515</td>
<td>108,563</td>
</tr>
<tr>
<td>Northern Ireland</td>
<td>5,632</td>
<td>5,655</td>
<td>3,477</td>
<td>6,153</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>97,242</td>
<td>111,394</td>
<td>135,443</td>
<td>156,405</td>
</tr>
<tr>
<td><strong>Total British landings</strong></td>
<td>656,693</td>
<td>696,297</td>
<td>706,005</td>
<td>719,215</td>
</tr>
<tr>
<td><strong>Total foreign landings</strong></td>
<td>123,329</td>
<td>108,783</td>
<td>104,492</td>
<td>121,912</td>
</tr>
<tr>
<td><strong>Grand total</strong></td>
<td>780,022</td>
<td>805,080</td>
<td>810,497</td>
<td>841,127</td>
</tr>
</tbody>
</table>

### TABLE IV. LANDINGS OF ROUND FISH FROZEN AT SEA AT TWO MAIN ENGLISH PORTS

<table>
<thead>
<tr>
<th>Year</th>
<th>Landings of fish (tons)</th>
<th>Percentage of total British landings</th>
</tr>
</thead>
<tbody>
<tr>
<td>1961</td>
<td>522</td>
<td>0.08</td>
</tr>
<tr>
<td>1962</td>
<td>2271</td>
<td>0.3</td>
</tr>
<tr>
<td>1963</td>
<td>4219</td>
<td>0.6</td>
</tr>
<tr>
<td>1964</td>
<td>6401</td>
<td>0.8</td>
</tr>
<tr>
<td>1965</td>
<td>16,082</td>
<td>a)</td>
</tr>
</tbody>
</table>

a) **Total figure for British landings not yet available.**

wholesaler, reaches the inland distributor the next day, if sold as fresh fish, and should be in the housewife’s shopping basket either that morning or at the latest the following morning. Surveys of the distribution chain in the United Kingdom have shown, however, that serious losses in quality, mainly due to high temperatures,
were occurring from the moment of discharge from the fishing vessel until sold over the counter. [6]. Calculations from the known rates of deterioration of fish at the mean temperatures suffered by fish during distribution showed that the best quality fish on landing from the distant waters (say five days in ice under the best conditions) instead of losing only one and a half days' quality, would have suffered a loss of four to five days, and that fish of just borderline quality, yet passed by the Public Health inspector, would have become inedible.

There is no doubt that quite a large proportion of the distant-water fish suffers considerable loss in quality through this distribution chain. Moreover, there is an additional hazard. Merchants, both wholesalers and retailers, frequently "over-buy", particularly when supplies are plentiful and prices cheap. These supplies are iced back often for days before being either dispatched to the inland markets or sold to the consumer. Although precise details of these holding times are lacking in the United Kingdom, it might be relevant in this connection to quote here the extensions in shelf life that various sections in the fishing industry in the United States would like to see for their products [21]

<table>
<thead>
<tr>
<th></th>
<th>(days)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Producers</td>
<td>20-30</td>
</tr>
<tr>
<td>Processors</td>
<td>7-30</td>
</tr>
<tr>
<td>Distributors</td>
<td>10-30</td>
</tr>
<tr>
<td>Retailers</td>
<td>1-30</td>
</tr>
</tbody>
</table>

If their British counterparts are icing back for even a fraction of these desired times, then again considerable losses in quality must be suffered by the fish before it is finally sold to the consumer. These losses in quality, both during normal distribution and in icing back, could be prevented by a method such as radiation pasteurization, and it is in this area of the fishing industry where, combined with packaging (see below), it could be most effective at present. Some of the likely extensions of shelf life in relation to the age of fish on ice, and subsequent temperatures of storage, are given in Figs. 1 and 2. With inshore, near and middle-water fish, the need is not likely to be so obvious, except when temperature conditions are high during distribution or icing back is practised for long periods.

Regarding fish frozen-at-sea, data on subsequent distribution are much less complete. It is understood that about 50% of the landings of frozen fish are defrosted and go through normal distribution channels, being sold by the fishmonger as "fresh sea-frozen fish".

There is another area in the British fish industry where irradiated preservation might play a part, in retail marketing. This, like the preservation of distant-water fish, has also been undergoing a revolution, with the advent of the supermarket and the gradual disappearance of the small shop, including the fishmonger. Some believe that the recent introduction of the poll tax in the United Kingdom will accelerate these changes. It is a fact that one of the few commodities lacking in most supermarkets is fresh fish, although frozen fish products, such as "fish sticks" are normally available. It is precisely in this fresh fish area that irradiation pasteurization might well play a part. The following is envisaged: Blocks of frozen, whole, gutted fish, such as cod, held as they
Now are in cold stores at the fishing ports, would be defrosted, filleted, cut into suitable consumer sizes, packaged, irradiated and kept in buffer stores, until dispatched to the supermarket. The temperature of the fish during irradiation, in the buffer stores, in transport and in the supermarket would never be allowed to rise above 3°C.
Packaging

Packaging itself offers several advantages [38, 40]. It protects the contents against outside contamination; the shopper is able to handle, select for weight, size, species and price, and to put it into the shopping bag along with other commodities, such as bread, vegetables and cereals, without the risk of contamination. If required, packaging can provide advertising space and more important perhaps, allows for brand identification of the product. If properly done, packaged fish can attract the buyer and promote sales. The type of package is, of course, of prime importance. It must be mechanically strong, must not impart any odour or flavour to the fish, either with or without irradiation, and be inert towards the oil and other constituents of the fish. It should not increase the rate of spoilage of the fish.

Work at the Torry Research Station on the effects of different types of packaging, including vacuum packing, on the storage characteristics of wet fish (cod, haddock and sole fillets) and smoked cod and haddock stored at 0°C to 4°C, has shown that shelf life, assessed by sensory, chemical and bacterial methods, is very much dependent on the type of film used. In general, the less permeable the film to gases such as O₂ and CO₂, the longer the shelf life. At 0°C these differences are not very evident until about the fifth day after packing, after which the better quality of the fish in the more impermeable packs becomes quite obvious. The impermeable films are quickly depleted of O₂ and build up CO₂ until it amounts to 60% of the free space, and this may account in some measure for the increased storage life.

An undesirable feature which detracts considerably from the sales appeal of packaged fillets is the "drip" which exudes from the cut surfaces and which accumulates in the package. This can be prevented by the use of polyphosphate dips, e.g. a 30-sec dip in 14% tripolyphosphate solution, and then drained for a further 30 sec [27], although it has been stated that some consumers can detect polyphosphate-treated fish by the bitter flavour.

(d) The Clostridium botulinum Type E hazard

A more important hazard is a microbiological one, viz. the possibility of food poisoning mainly from Cl. botulinum Type E. Although Cl. botulinum Type E has been associated for some time with food-poisoning outbreaks involving fish and fish products [13, 14, 19, 20, 37], it was only when several cases occurred with so-called vacuum-packed, hot, smoked fish from the Great Lakes area in the United States [14] that much attention was paid to this hazard. Ecological surveys in various parts of the world have shown that Cl. botulinum Type E is present in the fish and in the muds off the coast of Canada [13], the United States, in the Great Lakes [14], in the Baltic [19] and off the coast of Norway [7]. Some of the species of fish incriminated in Cl. botulinum poisoning are shown in Table V. Recently it has been recorded in herring landed in Great Britain, although its presence has yet to be recorded either in the fish or sea muds, taken from waters fished by British vessels [11]. Nevertheless, it is a hazard that has to be taken into account, more particularly when dealing with fish in impermeable packs, where anaerobic conditions could soon
TABLE V. SOME FISH KNOWN TO SUPPORT GROWTH AND TOXIN PRODUCTION OF CLOSTRIDIUM BOTULINUM TYPE E

<table>
<thead>
<tr>
<th>Marine sources</th>
<th></th>
<th>Fresh-water sources</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Fresh</td>
<td>Processed</td>
<td>Fresh</td>
</tr>
<tr>
<td>Herring</td>
<td>b)</td>
<td>Herring b)</td>
<td>Trout b)</td>
</tr>
<tr>
<td>Sebastes</td>
<td></td>
<td>Haddock</td>
<td>Chub</td>
</tr>
<tr>
<td>Cod</td>
<td></td>
<td>Kipper</td>
<td>Perch</td>
</tr>
<tr>
<td>Plaice</td>
<td></td>
<td>Sprats a) b)</td>
<td>Carp b)</td>
</tr>
<tr>
<td>Halibut</td>
<td>a) b)</td>
<td>Tuna</td>
<td></td>
</tr>
<tr>
<td>Scallops</td>
<td>b)</td>
<td>Sea bass</td>
<td></td>
</tr>
<tr>
<td>Plaice</td>
<td></td>
<td>Sole b)</td>
<td></td>
</tr>
<tr>
<td>Sebastes</td>
<td></td>
<td>Mackrel b)</td>
<td></td>
</tr>
<tr>
<td>Cod</td>
<td></td>
<td>Sardine b)</td>
<td></td>
</tr>
</tbody>
</table>

a) Commercial product
b) Responsible for outbreak of botulism

come established. Cl. botulinum Type E, like other Clostridium spp., forms a spore which is radiation resistant. Unlike other types of Clostridium this organism has the property of growing and producing toxin at chill temperatures (see below), although like the others, its toxin once formed is easily destroyed in cooking. So far as packaged fish is concerned, it is important to know the effect of a variety of factors on the development of the toxin of Cl. botulinum Type E. These include the species of fish, the time and temperature of storage, the use of polyphosphate 'dip', the initial level of quality either with or without irradiation, the level of Cl. botulinum contamination and finally irradiation itself. Work is at present being actively carried out on some of these problems at Torry Research Station and the results to date [7-11] may be briefly summarized as follows:

Time and temperature relationship of toxin production with Cl. botulinum Type E in some fish and fishery products

The results show that most of the more common, commercial species of fish (cod, haddock, plaice, halibut, herring, salmon) allow growth and toxin production of Cl. botulinum Type E, at temperatures of 5°C and above. Some typical results are shown in Table VI. Herring in particular seem to be a very botulinogen species. It is not yet known why this should be so; it may be associated with the extractives or lipid content, but it is more likely that it is with the 'eh' value of the flesh.

1 Oxidation reduction potential.
<table>
<thead>
<tr>
<th>Species</th>
<th>Days to toxin production</th>
<th>Maximum recorded titre MLD/g (^a) (days)</th>
<th>Days to toxin production</th>
<th>Maximum recorded titre MLD/g (^a) (days)</th>
<th>Days to toxin production</th>
<th>Maximum recorded titre MLD/g (^a) (days)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>(Stored at 20° C)</td>
<td></td>
<td>(Stored at 10° C)</td>
<td></td>
<td>(Stored at 5° C)</td>
<td></td>
</tr>
</tbody>
</table>

\(^a\) MLD is the maximum lethal dose.
The lowest temperature at which toxin production has been found in the experiments was 3.3°C, with herring inoculated with 10^6 spores/100 g of flesh, low transient titres being detected after 21 days. This supports some earlier data of Schmidt et al. [34] with broth cultures, and of others [3].

On the other hand, at 30°C, packs could become toxic within a matter of hours. Theoretically, therefore, packaged fish, particularly herring, should never be stored at temperatures above 3°C. In practice, however, it is envisaged that the total time of distribution from the packaging line to the consumer should not exceed seven days. The natural level of Cl. botulinum Type E infection is never likely to be as high as in the experiments quoted, probably nearer 1/100 g than 10 000/100 g, so that the rate of toxin development would also be much slower. Accordingly, there seems to be little real danger from storage at chill temperatures in the region of 4°C:

Also, the original quality of the fish, and hence the bacterial flora, are likely to have some effect on the growth and toxin production of Cl. botulinum, but at present the magnitude of this effect is largely unknown.

(e) Effect of irradiation on the Cl. botulinum Type E hazard

The effect of irradiation on growth and toxin production in several species of packaged fish is still being investigated, but the results to date may be summarized as follows. Toxin production, as might be expected, is largely dependent on the species of fish and the level of the spore inoculum used. With herring there seems to be little doubt that more toxin is produced, and about twice as fast, in the irradiated than unirradiated samples. In cod there appears to be little difference in the rate of production, although again titres were generally higher, more particularly after trypsination in the irradiated samples. With haddock, on the other hand, the toxin produced was less in the irradiated than in the unirradiated packs (Fig. 3). Other subsidiary experiments, with herring only, which, together with the main ones, gave all the combinations of irradiation and non-irradiation, using one level of spore inoculation (10^4/100 g), showed that there were two quite separate effects: irradiation of spores tended to depress their toxin-forming ability; and the irradiation of fish tended to increase the amount of toxin formed; with herring, at least, (b) was more important than (a) [10].

Theoretically, this would seem to indicate that irradiation might seem to enhance the botulinum hazard, at least with some species of fish. It has to be remembered, however, that as mentioned above the natural level of infection is likely to be much lower, nearer one spore per 100 g of fish, than the lowest inoculum used in these experiments, viz. 100 spores per 100 g of fish, and that consequently the time required to produce detectable amounts of toxin would be much increased. Moreover, if the temperature is never allowed to rise above 3-4°C, the increased hazard from irradiation is not likely to be of practical significance. Results also indicate that the polyphosphate dip used to prevent 'drip' in the package has little or no effect on toxin production either with or without irradiation. However, the property of the polyphosphate dip in
preventing 'drip' formation is somewhat impaired, but not sufficiently so to detract from its usefulness in this connection.

Finally, it should be stated that most of the packaged fish products being discussed here would be cooked after purchase and although data on the time-temperature relationship for the destruction of Cl. botulinum Type E toxin are few, our results seem to indicate that the time normally specified for the "boil in the bag" type of products, such as kippers and smoked haddock (12 min in boiling water) is sufficient to destroy any toxin present. The main hazard is likely to come from packs such as smoked salmon, or kippers used as savoury ingredients when both are eaten without further cooking. Smoked salmon is never likely to be irradiated, owing to the loss of pigment that occurs, and which severely detracts from its sales appeal.

If irradiation pasteurization of fish and fish products is to become a reality, it could come with the use of packaged fish, prepared from either iced or defrosted frozen fish. It is envisaged that the irradiation plant would have to be sited at a major fishing port (as say Hull or Grimsby in the United Kingdom) where buffer stores for the fish before and after irradiation, and a steady supply of fish, are likely to be readily available. After irradiation, the packaged fish would have to be trans-
ported in insulated containers capable of maintaining the products at adequate temperatures during distribution either to the supermarket or other stores.

It has been estimated that a plant irradiating approximately 2000 tons of fish a year at 0.3 Mrad, 24 h a day, 7 days a week, 50 weeks a year would add about \( \frac{3}{4} \) d/lb to the cost of the packaged article and this would include buildings, plant, overheads, depreciation, etc. At 8000 tons the cost would be less than \( \frac{1}{2} \) d/lb [31]. It seems likely that at Hull and Grimsby both these quantities of fish could be readily available for irradiation.

Fish meal

Another area in which it seems possible that irradiation might play a useful role in the fishing industry is in the decontamination, particularly from Salmonellae, of imported fish meal. Fairly extensive studies of the bacteriology of fish meal production in the United Kingdom, in which a variety of processes are used, almost invariably failed to find Salmonellae [5]. On the other hand, imported fish meals regularly show varying levels of contamination, up to \( 10^8 \)/g [1, 2, 18, 25] (Table VII) and some outbreaks of food poisoning have been traced to cattle fed on such contaminated meals [15, 33]. Many imported meals are produced by sun drying, where contamination from birds, etc. can hardly be avoided, and in others the hygiene of the process was unsatisfactory. Recently, considerable improvement has taken place in the production-hygiene of fish meal plants of some of the exporting countries, where contamination often occurred after manufacture. The most extensive studies on the use of irradiation for the decontamination of fish meal have been made by Dutch workers [26]. They recommend that 0.5 Mrad would be a safe dose for fish meal and would cause no loss in the nutritive value of the protein. This method has been adjudged to be one of the simplest and most promising for tackling this serious problem, although the pelleting method described in these Proceedings by Mossel and Kampelmacher appears simpler and just as effective.

CONCLUSIONS

There can be little doubt that irradiation is a most helpful addition to the battery of methods for preserving foodstuffs. It has the advantage, unlike its competitors, such as drying, salting, canning and even freezing, of retaining the properties of the fresh product, including wholesomeness. The fact, however, that to my knowledge no irradiated fish product is yet commercially available anywhere in the world would seem to indicate that any advantages the method appears to have are not overwhelmingly significant. In countries such as Britain where the cold chain from catching to consumption is already well established, or is becoming rapidly so, its main rival will be frozen fish products, and it will have to possess other advantages than quality, such as convenience or cheapness, for it to become a real competitor. Even so, there are certain areas even in Britain where it might play a part in the future, for example in the marketing of packaged unfrozen fish and fish products in the super-
<table>
<thead>
<tr>
<th>Author</th>
<th>Material examined</th>
<th>Samples examined (No.)</th>
<th>Positive a) (No.)</th>
<th>Percentage of total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Anon.[1]</td>
<td>Imported fish meal</td>
<td>315</td>
<td>47</td>
<td>14.9</td>
</tr>
<tr>
<td>Anon.[2]</td>
<td>Imported fish meal</td>
<td>260</td>
<td>16</td>
<td>6.2</td>
</tr>
<tr>
<td></td>
<td>Imported herring meal</td>
<td>166</td>
<td>1</td>
<td>0.6</td>
</tr>
<tr>
<td>Rohde and Bischoff [33]</td>
<td>Imported fish meal</td>
<td>270</td>
<td>43</td>
<td>15.6</td>
</tr>
<tr>
<td>Bain and Shewan</td>
<td>British fish meal</td>
<td>180</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

a) About 50 serological types of Salmonella have now been found in imported fish meals (see Mon. Bull. Min. Hlth and Publ. Hlth Lab. Serv., HMSO, Lond. 24 (1965) 164).
markets. In other countries where the cold chain operates less effectively or not at all, irradiation might well become an important method of preserving fish and fish products of all kinds.

A most likely practical application seems to be the decontamination of imported fish meals.

There are other circumstances, such as in defence needs, where convenience and suitability are more important than costs, in which the irradiation of a variety of fish and fish products might well solve some rather intractable messing problems.

It is possible that irradiation would become a more practical proposition if some means could be evolved of eliminating the microbiological hazards completely, and so producing a sterile or near-sterile pack, while at the same time retaining the natural organoleptic properties of the fresh product; it seems that future success of the method lies in this direction.

REFERENCES


DISCUSSION

D. MASSA: I agree with you and Dr. Slavin that the initial bacteriological count of the fish samples before irradiation is an important factor in obtaining a better product from the bacteriological and chemical point of view. This is confirmed by experiments carried out in Italy on radiopasteurized (0.3 Mrad) cod having different bacteriological counts. What were the initial bacteriological counts in your experiments?

J.W. SHEWAN: They were of the order of $10^4$–$10^6$ organisms per gramme.

R.O. SINNHUBER: Can you offer an explanation for your statement that toxin development from *Clostridium botulinum* was more rapid in herring than cod?

J.W. SHEWAN: No, we cannot. We thought it might be due to differences in the nature and amounts of the extractives in the herring as compared with the cod, but experiment has shown that this is not so. It might be due to the high lipid content of herring or to a difference in the oxidation-reduction potential, which we believe to be lower in the herring.
STATUS OF RESEARCH AND DEVELOPMENTAL STUDIES ON RADIATION PASTEURIZATION OF FISH AND SHELLFISH IN THE UNITED STATES

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Abstract — Résumé — Аннотация — Resumen

STATUS OF RESEARCH AND DEVELOPMENTAL STUDIES ON RADIATION PASTEURIZATION OF FISH AND SHELLFISH IN THE UNITED STATES. This paper reviews the status of research on radiation-pasteurization of fish and shellfish in the United States and describes plans for commercialization of the process.

The authors discuss: (a) laboratory studies at universities and governmental research institutions on quality and microbiological aspects of irradiated sea food; (b) developmental investigations on irradiating fish ashore and at sea; and (c) United States clearance of radiation-pasteurized sea food and use of the process in the fishing industry.

Quality studies indicate that irradiation with cobalt-60 at levels of 150,000 to 450,000 rad can at least double the refrigerated shelf life of 16 species of fish and shellfish, which include the major species marketed as fresh or frozen in the United States. Storage temperature, quality of raw material, and dose level significantly affect product quality and shelf life; packaging is of less significance.

Synergistic systems, using bactericidal salts or heat, in conjunction with radiation, effectively destroy bacteria and offer promise in reducing radiation levels and extending product shelf life over that when radiation is used alone. Irradiation at very low levels significantly changes the microbial flora of fish fillets, but interestingly enough this change is no greater than that which occurs when storing the product in an anaerobic environment. In discussing microbiological changes in irradiated and non-irradiated fish, the authors point out that treated fish fillets are as safe and wholesome as the non-treated fish. Work on safety aspects of irradiated fish fillets is discussed in detail.

Developmental studies received emphasis with construction and operation of a 250,000 Ci cobalt-60 fish-processing facility at Gloucester, Mass. Tests on packaging and shipping irradiated products under simulated commercial conditions show that pasteurized fish can be handled in the same manner as fresh fish, with a resultant doubling of shelf life for the former. In co-operation with private and governmental organizations, irradiated sea foods have been shipped across the United States in commercial carriers and evaluated for quality. Results are very encouraging and indicate that the process would be extremely valuable to industry.

Irradiation of fish at sea shows promise as a means of increasing the landings of fresh fish. Preliminary findings indicate that it may be feasible to irradiate eviscerated groundfish at sea with levels less than 100,000 rad and then re-irradiate the fish ashore after filleting and packaging.

ETAT DES ETUDES ET DES REALISATIONS EN MATIERE DE RADIOPASTEURISATION DES POISSONS, CRUSTACES ET MOLLUSQUES AUX ETATS-UNIS. Le mémoire donne un aperçu des recherches sur la radiopasteurisation des poissons, crustacés et mollusques aux Etats-Unis et expose les plans de commercialisation de ce procédé.

Les auteurs examinent: a) les études de laboratoire dans les universités et les instituts de recherche de l'Etat sur la qualité et les aspects microbiologiques des produits marins irradiés; b) les essais d'irradiation des poissons à terre et en mer; c) l'autorisation officielle, aux Etats-Unis, de la vente des produits de la mer radiopasteurisés et de l'utilisation de ce procédé par l'industrie de la pêche.

Les études sur la qualité des produits indiquent que l'irradiation avec du cobalt-60 à des doses de 150,000 à 450,000 rad permet au moins de doubler la durée de conservation sous réfrigération de 16 espèces de poissons et de crustacés ou mollusques, dont les principales espèces vendues aux Etats-Unis à l'état frais ou congelé. La température d'emmagasinage, la qualité de la matière première et la dose...
Les effets synergie-tiques obtenus par l'emploi de sels bactéricides ou de la chaleur en combinaison avec les rayonnements détruisent efficacement les bactéries et permettront sans aucun doute de réduire les doses de rayonnements et d'assurer une conservation plus longue qu'après un traitement uniquement par irradiation. L'irradiation à faibles doses modifie sensiblement la flore microbienne des filets de poisson; il est cependant intéressant de constater que cette modification n'est pas plus considérable que celle qui intervient lorsque le produit est conservé en milieu anaérobie. En examinant les changements microbiologiques qui se produisent dans le poisson irradié et non irradié, les auteurs font ressortir que les filets de poisson traités ont la même innocuité et la même comestibilité que le poisson non traité. Le mémoire examine en détail les études portant sur l'innocuité des filets de poisson irradiés.

Dans le domaine des réalisations, une importance particulière doit être accordée à la construction et à l'exploitation, à Gloucester (Mass.), d'une usine de traitement de poisson utilisant une source de cobalt-60 de 250 000 Ci. Les essais de conditionnement et d'expédition des produits irradiés dans des conditions commerciales simulées indiquent que le poisson pasteurisé peut être manipulé de la même façon que le poisson frais et que sa durée de conservation est doublée. Avec le concours de plusieurs organismes privés et d'État, des produits marins irradiés ont été expédiés à travers les États-Unis par les moyens de transports normaux, et leur qualité a été évaluée. Les résultats sont très encourageants et indiquent que le procédé présenterait un très grand intérêt pour l'industrie.

Il semble que l'irradiation du poisson en mer permettra de débarquer de plus grandes quantités de poisson frais. Des constatations préliminaires indiquent qu'il sera sans doute possible d'irradiator en mer des poissons de fond vivant, à des doses inférieures à 100 000 rad, et de procéder ensuite, à terre, à une nouvelle irradiation des filets conditionnés pour la vente.

COSTÓJÉNJE NAUKO-BISSEOCHAL'SKICH RABOT PO RADIIÀCJOJII PASTÉTizAÇIÌ RYB I KRAPOB V SOEJDNNYH SHTAAX. V dokoade deyets' obzor sostojeniya naukowych issledovanii po radiacionnoj pasteryazii ryb i krapov v Soedinennyh Shtaax i pryvodyaets' plany pervoznya danogo processa na kommercheskuju osnovu.

Avtory izlagaet': 1) laaboratornye issledovanii v universitetax i gosudarstvennyh naukowych-issechiostax, po kachestvennym i mikrobiologicheskim aspektam oblochenyh semyodnymy produktam morya, 2) issledovательскиe raboty po oblochenii ryby na beregu i v mere i 3) kontrol' so strony amerikanskich vlastey za radiacionno pasternizovannymi semyodnymi produktami morya i ispol'zovanie danogo processa v rybolovnoj promyshlennosti.

Kachestvennye issledovanie pokazывают, что облучение кобальтом-60 при 150 000 – 450 000 рад может по меньшей мере удвоить срок хранения в замороженном виде 16 видов рыбы, крабов и устриц, которые относятся к основным видам рыбных продуктов, продаваемых в свежем или замороженном виде в Соединенных Штатах. Температура хранения, качество сырья и уровень дозы значительно влияют на качество продукта и сроки хранения; упаковка имеет существенное значение.

Синергетические системы с использованием бактерицидных солей или нагрева в связи с излучением эффективно уничтожают бактерии и свидетельствуют о возможности сокращения радиационных уровней и увеличения сроков хранения продуктов по сравнению со сроками, когда применяется лишь излучение. Облучение на очень низких уровнях значительно изменяет микробную флору рыбного филе, но интересно, что это изменение больше изменения, которое имеет место при хранении продуктов в анаэробной окружающей среде. Обсуждая микробиологические изменения в облученной и необлученной рыбь, авторы отмечают, что обработанные рыбные филе являются такими же безопасными и съедобными, как и необработанный виде. В докладе подробно обсуждаются работы по аспектам безопасности облученных рыбных филе.

Проведение исследовательских работ активизировалось после сооружения и пуска в эксплуатацию установки по обработке рыбы с помощью кобальта-60 мощностью в 250 000 кюри в Глостере, Массачусетс. Испытания по упаковке и перевозке облученных продуктов в искусственных коммерческих условиях показывают, что с пастеризованной рыбой можно обращаться так же, как и со свежей рыбой, причем срок хранения пастеризованной рыбы в два раза выше. В сотрудничестве с частными и государственными организациями облученные съедобные продукты моря перевозились по территории Соединенных Штатов в коммерческих контейнерах и проводилась оценка на качество. Результаты — весьма обнадеживающие и свидетельствуют о том, что данный процесс будет иметь чрезвычайно ценное значение для промышленности.

Облучение рыбы в море говорит о перспективе использования этого метода в качестве средства увеличения срока хранения выловленной свежей рыбы. Предварительные результаты указывают на то, что, возможно, практически осуществимо облучение потрошеной глубо-
ESTADO DE LAS INVESTIGACIONES Y ESTUDIOS EXPERIMENTALES SOBRE LA RADIOPASTEURIZACIÓN DE PESCADOS Y MARISCOS EN LOS ESTADOS UNIDOS. En la memoria se examina el estado de las investigaciones sobre radiopasteurización de pescados y mariscos en los Estados Unidos y se exponen los planes para la comercialización de este proceso.

Los autores tratan a) de los estudios de laboratorio realizados en institutos universitarios y gubernamentales de investigación sobre la calidad y los aspectos microbiológicos de los alimentos irradiados de origen marino, b) de las experiencias sobre irradiación de pescado en tierra y en el mar, c) de la autorización en los Estados Unidos de la radiopasteurización de pescados y mariscos, y de la aplicación de ése proceso en la industria pesquera.

Los estudios sobre calidad indican que la irradiación con cobalto-60 en dosis de 150 a 450 krad puede ampliar al doble, por lo menos, el período de almacenamiento de frigoríficos de 16 especies de peces y mariscos, que comprenden las principales variedades en venta (pescado fresco o congelado) en los Estados Unidos. La temperatura de almacenamiento, la calidad del pescado y la dosis de irradiación influyen apreciablemente en la calidad del producto y en el período de almacenamiento; el envase tiene menor importancia.

Los sistemas combinados, que emplean sales o tratamientos térmicos bactericidas, además de las radiaciones, destruyen eficazmente las bacterias, permiten reducir las dosis de radiaciones y prolongar más el período de almacenamiento que cuando sólo se utilizan radiaciones. La irradiación en dosis muy bajas aparece desfavorablemente la flora microbiana de los filetes de pescado, pero cabe señalar que esta alteración no es mayor que la que se produce cuando el producto se almacena en ambiente anaerobio. Al tratar de los cambios microbiológicos en el pescado irradiado y no irradiado, los autores indican que los filetes de pescado tratado poseen las mismas condiciones de seguridad y comestibilidad que los de pescado no tratado. En la memoria se examinan en detalle los trabajos relativos a los problemas de seguridad que suscitan los filetes de pescado irradiado.

Los estudios experimentales han cobrado impulso con la construcción y puesta en servicio en Gloucester (Massachusetts) de una instalación de irradiación de pescado con 60Co, de 250 000 Ci. Los ensayos de envase y transporte de productos irradiados en condiciones comerciales simuladas muestran que el pescado pasteurizado puede manipularse de la misma manera que el pescado fresco, pero el período de almacenamiento del primero es dos veces mayor que el del segundo. En cooperación con entidades particulares y oficiales, se han expedido a diversos puntos de los Estados Unidos, en vehículos comerciales, pescados y mariscos irradiados y se ha estudiado su calidad. Los resultados son muy alentadores e indican que este proceso sería sumamente útil para la industria.

La irradiación de pescado en el mar permitirá desembarcar mayores cantidades de pescado fresco. Los resultados iniciales indican que quizá sea posible irradiar en el mar el pescado (una vez extraídas las vísceras) en dosis inferiores a 100 krad, y volverlo a irradiar en tierra una vez cortado en filetes y envasado.

I. INTRODUCTION

The United States Atomic Energy Commission's programme on radiopasteurization of fish and shellfish formally began in 1960 with a feasibility study by Proctor et al. [1], followed by specific outlines of project proposals dealing with wholesomeness, quality, and economics by Nickerson et al. [2].

The Proceedings of the International Conference on Radiation Preservation of Foods [3] and the report of the United States Congressional Subcommittee on Atomic Energy [4] provide a comprehensive review of progress in the United States food irradiation programme, including sea foods, up to June 1965. Recently, these reports were supplemented by other reviews on the radiation pasteurization of fish and shellfish [5, 6, 7].

Since these are rather complete reviews, the discussions in this paper are limited to an evaluation of technical progress and development toward the commercialization of radiation-pasteurized sea foods.
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u) Shelf life: That point at which the product is considered unmarketable.
y) Total plate count.
x) Optimum dose is the dose which provides a significant shelf life extension without altering product acceptability.
v) Trimethylamine nitrogen.
S: US Bureau of Commercial Fisheries Technological Laboratory, Seattle, Wash.
L: Louisiana State University, Baton Rouge, La.
O: Oregon State University, Corvallis, Oreg.
II. QUALITY CONSIDERATIONS

A summary of recent data on 19 radiation-pasteurized fish and shellfish is contained in Table I. Although the literature is replete with information attesting to the effectiveness of low levels of gamma radiation for the preservation of sea food, only limited data are available to permit a penetrating analysis of the factors that influence the quality and shelf life of the product. In this section, quality changes in irradiated fish and shellfish are discussed, and an attempt is made to analyse some of the factors affecting quality.

Quality changes in radiation-pasteurized fish

Information presented in Table II shows that the microbial flora of certain species of fish and shellfish is influenced by the radiation level, processing method, packaging, and temperature of storage. When aerobically-packed dover sole fillets were subjected to doses of 0.1 to 0.3 Mrad and stored at 43°F, pseudomonad species were eliminated and achromobacter species predominated at spoilage [8]. According to other researchers [9-12], pseudomonads grew back in irradiated haddock and flounder fillets held at 33-43°F. The spoilage flora of aerobically-packed irradiated dover sole consisted of achromobacter and yeasts, whereas the vacuum-packed irradiated samples contained mainly lactic acid bacteria [12]. Interestingly enough, radiation-induced changes in microbial flora of clam meats were different from those in haddock fillets [11]. Changes in microbial flora as a result of irradiation are no more spectacular than changes resulting from other environmental factors, such as temperature, gas composition, salts, etc. Although total plate counts are reduced with increased radiation dose (Fig.1), they achieve a higher level than in non-irradiated fish at the end of the product shelf life. Ratios of total plate counts (T1/C) for a given quality level (Q) at the end of the product shelf life have been calculated from some recent studies and are reported in Table III. Indications are that T1/C/Q for irradiated fish is several to 100 times greater than it is for non-irradiated fish. This might indicate that the bacteria remaining after irradiation are not as active biochemically as those normally found in fresh fish; thus greater numbers of surviving bacteria are needed to produce the same effect as a small amount of the more potent spoilage bacteria.

Goldblith and Nickerson [13] reported that air-packed haddock fillets irradiated at 0.15 to 0.35 Mrad, and held at temperatures of 33-45°F, have a putrid ammoniacal odour when total plate counts approximate $1 \times 10^8/g$. Dassow and Miyauchi [14] reported that vacuum-packed king crab meat irradiated at 0.2 Mrad was of unacceptable quality when total plate counts approximated this same level. An assessment of the organoleptic quality of irradiated and non-irradiated cod fillets stored at different temperatures (Table IV) shows that, in samples irradiated at a dose level of 0.15 Mrad, spoilage manifestations are somewhat similar to those of the non-irradiated product. It is thus evident that the type as well as rate of quality change in the irradiated product can be controlled by dose level to produce organoleptic indicators of spoilage as recognizable as those in the non-irradiated product. This is illustrated in Fig.2. It can be noted that, as the dose level decreases, the rate of
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Note: The table represents data collected from irradiation experiments at different dose rates and temperatures. The columns indicate the dose rate, temperature, and irradiation status (irradiated or non-irradiated), while the rows show the percentage values for each condition.
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**Note:** Composition of microflora is given as a percentage with the exception of yeasts, which are not specified in the table.
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| Oyster meats                  | Untreated | Treated with 0.1% sodium benzoate | Irradiated 0.1 Mrad | | | | | |
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|                               | 0         |                                               |                      | 2         |                                               |                      | 2         |                                               |                      |
|                               | 2         |                                               |                      | 4         |                                               |                      | 4         |                                               |                      |
|                               | 6         |                                               |                      | 7         |                                               |                      | 7         |                                               |                      |
|                               | 17        |                                               |                      | 17        |                                               |                      | 17        |                                               |                      |
|                               | 5         |                                               |                      | 5         |                                               |                      | 5         |                                               |                      |
|                               | 2         |                                               |                      | 2         |                                               |                      | 2         |                                               |                      |
|                               | 38        |                                               |                      | 38        |                                               |                      | 38        |                                               |                      |
|                               | 56        |                                               |                      | 56        |                                               |                      | 56        |                                               |                      |
|                               | 78        |                                               |                      | 78        |                                               |                      | 78        |                                               |                      |
|                               | 18        |                                               |                      | 18        |                                               |                      | 18        |                                               |                      |
|                               | 65        |                                               |                      | 65        |                                               |                      | 65        |                                               |                      |
|                               | 65        |                                               |                      | 65        |                                               |                      | 65        |                                               |                      |
|                               | 42        |                                               |                      | 42        |                                               |                      | 42        |                                               |                      |
|                               | 13        |                                               |                      | 13        |                                               |                      | 13        |                                               |                      |
|                               | 30        |                                               |                      | 30        |                                               |                      | 30        |                                               |                      |
|                               | 3         |                                               |                      | 3         |                                               |                      | 3         |                                               |                      |
|                               | 1         |                                               |                      | 1         |                                               |                      | 1         |                                               |                      |
|                               | 71        |                                               |                      | 71        |                                               |                      | 71        |                                               |                      |
|                               | 65        |                                               |                      | 65        |                                               |                      | 65        |                                               |                      |
|                               | 65        |                                               |                      | 65        |                                               |                      | 65        |                                               |                      |
|                               | 58        |                                               |                      | 58        |                                               |                      | 58        |                                               |                      |
|                               | 58        |                                               |                      | 58        |                                               |                      | 58        |                                               |                      |
|                               | 10        |                                               |                      | 10        |                                               |                      | 10        |                                               |                      |
|                               | 58        |                                               |                      | 58        |                                               |                      | 58        |                                               |                      |
|                               | 58        |                                               |                      | 58        |                                               |                      | 58        |                                               |                      |
|                               | 20        |                                               |                      | 20        |                                               |                      | 20        |                                               |                      |
|                               | 5         |                                               |                      | 5         |                                               |                      | 5         |                                               |                      |
|                               | 1         |                                               |                      | 1         |                                               |                      | 1         |                                               |                      |
|                               | 95        |                                               |                      | 95        |                                               |                      | 95        |                                               |                      |
|                               | 95        |                                               |                      | 95        |                                               |                      | 95        |                                               |                      |
|                               | 95        |                                               |                      | 95        |                                               |                      | 95        |                                               |                      |
|                               | 2         |                                               |                      | 2         |                                               |                      | 2         |                                               |                      |
|                               | 97        |                                               |                      | 97        |                                               |                      | 97        |                                               |                      |
|                               | 95        |                                               |                      | 95        |                                               |                      | 95        |                                               |                      |
|                               | 95        |                                               |                      | 95        |                                               |                      | 95        |                                               |                      |
|                               | 4         |                                               |                      | 4         |                                               |                      | 4         |                                               |                      |
|                               | 4         |                                               |                      | 4         |                                               |                      | 4         |                                               |                      |
|                               | 11        |                                               |                      | 11        |                                               |                      | 11        |                                               |                      |
|                               | 14        |                                               |                      | 14        |                                               |                      | 14        |                                               |                      |
|                               | 11        |                                               |                      | 11        |                                               |                      | 11        |                                               |                      |
|                               | 8         |                                               |                      | 8         |                                               |                      | 8         |                                               |                      |
|                               | 4         |                                               |                      | 4         |                                               |                      | 4         |                                               |                      |
|                               | 4         |                                               |                      | 4         |                                               |                      | 4         |                                               |                      |
|                               | 18        |                                               |                      | 18        |                                               |                      | 18        |                                               |                      |
|                               | 25        |                                               |                      | 25        |                                               |                      | 25        |                                               |                      |
|                               | 24        |                                               |                      | 24        |                                               |                      | 24        |                                               |                      |
|                               | 12        |                                               |                      | 12        |                                               |                      | 12        |                                               |                      |
|                               | 7         |                                               |                      | 7         |                                               |                      | 7         |                                               |                      |

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FIG. 1. Effect of different pasteurizing radiation doses on the total plate count in dover sole [25]

FIG. 2. Effect of different radiation doses on quality degradation rates of air and vacuum-packed haddock fillets stored at 33 and 42°F

5 = excellent, 4 = very good, 3 = good, 2 = fair, 1 = poor
quality loss for vacuum-packed products approaches that of the aerobically-packed samples.

Factors influencing quality

Little is known about the factors that influence the quality of radiation-pasteurized sea foods. Although it is generally recognized that the type and/or amount of lipids and, in the case of salmon, carotenoid pigments, may limit acceptability, more penetrating studies are needed to determine the effect of the basic biochemical properties of the product on tolerance to irradiation.

Some very recent preliminary studies conducted at this laboratory indicate that a state of rigor may influence the quality of the irradiated product. The results of one experiment (Fig. 3) show that cod fillets irradiated in a pre-rigor condition kept longer and at a higher quality level than those irradiated post-rigor.

The quality of raw material used for irradiation directly influences the quality and shelf life of the irradiated product. In Fig. 4 it can be seen that, as the pre-irradiation iced storage time is increased, the rate of shelf life reduction is also increased.

Methods of processing, handling, packaging, and storage also affect the quality of radiation-pasteurized fish and shellfish. The level of radiation significantly influences shelf life. In Fig. 5 it can be seen that the temperature of storage has a very pronounced effect on the shelf life of the irradiated product, closely approximating $Q_{10} = 3$, reported by Spencer and Baines for fresh fish [15]. As the storage temperature increases, the rate of quality loss in the aerobically-packed irradiated product more closely approximates that of the fresh control.

The influence of packaging must not be overlooked. Vacuum packaging minimizes oxidative reactions, which is beneficial in some of the fatty species – i.e. petrale sole and halibut – but is of little value for lean fish. It is generally true that with radiation-pasteurized fish the onset of spoilage is less rapid in a vacuum pack than in an aerobic pack. Fish fillets aerobically packed in 20- to 30-lb tins in bulk spoil faster
<table>
<thead>
<tr>
<th>Product</th>
<th>Dose level (Mrad)</th>
<th>TPC/g of non-irradiated samples (n)</th>
<th>TPC/g of irradiated samples (i)</th>
<th>Ratio i/n</th>
<th>Source of information</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cod</td>
<td>0.15</td>
<td>$2.1 \times 10^7$</td>
<td>$1.5 \times 10^8$</td>
<td>7/1</td>
<td>BCF Technological Laboratory, Gloucester, Mass.</td>
</tr>
<tr>
<td>Petrale sole</td>
<td>0.25</td>
<td>$1 \times 10^7$</td>
<td>$1 \times 10^8$</td>
<td>10/1</td>
<td>BCF Technological Laboratory, Seattle, Wash.</td>
</tr>
<tr>
<td>King crab</td>
<td>0.20</td>
<td>$1 \times 10^6$</td>
<td>$1 \times 10^6$</td>
<td>100/1</td>
<td>BCF Technological Laboratory, Seattle, Wash.</td>
</tr>
</tbody>
</table>

O = Borderline quality by taste panel.
TABLE IV. SPOILAGE CHARACTERISTICS AND SHELF LIFE OF IRRADIATED (150,000 rad) AND NON-IRRADIATED COD FILLETS STORED AT DIFFERENT TEMPERATURES

<table>
<thead>
<tr>
<th>Sample</th>
<th>Storage temperature (°F)</th>
<th>Shelf life of product served steamed (d)</th>
<th>Comments of Panel</th>
</tr>
</thead>
<tbody>
<tr>
<td>Irradiated in air-packed cans</td>
<td>33</td>
<td>36</td>
<td>Off odour, musty, old</td>
</tr>
<tr>
<td></td>
<td>37</td>
<td>15</td>
<td>Ammonia, bitterness</td>
</tr>
<tr>
<td></td>
<td>42</td>
<td>12</td>
<td>Irradiation taste, bitter, burnt taste</td>
</tr>
<tr>
<td></td>
<td>47</td>
<td>12</td>
<td>Ammonia, putrid, inedible</td>
</tr>
<tr>
<td>Irradiated in bulk-packed 30-lb tins</td>
<td>33</td>
<td>30</td>
<td>Spoiled, irradiation odour, irradiation flavour, ammonia</td>
</tr>
<tr>
<td></td>
<td>37</td>
<td>15</td>
<td>Putrid, ammonia, irradiation odour</td>
</tr>
<tr>
<td></td>
<td>42</td>
<td>12</td>
<td>Musty, rancid</td>
</tr>
<tr>
<td></td>
<td>47</td>
<td>12</td>
<td>Ammonia, stale odour</td>
</tr>
<tr>
<td>Non-irradiated, bulk-packed in 30-lb tins</td>
<td>33</td>
<td>15</td>
<td>Ammonia, putrid, sour, inedible</td>
</tr>
<tr>
<td></td>
<td>37</td>
<td>12</td>
<td>Ammonia, inedible, putrid</td>
</tr>
<tr>
<td></td>
<td>42</td>
<td>12</td>
<td>Ammonia, putrid, rancid, sour, bad</td>
</tr>
<tr>
<td></td>
<td>47</td>
<td>5</td>
<td>Ammonia</td>
</tr>
</tbody>
</table>
FIG. 4. Effect of pre-irradiation quality of iced eviscerated fish on the post-irradiation shelf life of the fillets stored at 33°F.

FIG. 5. Effect of storage temperature, packaging, and irradiation (0.15 Mrad) on the shelf life of cod fillets.

FIG. 6. Shelf life of cod fillets as a function of irradiation and hermetic packaging. Storage at 33°F.

5 = very good, 4 = good, 3 = fair, 2 = borderline, 1 = poor
A - non-irradiated, non-hermetically packed
B - irradiated (0.15 Mrad), non-hermetically packed
C - irradiated (0.15 Mrad), hermetically packed

than those packed in sealed cans, but still have a significant extension in shelf life over non-treated samples (Fig. 6).

Synergistic, or complementary, effects to further extend shelf life occur when using radiation in combination with heat [16, 17] or additives.
i.e. sodium benzoate, potassium sorbate, and sodium salts of methyl and propyl esters of para-hydroxybenzoic acids [18]. These complementary effects must, however, be fully appraised with regard to the product spoilage pattern, total shelf life, and outgrowth of Clostridium botulinum, Type E.

III. WHOLESAKENESS CONSIDERATIONS

A complete report of the wholesomeness and nutritive value of radiation-pasteurized marine products can be found in the proceedings of the hearings before the Joint Congressional Committee on Atomic Energy [4] and in the petition submitted to the United States Food and Drug Administration (USFDA) for clearance of irradiated marine products [19].

Since no abnormal responses were found in animals fed at high dietary levels with codfish, salmon, haddock, whitefish, and tunafish irradiated at 2.79 to 5.58 Mrad, it is logical to conclude that ingestion of fish irradiated at these and pasteurization levels does not induce the formation of toxic substances. Protein utilization studies with fish treated at sterilizing and pasteurizing doses show that protein quality is not adversely affected by irradiation. Also, with the exception of thiamine, no significant changes occurred in the water-soluble vitamins of haddock fillets and clam meats subjected to pasteurizing doses of radiation.

The 1963 incidences involving Clostridium botulinum, Type E in smoked fish, and lack of information on the presence of this organism in the product and on the factors contributing to its growth in fish, raised concern about the likelihood of toxin development in fish treated with sub-sterilizing doses of radiation. Evidence accumulated by Nickerson, however, indicates that haddock fillets are a poor substrate for the growth of Clostridium botulinum, Type E [13]. No toxin was found in haddock fillets that had been inoculated with $1 \times 10^2$ spores/g, irradiated at 0.15, 0.25, or 0.35 Mrad, and held at 45°F for three times the product shelf life. Similarly treated haddock fillets inoculated with $1 \times 10^4$ spores/g became toxic at two times the shelf life at 45°F, and fillets inoculated with $1 \times 10^6$ spores/g became toxic at the maximum shelf life at 45°F.

It is interesting to note that Nickerson and his co-workers found the level of contamination in fish fillets to be not more than 0.17 clostridia per gram, an amount about 100,000 times less than that required to produce toxin at 45°F.

The role of Clostridium botulinum should be appraised in a manner which will permit an accurate and objective evaluation of any possible public health hazard. Some recent studies, which indicate that toxin can be produced in inoculated packs, have little significance because of the high inoculation levels used, and failure to consider the safety gap between the period of recognizable spoilage and toxin development in non-irradiated as well as in radiation-pasteurized fish.

The factors influencing the safety of radiation-pasteurized fish can be graphically presented, as shown in Fig. 7. This example, which is intended to demonstrate the concept, shows how the difference between rejection time of spoilage and toxin development time can be related as a function of temperature, radiation dose, and inoculation level. This
kind of data would be valuable for evaluating the role of Clostridium botulinum in marine products, or in any food, and the authors suggest that researchers in the subject give it serious consideration. Although the data shown in Fig. 7 are merely preliminary, the implication that these data are essential should be obvious.

As expected, the samples inoculated at the higher levels developed toxin first and, as pointed out earlier, samples inoculated with $10^2$ spores/g of Clostridium botulinum, Type E did not develop toxin at all, and are omitted in the graph. The data further suggest that the toxin outbreak time, as well as product shelf life, is increased as a function of applied irradiation dose.

Present indications are that haddock and cod fillets inoculated with up to $10^4$ spores/g will undergo spoilage and be rejected by consumers well in advance of toxin development. The time elements in samples inoculated with $10^6$ spores/g are still vague, and more work is required before conclusions can be made.

IV. COMMERCIALIZATION

Public Health clearance, market acceptability, and economics are essential considerations in evaluating the application of radiation pasteurization in the fishing industry.
Public Health clearance

Approval by the United States Food and Drug Administration is, of course, a necessary prerequisite to commercial development of the process. A petition for the approval of radiation-pasteurized fish fillets of haddock, cod, flounder and sole, pollock, and ocean perch was submitted to the USFDA on 7 July 1965; formal comments have been received requesting information on commercial shipping tests. This petition specifies radiation levels of 0.2 Mrad or less, and packaging and handling in the usual conventional manner, using well-established refrigeration practices.

Feeding studies are being conducted in preparation for a petition on soft shell clam meats. It is anticipated that, in the future, petitions will be prepared for oysters, scallops, shrimp, and king crab, all products of high acceptability and value.

Market acceptability

Quality evaluations by about 15 United States fishing firms substantiate laboratory findings and indicate that the irradiated product keeps over a week longer than fresh controls [20]. These findings are similar to those obtained in other acceptability tests conducted at Fort Lee, Va, in cooperation with the United States Army Natick Laboratories, and by other voluntary industry groups (Tables V and VI).

In the United States, the three distinct and separate market outlets can be classified as (1) restaurant or institutional; (2) supermarket; or (3) re-processing into frozen or prepared foods. In the absence of specific market test data, it is not possible to estimate accurately consumer demand for radiation-pasteurized fish. We do feel, however, that the restaurant outlet might be best because, in the United States, fresh fish enjoys a very healthy demand in eating establishments, and radiation-pasteurized fish might help to fulfill this demand. Supermarkets rank next, because of their somewhat limited use of fresh fish in these outlets and difficulty in predicting consumer reaction to irradiation. Re-processing into frozen or prepared foods may be very useful, particularly if quality and economic requirements can be satisfied. It will be necessary at the appropriate time to conduct a comprehensive marketing test and consumer evaluation programme.

Economics

Accurate information on the economics of producing radiation-pasteurized fish is not available. A report on the Marine Products Development Irradiator [21] indicates that radiation costs may be approximately two cents per pound of product, with a production of one ton per hour for 24 hours daily for 50 weeks a year. With variations in supply, a conservative estimate of cost would be not more than four cents per pound. Packaging costs would be less than one cent per pound; thus, since shipping and handling costs would be the same for fresh fish, the increase should not exceed five cents per pound of irradiated product. The reduction in product waste, due to spoilage and shrinkage, through
**TABLE V. ACCEPTABILITY TESTS ON RADIATION-PASTEURIZED SEA FOOD (UNITED STATES ARMY TEST AND EVALUATION COMMAND, FORT LEE, VA.)**

<table>
<thead>
<tr>
<th>Product</th>
<th>Panel members (No.)</th>
<th>Dose (Mrad)</th>
<th>Storage temperature (°F)</th>
<th>Storage period (d)</th>
<th>Average taste scores&lt;sup&gt;c)&lt;/sup&gt;</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Irradiated</td>
</tr>
<tr>
<td>Haddock fillets&lt;sup&gt;a)&lt;/sup&gt;</td>
<td>314</td>
<td>0.25</td>
<td>33</td>
<td>15</td>
<td>5.76</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>29</td>
<td>5.80</td>
</tr>
<tr>
<td>Petrale sole fillets&lt;sup&gt;a)&lt;/sup&gt;</td>
<td>333</td>
<td>0.20</td>
<td>32-35</td>
<td>16</td>
<td>5.90</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>28</td>
<td>6.52</td>
</tr>
<tr>
<td>Haddock fillets&lt;sup&gt;b)&lt;/sup&gt;</td>
<td>693</td>
<td>0.15</td>
<td>33</td>
<td>7</td>
<td>6.19</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>14</td>
<td>5.99</td>
</tr>
<tr>
<td>Cod fillets&lt;sup&gt;b)&lt;/sup&gt;</td>
<td>588</td>
<td>0.15</td>
<td>33</td>
<td>17</td>
<td>6.59</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>24</td>
<td>6.31</td>
</tr>
</tbody>
</table>

<sup>a)</sup> Packed in air, hermetically-sealed cans.
<sup>b)</sup> Packed in 30-lb fillet tins to approximate commercial conditions.
<sup>c)</sup> Based on hedonic scale where: 9 = like extremely; 8 = like very much; 7 = like moderately; 6 = like slightly; 5 = neither like nor dislike; 4 = dislike slightly; 3 = dislike moderately; 2 = dislike very much; 1 = dislike extremely.
TABLE VI. ACCEPTABILITY SCORES\textsuperscript{a}) BY DIFFERENT PANELS OF RADIATION-PASTEURIZED SEA FOODS HELD AT 33°F FOR ABOUT TWO WEEKS

<table>
<thead>
<tr>
<th>Panel</th>
<th>Panel members (No.)</th>
<th>Fried haddock</th>
<th>Lobster salad</th>
<th>Clam chowder</th>
<th>Cod fillets</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gloucester (trained)</td>
<td>14</td>
<td>7.4</td>
<td>8.4</td>
<td>7.7</td>
<td>6.0</td>
</tr>
<tr>
<td>Consumer type</td>
<td>278</td>
<td>7.2</td>
<td>7.7</td>
<td>6.4</td>
<td>-</td>
</tr>
<tr>
<td>Natick (trained)</td>
<td>8</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>6.5</td>
</tr>
<tr>
<td>Natick (consumer type)</td>
<td>36</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>6.9</td>
</tr>
</tbody>
</table>

\textsuperscript{a}) Based on hedonic scale where: 9 = like extremely; 8 = like very much; 7 = like moderately; 6 = like slightly; 5 = neither like nor dislike; 4 = dislike slightly; 3 = dislike moderately; 2 = dislike very much; 1 = dislike extremely.

- No test.

the use of radiation pasteurization might amount to over 3\% [22], thus approximating a net increase of one to two cents per pound.

Another consideration is the amount of high-quality raw material available for radiation pasteurization. Some surveys of the quality of haddock landed at Boston indicate that over 85\% of the fish being landed is of a quality suitable for irradiation. Thus, in the New England area, annually, probably 50\% of the haddock, cod, flounder, and pollock landed would be of a quality suitable for radiation pasteurization. If half the fillets from these fish are marketed in local areas without treatment, about 140 million pounds [23] would be left for distribution in the irradiated condition annually.

V. CONCLUSIONS

Since 1960 considerable technical progress has been made in the United States in research on the radiation pasteurization of fish and shellfish.

The refrigerated shelf life of about 19 different species of fish and shellfish can be significantly increased with low doses of gamma radiation, without the introduction of irradiation odours or flavours.

Storage time for a particular species is a function of pre-irradiation quality, dose level, packaging, and storage temperature. At radiation doses of 0.15 Mrad or lower, spoilage in fish fillets manifests itself organoleptically in a manner similar to that of non-irradiated products.

The role of Clostridium botulinum can be accurately evaluated by appraising the difference between spoilage rejection time and time for toxin development as a function of the level of contamination, radiation
dose, and storage temperature. Haddock fillets are a very poor substrate for the growth of Clostridium botulinum.

Radiation pasteurization has significant economic potential for the fishing industry in the United States in reducing waste and extending markets.

Greater attention must be directed towards obtaining FDA clearance of radiation-pasteurized sea food.

REFERENCES


ANON., Petition for radiopasteurization of marine products submitted to the Food and Drug Administration by the USAEC and Dept. of the US Army (1965).


ANON., Monthly progress report No. 34 from Dept. Food Sci. and Technology, Oregon State University, to USAEC under Contract No. AT(04-3)-502 (Feb. 1966).

DISCUSSION

D. MASSA: What were the initial bacteriological counts in your experiments?

J. W. SLAVIN: For fish from one to two days old the bacteria counts varied between 100 000 and 500 000 organisms per gram.

R. MOUTON: With regard to the fish which you irradiated before rigor mortis, did irradiation take place between death and the onset of rigor mortis or before death?

J. W. SLAVIN: The fish were dead when they were irradiated.
DEVELOPMENT OF RADIATION-STERILIZED SEA FOOD PRODUCTS*

I. ENZYME-INACTIVATED COD AND HALIBUT PATTIES

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Abstract — Résumé — Аннотация — Resumen

DEVELOPMENT OF RADIATION-STERILIZED SEA FOOD PRODUCTS. I. ENZYME-INACTIVATED COD AND HALIBUT PATTIES. Radiation-sterilized enzyme-inactivated cod (Gadus macrocephalus) and halibut (Hippoglossus stenolepsis) patties or cakes were developed which show promise as commercial products. They were prepared by incorporating the comminuted fish with white corn meal, gelatin, and salt and forming the mixture into sausages. Enzymes were inactivated by heating the sausages in a boiling water-bath. After cooling overnight to set the protein, the sausages were sliced into 3/8-in-thick patties, packed in cans and given a radiation dose of 4.5 Mrad. The radiation sterilized products were stored for 12 months at 72°F with periodic evaluations to assess the quality and the effect of various treatments. The treatments included vacuum packing, the addition of various antioxidants, and the use of charcoal packets. The products just prior to serving were dipped in batter and breading and deep-fried. The fish patties were evaluated by flavor panels and objective measurements, such as total volatile bases, 2-thiobarbituric acid number, pH and color-reflectance values.

The products received acceptable flavor scores from preference panels (140 to 170 judges) during twelve months of storage at 72°F. Although the panels preferred the non-irradiated control samples to the irradiated samples after 12 months, all stored irradiated patties scored on the “like” side of the 9-point hedonic scale. The color-reflectance values of radiation-sterilized seafood products can be used as a measure of the radiation-induced browning and seemed to correlate with length of storage.

* Approved for publication as Technical Paper 2148, Oregon State Agricultural Experiment Station.
** Deceased December, 1964.
témoins non irradiés aux échantillons irradiés, après 12 mois, tous les pâtés irradiés conservés ont été classés du côté positif de l'échelle hédonistique des qualités (neuf degrés). Le coefficient de réflexion des couleurs des produits alimentaires d'origine marine radio-sterilisés peut servir à évaluer le brunissement produit par l'action des rayonnements et paraît être en rapport avec la durée de conservation.

ПРИМЕНЕНИЕ ИЗЛУЧЕНИЯ ДЛЯ СТЕРИЛІЗАЦІЇ МОРСЬКИХ ПІЩЕВИХ ПРОДУКТОВ.

Були приготовлені лепешки из трески (Gadus macrocephalus) и палтуса (Hippoglossus stenolepis), стерилизованные с помощью облучения и инактивированные в отношении действия энзимов, которые являются перспективными с коммерческой точки зрения. Они приготавливаются путем смешения размельченной рыбы с белой кукурузной мукой, желатином и солью, после чего этой смеси придается форма колбасок. Инактивация энзимов достигается посредством нагревания колбасок в банке с кипящей водой. После того, как колбаски в течение ночи остали и протекли завердел, их разрезали на лепешки толщиной 3/8 дюйма, по- местили в банки и облучили дозой в 4,5 Мрад. Стерилизованные облучением продукты хранились в течение 12 месяцев при температуре 72°F, при этом периодически производилась оценка качества, а также последствий различной обработки. Эта обработка включала упаковку в вакууме, включение различных антиокислителей и использование пакетов для древесного угля. Непосредственно перед потреблением продукты покрывались взбитым тестом и панировочными сухарями и как следует прожаривались. Оценка рыбных пирожков производилась дегустаторами, а также путем измерения объективных показателей, таких как общие летучие основания, 2-тиобарбитурное кислотное число, pH и цветная отражательная способность.

Группы дегустаторов (140 - 170 человек) дали удовлетворительную оценку вкусовых качеств продуктов в течение 12 месяцев хранения при температуре 72°F. Хотя после 12 месяцев дегустаторы отдали предпочтение необлученным контрольным образцам, все хранившиеся облученные пирожки получили положительную оценку по 9-ти бальной гедонической системе. Цветная отражательная способность стерилизованных облучением морских пищевых продуктов использовалась в качестве мерила, вызванного облучением потемнения продуктов и, кажется, зависит от продолжительности хранения.

préparacion de alimentos de origen marino esterilizados por irradiación.

I. Pastelillos de bacalao y de hipogloso con enzimas inactivadas. Se han preparado pastelillos o tortas de bacalao (Gadus macrocephalus) e hipogloso (Hippoglossus stenolepis) esterilizados por irradiación, con inactivación de enzimas, productos que ofrecen interés desde el punto de vista comercial. Se prepararon mezclando el pescado picado con harina de maíz, gelatina y sal y dando a la masa forma de salchicha. Las enzimas se inactivaron calentando las salchichas en un baño de agua hirviente. Después de dejarlas enfriar durante un día, para que las proteínas se asentasen, se cortaron en pastelillos de 3/8 pulg. de espesor, se envueltieron en latas y se sometieron a una dosis de irradiación de 4,5 Mrad. Los productos radio-esterilizados se almacenaron durante 12 meses a 72°F, y se sometieron a exámenes periódicos para evaluar la calidad y el efecto de varios tratamientos. Los tratamientos que se aplicaron fueron: envasado al vacío, adición de varios antioxidantes y empleo de paquetes de carbón vegetal. Antes de servirlos, los pastelillos fueron rebozados en bésame y empanados, y se frieron bien. La consistencia de los pastelillos se estudió por medio de grupos de catadores y de mediciones objetivas, tales como contenido total de bases volátiles, índice de ácido 2-tiobarbitúrico, pH e índice de reflectancia Cromática.

El sabor de los productos recibió puntuaciones aceptables de grupos de catadores (140 a 170 personas) durante 12 meses de almacenamiento a 72°F. Aunque los catadores prefirieron las muestras testigo no irradiadas a los productos irradiados, todos los pastelillos irradiados almacenados puntuaron en la parte positiva de la escala hedonística de 9 puntos. Los índices de reflectancia Cromática de los productos alimenticios marinos radio-esterilizados pueden utilizarse para medir el dorado producido por la irradiación y parecen guardar correlación con la duración del almacenamiento.

INTRODUCTION

The discovery that ionizing radiation may be employed to destroy microorganisms and thereby extend the shelf life of food with little or no refrigeration has been the subject of considerable research during the past ten years. The development and application of atomic energy for the benefit of mankind has been sponsored by the Atomic Energy Commission...
and the Army Quartermaster Research and Engineering Command. The Army Quartermaster, concerned with providing food which is wholesome, nutritious and of the highest quality, has pioneered the use of radiation as a potential method of food sterilization.

Relatively little has been reported on the radiation preservation of fishery products, and this is largely confined to pasteurization levels of radiation to extend refrigerated storage life of the sea food products. Miyauchi [1] irradiated pre-cooked fish sticks at various levels up to 2.0 Mrad, and stored them at room temperature and at 35°F. He found that the fish sticks irradiated at 1.0 and 2.0 Mrad had poor storage characteristics at room temperature. Storage life at 35°F was 8 to 12 weeks, but a musty odour developed and the white meat darkened. Nickerson et al. [2] reported that the flavour of fresh halibut steaks was not adversely affected by radiation at $2.5 \times 10^6$ rep and cod fish cakes irradiated at $2.0 \times 10^6$ rep, whether air-packed at room temperature, vacuum-packed, or frozen, were not scored significantly different in flavour from the control sample. The halibut steaks were pan-fried and the cod cakes were deep fat fried at the time of serving. Hannan [3] reported that irradiation at $1.0 \times 10^6$ rep of haddock, lemon sole and mackerel showed little or no effect on appearance, odour and flavour, while irradiation at $2.0 \times 10^6$ rep had an adverse effect. Amano and Yamada [4] subjected 22 species of fish to irradiation at 1.0 Mrad and showed that storage time at refrigerated temperature was prolonged to 40 or 50 d, but there was a certain amount of damage to flavour, odour, colour and texture. Halibut, irradiated at 0.5, 1.0, 2.0 and 4.0 Mrad, showed no colour, texture or large odour changes when packed in a nitrogen atmosphere, although there were significant flavour differences from the control according to Groninger et al. [5]. They recommended that irradiation be carried out in an inert atmosphere or vacuum. Heiligman et al. [6] reported that halibut steaks had good texture, odour and taste after 63 d at 72°F when packed under high vacuum (28 in.) and irradiated at 4.5 Mrad. Charcoal packets and glucose-oxidase scavenger solutions were used, but there was some yellow discolouration of the halibut. Investigations, in general, showed that low fat fish had better acceptability after irradiation than fatty fish.

The objectives of this study were to develop radiation-sterilized sea-food products which would withstand ambient storage for periods of up to a year. In addition, the storage stability and the effect of antioxidants on radiation-sterilized sea food products were determined. Treatments were utilized that are known to improve flavour, such as vacuum packing and the use of charcoal packets to lessen radiation odours and flavours. Consumer-type preference panels were used to determine the quality of the products and the effect of various treatments. Storage changes were evaluated by objective tests, including thiobarbituric acid number, total volatile bases, pH and colour measurements.

**EXPERIMENTAL METHODS AND PROCEDURES**

**Preparation of enzyme-inactivated cod and halibut patties**

After considerable experimentation, which is described in Technical Report FD-16 [7], the following formula for fish patties was developed:
to each 100 lb ground Pacific cod (Gadus macrocephalus) or Pacific halibut (Hippoglossus stenolepsis) were added 4 lb of white corn meal, 1.5 lb of gelatin, 0.35 lb salt. Tenox VI, 2, 2, 4, 5-trihydroxybutyrophenone (THBP) or thiodipropionic acid (TDPA) was added to achieve a level of 50 ppm in the total mix. Citric acid (100 ppm) was added to the samples containing THBP or TDPA prior to the addition of the antioxidant. The ground fish was stuffed into meat casings, 2½ in. diam., and the "sausages" were cooked in a boiling water-bath to achieve enzyme inactivation. This required an internal temperature of 160°F for at least 15 sec [8], and took approximately 45 to 50 min. The sausages were held at 34°F overnight, sliced into 3/8 in. -thick patties, and three patties were packed in each 307 X 200.25s (No. ½ flat) "C" enamelled can. Parchment paper separated the patties and protected the 1-g charcoal packet attached to the under side of the lid. The cans were sealed under 26 in. vacuum and stored frozen until radiation.

**Radiation procedure and storage conditions**

The frozen samples were shipped under dry ice, via Railway Express, to the Materials Testing Reactor at Arco, Idaho, for irradiation and were returned to Oregon State University under the same conditions. In the investigations, all sterilization radiation was at the 4.5 Mrad level. Radiation was effected in water at ambient temperature, using spent fuel rods as the radiation source. Dose-rates averaged $11.0 \times 10^6$ rad/h for the cod patties and $3.8 \times 10^6$ rad/h for the halibut patties.

After irradiation, the sea food products were stored in controlled-temperature rooms at the Department of Food Science and Technology, Oregon State University, at 72°F. The non-irradiated control samples were held at 0°F. Two separate and complete studies for cod and halibut were carried out. A preliminary storage trial of 6 months' duration was followed by a longer experiment lasting 12 months.

**Toxicity trials**

Mouse lethality tests for the detection of *Clostridium botulinum* toxin were conducted on all samples prior to presentation for panel evaluation to assure their safety. A composite sample for each treatment was prepared by taking samples from each can. The samples were weighed and diluted with an equal volume of saline and shaken vigorously for 30 min. They were then centrifuged, and 0.5 ml of the supernatants from each sample was injected intraperitoneally into two mice. Part of the supernatant was trypsin, activated by mixing with an equal volume of 0.1% Bacto-trypsin (1: 250) in gelatin-phosphate buffer and incubated at 37°C for 45 min. The trypsinized and heated supernatants were injected into control mice for the detection of the presence of protoxin and non-specific lethal  

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1 Viscomix by Swift & Co., Kerney, New Jersey.
2 Contains 10% butylated hydroxyanisole, 10% butylated hydroxytoluene, 6% propyl gallate, 6% citric acid, 12% propylene glycol and 50% vegetable oil.
5 This can, usually used for salmon, measures 3 1/2 in. diam. and is 2.0156 in. high.
6 Tests performed by Dr. Jong S. Lee of the Department of Food Science and Technology.
agents. The mice used were Swiss-strain white mice weighing approximately 20 g. The injected mice were observed for 5 d for any unusual symptoms. No samples were lethal to mice.

Subjective methods of evaluation

Large student panels were employed for the organoleptic evaluation of the sea food products. The panels consisted of 140 to 170 untrained, volunteer students of the University and were used to measure preferences. These student evaluations are used as an indication of consumer preference, since the students generally show the same preference ratings as home consumers [9]. The preference ballot, with a 9-point hedonic scale, was used. This went progressively from a score of 1, indicating "dislike extremely" to a score of 9, indicating "like extremely". According to the hedonic scale, an arbitrary value of 5.0 was selected as the division between "acceptable" and "unacceptable". All flavour data were analysed by analysis of variance at the 5% significance level.

At the time of serving, the enzyme-inactivated patties were breaded and deep-fried at 360-365°F for 3 min. The tasters were seated in individual booths, which were illuminated with amber lights to mask the colour of the samples. The samples were served in randomly-coded paper cups, 1/4 patty per treatment.

An alternate method of serving enzyme-inactivated fish patties was employed to determine the value and effect of several adjuncts on the acceptability of irradiated sea foods. Unbreaded halibut patties, which had been irradiated at 4.5 Mrad, were heated in a 400°F oven for 15 min and served with the following four adjuncts:

1. Medium-thick white sauce containing hard-cooked eggs and onion salt. Paprika was sprinkled on top.
2. Canned mushroom soup, thinned one-half with whole milk.
3. Imitation sour cream containing dehydrated chopped onion and salt. Dried parsley flakes were sprinkled on top.
4. Tomato sauce, conventionally prepared as served with baked fish.

Objective methods of evaluation

Objective methods of quality evaluation of irradiated sea food products were performed to supplement the subjective tests. Although a number of chemical changes are known to occur during and after irradiation, there is no chemical procedure which correlates with the radiation dose or that may be used as a measure of the quality of irradiated sea foods; 2-thiobarbituric acid number [10], total volatile bases [11], pH and colour determinations were performed after storage and compared with the non-irradiated frozen control.

The 2-thiobarbituric acid (TBA) method for the determination of oxidative rancidity is based upon the reaction of malonaldehyde with TBA. The autoxidation of polyunsaturated lipids yields undesirable lipoperoxides which react with TBA to form the red chromogen, which is a malonaldehyde-TBA complex [12]. Previous work with ground halibut [13], irradiated at 0.5 Mrad and stored for 5 weeks at 34°F, showed a significant increase in TBA value, as did a sample containing 0.005% TDPA, while oxidative rancidity was inhibited in a sample containing 0.005% Tenox VI.
The total volatile bases (TVB) determination is widely used as an index of the quality of fresh fish. Enzymatic activity during storage by microorganisms and tissue enzymes produces basic volatile substances, such as ammonia and amines. The procedure for TVB described by Stansby et al. [11] was used with certain modifications; the distillate was collected in 20 ml 4% boric acid instead of 50 ml 0.05 N HCl, and 0.05 N HCl was used to titrate the distillate in place of standard alkali. Methyl red-bromo cresol green was used as the indicator.

The pH of the fish patties was measured with a Beckman Zeromatic pH meter which had been standardized with a buffer at pH 7.0. Ten grams of sample were mixed with ten milliliters of distilled water.

Colour reflectance readings of the fish were taken to determine the changes in colour and the degree of browning which occurred during storage. A photoelectric reflection meter with a tri-green filter was used to measure colour differences between treatments. Three readings were taken on the surface of the top patty from fourteen cans of each treatment of the enzyme-inactivated patties. The readings were averaged for each treatment and presented as mean per cent reflectance readings.

RESULTS AND DISCUSSION

Subjective methods of evaluation

Storage studies for six months

The general appearance of the patties after irradiation and storage were very similar to the non-irradiated frozen control. The product was moist, and there was little or no liquid in the can. It was firm in texture and could be easily handled without breakage during the batter-and-breading procedure before deep frying. Student panels evaluated the irradiated products, which had been stored for as long as 6 months at 72°F, with and without the addition of the antioxidants, Tenox VI and TDPA. The results are presented in Table I. Initially, and after 3 months' storage, the panel could detect no significant difference between treatments for the cod patties. All the irradiated cod samples received a higher average score than the non-irradiated samples after 6 months' storage at 72°F. The panel preferred the non-irradiated halibut patties initially, but this was not the case after storage. There were no significant differences between treatments after 3 or 6 months' storage.

Storage studies for twelve months

The encouraging panel scores for the radiation-sterilized fish patties after 6 months' storage led to further studies, with the storage time increased to 12 months. Tenox VI and THBP were the antioxidants used in this trial. The flavour panel results are given in Table II. In general, the scores were lower for this study, possibly due to the slightly poorer initial quality of the fish. There were significant differences between

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7 Model 610, Photovolt Corporation, 95 Madison Avenue, New York, N. Y., United States.
the control and the irradiated samples stored at 72°F. The tasters preferred the control samples to the radiated samples, although all patties received scores in the range of acceptability (above 5.0).

Alternate methods of serving irradiated fish patties

The mean flavour scores for halibut patties, irradiated at 4.5 Mrad and served with four adjuncts, were as follows: white sauce with chopped egg, 5.93; mushroom soup, 6.15; sour cream with onion, 5.91; tomato sauce, 5.93. There were no significant differences between treatments.

Objective methods of evaluation

The results of the chemical tests and pH determinations of enzyme-inactivated cod and halibut patties after 12 months' storage at 72°F are presented in Tables III and IV, respectively.

The TBA values were relatively low after irradiation, storage and the addition of antioxidants, indicating that only minor autoxidation had occurred. This is probably due to the limited amount of oxygen present in the vacuum-sealed cans. The generally elevated TBA levels of halibut are a reflection of the fat content, which is higher in halibut than in cod. The TVB values of the enzyme-inactivated cod patties showed a slow and gradual increase with storage time, but the values even after 12 months of storage, were not excessive. The TVB values of halibut patties, which were initially higher than cod, remained essentially unchanged during the 12 months' storage trial. The pH values for cod and halibut showed little change due to irradiation, storage and the use of antioxidants.

The colour reflectance values, which are a measure of the change in colour of the product and the degree of browning of stored products, are shown in Table V. The higher the reflectance reading, the lighter the colour of the fish and, conversely, the lower readings indicate a greater degree of browning. There were statistically significant colour differences in the irradiated products after storage at 72°F, with a slow but progressive development of a "tan or brownish" colour, which was noticeable in the cod samples treated with THBP and in all samples after the 12 months' interval. Variable results were obtained with the use of antioxidants. The brownish discolouration that occurred after 12 months' storage is considered to be a serious acceptance problem which must be overcome if radiation-sterilized fish products are to become a commercial possibility. It appears that this is a carbonyl-amine reaction that may be amenable to solution by control of oxygen and the use of appropriate antioxidants or browning inhibitors.

CONCLUSIONS

Two radiation-sterilized sea food products, enzyme-inactivated cod patties and enzyme-inactivated halibut patties, which appear to have considerable promise, were developed. All products were packed in "C" enamelled cans containing charcoal packets, vacuum sealed, and irradiated at 4.5 Mrad at ambient temperature. Three antioxidant preparations, Tenox VI, THBP and TDPA, were evaluated. They were tested periodi-
**TABLE I. MEAN FLAVOUR SCORES$^a$ FOR ENZYME-INACTIVATED FISH PATTIES**

<table>
<thead>
<tr>
<th>Product</th>
<th>Treatment</th>
<th>Radiation level (Mrad)</th>
<th>Storage temp. (°F)</th>
<th>Storage time (months)</th>
<th>0</th>
<th>3</th>
<th>6</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cod</td>
<td>Without antioxidant</td>
<td>0</td>
<td>0</td>
<td></td>
<td>6.87</td>
<td>6.28</td>
<td>6.42</td>
</tr>
<tr>
<td></td>
<td>Without antioxidant</td>
<td>4.5</td>
<td>70</td>
<td></td>
<td>6.93</td>
<td>6.49</td>
<td>6.60</td>
</tr>
<tr>
<td></td>
<td>With Tenox VI</td>
<td>4.5</td>
<td>70</td>
<td></td>
<td>6.78</td>
<td>6.44</td>
<td>6.72b</td>
</tr>
<tr>
<td></td>
<td>With TDPA</td>
<td>4.5</td>
<td>70</td>
<td></td>
<td>6.55b</td>
<td>6.39</td>
<td>6.71</td>
</tr>
<tr>
<td>Halibut</td>
<td>Without antioxidant</td>
<td>0</td>
<td>0</td>
<td></td>
<td>7.17</td>
<td>6.58</td>
<td>6.65</td>
</tr>
<tr>
<td></td>
<td>Without antioxidant</td>
<td>4.5</td>
<td>70</td>
<td></td>
<td>6.81b</td>
<td>6.41</td>
<td>6.53</td>
</tr>
<tr>
<td></td>
<td>With Tenox VI</td>
<td>4.5</td>
<td>70</td>
<td></td>
<td>6.50b</td>
<td>6.37</td>
<td>6.67</td>
</tr>
<tr>
<td></td>
<td>With TDPA</td>
<td>4.5</td>
<td>70</td>
<td></td>
<td>6.55b</td>
<td>6.39</td>
<td>6.71</td>
</tr>
</tbody>
</table>

$^a$ Score 9 high, 1 low.

$^b$ Significantly different from the control at 5% significance level.
<table>
<thead>
<tr>
<th>Product</th>
<th>Treatment</th>
<th>Radiation level (Mrad)</th>
<th>Storage temperature (°F)</th>
<th>Storage time (months)</th>
<th>0</th>
<th>3</th>
<th>6</th>
<th>9</th>
<th>12</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cod</td>
<td>Without antioxidant</td>
<td>0</td>
<td>0</td>
<td>6.63</td>
<td>6.81</td>
<td>6.35</td>
<td>6.84</td>
<td>6.66</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Without antioxidant</td>
<td>4.5</td>
<td>72</td>
<td>6.38&lt;sup&gt;b&lt;/sup&gt;</td>
<td>6.49&lt;sup&gt;b&lt;/sup&gt;</td>
<td>6.59</td>
<td>6.72</td>
<td>5.93&lt;sup&gt;b&lt;/sup&gt;</td>
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<tr>
<td></td>
<td>With Tenox VI</td>
<td>4.5</td>
<td>72</td>
<td>6.20&lt;sup&gt;b&lt;/sup&gt;</td>
<td>6.48&lt;sup&gt;b&lt;/sup&gt;</td>
<td>6.81&lt;sup&gt;b&lt;/sup&gt;</td>
<td>6.82</td>
<td>6.18&lt;sup&gt;b&lt;/sup&gt;</td>
<td></td>
</tr>
<tr>
<td></td>
<td>With THBP</td>
<td>4.5</td>
<td>72</td>
<td>6.37&lt;sup&gt;b&lt;/sup&gt;</td>
<td>6.55&lt;sup&gt;b&lt;/sup&gt;</td>
<td>6.41</td>
<td>6.57&lt;sup&gt;b&lt;/sup&gt;</td>
<td>5.90&lt;sup&gt;b&lt;/sup&gt;</td>
<td></td>
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<td>0</td>
<td>6.34</td>
<td>6.00</td>
<td>6.33</td>
<td>6.58</td>
<td>6.40</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Without antioxidant</td>
<td>4.5</td>
<td>72</td>
<td>5.98&lt;sup&gt;b&lt;/sup&gt;</td>
<td>5.85</td>
<td>6.02&lt;sup&gt;b&lt;/sup&gt;</td>
<td>6.24&lt;sup&gt;b&lt;/sup&gt;</td>
<td>5.99&lt;sup&gt;b&lt;/sup&gt;</td>
<td></td>
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<tr>
<td></td>
<td>With Tenox VI</td>
<td>4.5</td>
<td>72</td>
<td>6.19</td>
<td>5.88</td>
<td>6.17</td>
<td>6.36</td>
<td>5.91&lt;sup&gt;b&lt;/sup&gt;</td>
<td></td>
</tr>
<tr>
<td></td>
<td>With THBP</td>
<td>4.5</td>
<td>72</td>
<td>6.07&lt;sup&gt;b&lt;/sup&gt;</td>
<td>5.90</td>
<td>5.95&lt;sup&gt;b&lt;/sup&gt;</td>
<td>6.13&lt;sup&gt;b&lt;/sup&gt;</td>
<td>5.57&lt;sup&gt;b&lt;/sup&gt;</td>
<td></td>
</tr>
</tbody>
</table>

<sup>a</sup> Score 9 high, 1 low.

<sup>b</sup> Significantly different from the control at 5% significance level.
TABLE III. OBJECTIVE DETERMINATIONS OF ENZYME-INACTIVATED COD PATTIES

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Radiation level (Mrad)</th>
<th>Storage time (months)</th>
<th>Storage temp. (°F)</th>
<th>TBA Mg Mal³/µg fish</th>
<th>TVB Mg N/100g fish</th>
<th>(pH)</th>
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</thead>
<tbody>
<tr>
<td>Without antioxidant</td>
<td>0</td>
<td>0</td>
<td>3.60</td>
<td>7.88</td>
<td>6.85</td>
<td></td>
</tr>
<tr>
<td>Without antioxidant</td>
<td>4.5</td>
<td>0</td>
<td>2.74</td>
<td>6.83</td>
<td>6.85</td>
<td></td>
</tr>
<tr>
<td>With Tenox VI</td>
<td>4.5</td>
<td>0</td>
<td>1.36</td>
<td>8.58</td>
<td>6.80</td>
<td></td>
</tr>
<tr>
<td>With THBP</td>
<td>4.5</td>
<td>0</td>
<td>1.45</td>
<td>7.00</td>
<td>6.90</td>
<td></td>
</tr>
<tr>
<td>Without antioxidant</td>
<td>0</td>
<td>3</td>
<td>1.65</td>
<td>5.95</td>
<td>6.85</td>
<td></td>
</tr>
<tr>
<td>Without antioxidant</td>
<td>4.5</td>
<td>72</td>
<td>1.13</td>
<td>13.48</td>
<td>6.90</td>
<td></td>
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<td>With Tenox VI</td>
<td>4.5</td>
<td>72</td>
<td>0.75</td>
<td>15.93</td>
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<td></td>
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<td>With THBP</td>
<td>4.5</td>
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<td>Without antioxidant</td>
<td>0</td>
<td>6</td>
<td>2.23</td>
<td>6.65</td>
<td>6.85</td>
<td></td>
</tr>
<tr>
<td>Without antioxidant</td>
<td>4.5</td>
<td>72</td>
<td>0.83</td>
<td>16.63</td>
<td>6.95</td>
<td></td>
</tr>
<tr>
<td>Without antioxidant</td>
<td>4.5</td>
<td>72</td>
<td>0.58</td>
<td>17.15</td>
<td>6.90</td>
<td></td>
</tr>
<tr>
<td>With THBP</td>
<td>4.5</td>
<td>72</td>
<td>0.69</td>
<td>15.23</td>
<td>6.90</td>
<td></td>
</tr>
<tr>
<td>Without antioxidant</td>
<td>0</td>
<td>9</td>
<td>1.94</td>
<td>7.00</td>
<td>6.85</td>
<td></td>
</tr>
<tr>
<td>Without antioxidant</td>
<td>4.5</td>
<td>72</td>
<td>3.07</td>
<td>18.38</td>
<td>6.95</td>
<td></td>
</tr>
<tr>
<td>With Tenox VI</td>
<td>4.5</td>
<td>72</td>
<td>1.07</td>
<td>18.20</td>
<td>6.85</td>
<td></td>
</tr>
<tr>
<td>With THBP</td>
<td>4.5</td>
<td>72</td>
<td>0.87</td>
<td>19.08</td>
<td>6.90</td>
<td></td>
</tr>
<tr>
<td>Without antioxidant</td>
<td>0</td>
<td>12</td>
<td>3.85</td>
<td>7.26</td>
<td>6.85</td>
<td></td>
</tr>
<tr>
<td>Without antioxidant</td>
<td>4.5</td>
<td>72</td>
<td>1.82</td>
<td>21.44</td>
<td>7.00</td>
<td></td>
</tr>
<tr>
<td>With Tenox VI</td>
<td>4.5</td>
<td>72</td>
<td>1.22</td>
<td>21.96</td>
<td>6.90</td>
<td></td>
</tr>
<tr>
<td>With THBP</td>
<td>4.5</td>
<td>72</td>
<td>1.03</td>
<td>18.81</td>
<td>6.95</td>
<td></td>
</tr>
</tbody>
</table>

a Malonaldehyde.

cally, during 6 and 12 months of storage at 72°F, by subjective and objective methods.

In the six months' storage study, preference panels indicated that the radiation-sterilized cod patties without antioxidant and with TDPA were preferred to the non-irradiated control after 6 months' storage at 72°F. There were no significant differences between treatments for the halibut patties after 6 months' storage.

In the twelve months' storage study, the panels preferred the non-irradiated control samples to the irradiated samples for the cod and halibut patties. However, all irradiated samples received scores in the range of
### TABLE IV. OBJECTIVE DETERMINATIONS OF ENZYME-INACTIVATED HALIBUT PATTIES

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Radiation level (Mrad)</th>
<th>Storage time (months)</th>
<th>Storage temperature (°C)</th>
<th>TBA Mg Mal(^3)/kg fish</th>
<th>TVB Mg N/100g fish</th>
<th>(pH)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Without antioxidant</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>4.00</td>
<td>35.35</td>
<td>7.00</td>
</tr>
<tr>
<td>Without antioxidant</td>
<td>4.5</td>
<td>0</td>
<td>8.40</td>
<td>33.60</td>
<td>6.95</td>
<td></td>
</tr>
<tr>
<td>With Tenox VI</td>
<td>4.5</td>
<td>0</td>
<td>1.94</td>
<td>22.75</td>
<td>6.80</td>
<td></td>
</tr>
<tr>
<td>With THBP</td>
<td>4.5</td>
<td>0</td>
<td>1.74</td>
<td>35.09</td>
<td>6.90</td>
<td></td>
</tr>
<tr>
<td>Without antioxidant</td>
<td>0</td>
<td>3</td>
<td>3.51</td>
<td>33.86</td>
<td>7.00</td>
<td></td>
</tr>
<tr>
<td>Without antioxidant</td>
<td>4.5</td>
<td>72</td>
<td>5.35</td>
<td>36.58</td>
<td>6.95</td>
<td></td>
</tr>
<tr>
<td>With Tenox VI</td>
<td>4.5</td>
<td>72</td>
<td>2.73</td>
<td>27.74</td>
<td>6.80</td>
<td></td>
</tr>
<tr>
<td>With THBP</td>
<td>4.5</td>
<td>72</td>
<td>2.79</td>
<td>37.36</td>
<td>6.90</td>
<td></td>
</tr>
<tr>
<td>Without antioxidant</td>
<td>0</td>
<td>6</td>
<td>3.60</td>
<td>32.99</td>
<td>7.00</td>
<td></td>
</tr>
<tr>
<td>Without antioxidant</td>
<td>4.5</td>
<td>72</td>
<td>5.60</td>
<td>37.63</td>
<td>7.00</td>
<td></td>
</tr>
<tr>
<td>With Tenox VI</td>
<td>4.5</td>
<td>72</td>
<td>1.63</td>
<td>30.10</td>
<td>6.80</td>
<td></td>
</tr>
<tr>
<td>With THBP</td>
<td>4.5</td>
<td>72</td>
<td>1.59</td>
<td>38.33</td>
<td>6.85</td>
<td></td>
</tr>
<tr>
<td>Without antioxidant</td>
<td>0</td>
<td>9</td>
<td>1.65</td>
<td>30.80</td>
<td>6.95</td>
<td></td>
</tr>
<tr>
<td>Without antioxidant</td>
<td>4.5</td>
<td>72</td>
<td>0.62</td>
<td>35.00</td>
<td>6.85</td>
<td></td>
</tr>
<tr>
<td>With Tenox VI</td>
<td>4.5</td>
<td>72</td>
<td>1.71</td>
<td>33.78</td>
<td>6.75</td>
<td></td>
</tr>
<tr>
<td>With THBP</td>
<td>4.5</td>
<td>72</td>
<td>1.02</td>
<td>40.60</td>
<td>6.80</td>
<td></td>
</tr>
<tr>
<td>Without antioxidant</td>
<td>0</td>
<td>12</td>
<td>0.84</td>
<td>35.00</td>
<td>7.00</td>
<td></td>
</tr>
<tr>
<td>Without antioxidant</td>
<td>4.5</td>
<td>72</td>
<td>0.43</td>
<td>40.25</td>
<td>6.90</td>
<td></td>
</tr>
<tr>
<td>With Tenox VI</td>
<td>4.5</td>
<td>72</td>
<td>1.14</td>
<td>34.30</td>
<td>6.75</td>
<td></td>
</tr>
<tr>
<td>With THBP</td>
<td>4.5</td>
<td>72</td>
<td>0.86</td>
<td>40.08</td>
<td>6.80</td>
<td></td>
</tr>
</tbody>
</table>

a Malonaldehyde.

Acceptability. The addition of antioxidants had little or no effect on the flavour of the stored irradiated products.

Adjuncts to improve the acceptability of radiation-sterilized sea food products were investigated. Four sauces, served on enzyme-inactivated halibut patties, proved to be acceptable, alternate methods of serving this product. The usual method is breading and deep-frying at the time of serving.

Objective evaluations of the radiation-sterilized sea food products included thiobarbituric acid number, total volatile bases, pH and colour reflectance measurements. The colour reflectance values increased with
TABLE V. MEAN COLOUR REFLECTANCE MEASUREMENTS of ENZYME-INACTIVATED FISH PATTIES

<table>
<thead>
<tr>
<th>Product</th>
<th>Treatment</th>
<th>Radiation level (Mrad)</th>
<th>Storage temperature (°F)</th>
<th>0</th>
<th>3</th>
<th>6</th>
<th>9</th>
<th>12</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cod</td>
<td>Without antioxidant</td>
<td>0</td>
<td>0</td>
<td>55.3</td>
<td>53.1</td>
<td>54.9</td>
<td>55.8</td>
<td>50.5</td>
</tr>
<tr>
<td></td>
<td>Without antioxidant</td>
<td>4.5</td>
<td>72</td>
<td>55.2</td>
<td>45.0b</td>
<td>44.6b</td>
<td>46.6b</td>
<td>40.4b</td>
</tr>
<tr>
<td></td>
<td>With Tenox VI</td>
<td>4.5</td>
<td>72</td>
<td>54.0b</td>
<td>46.7b</td>
<td>46.6b</td>
<td>48.2b</td>
<td>37.3b</td>
</tr>
<tr>
<td></td>
<td>With THBP</td>
<td>4.5</td>
<td>72</td>
<td>49.8b</td>
<td>41.9b</td>
<td>39.7b</td>
<td>42.0b</td>
<td>37.7b</td>
</tr>
<tr>
<td>Halibut</td>
<td>Without antioxidant</td>
<td>0</td>
<td>0</td>
<td>64.2</td>
<td>60.0</td>
<td>65.5</td>
<td>61.2</td>
<td>63.0</td>
</tr>
<tr>
<td></td>
<td>Without antioxidant</td>
<td>4.5</td>
<td>72</td>
<td>63.0b</td>
<td>57.4b</td>
<td>65.6</td>
<td>62.2b</td>
<td>57.1b</td>
</tr>
<tr>
<td></td>
<td>With Tenox VI</td>
<td>4.5</td>
<td>72</td>
<td>63.4b</td>
<td>55.4b</td>
<td>53.5b</td>
<td>53.0b</td>
<td>47.6b</td>
</tr>
<tr>
<td></td>
<td>With THBP</td>
<td>4.5</td>
<td>72</td>
<td>62.5b</td>
<td>56.4b</td>
<td>60.5b</td>
<td>58.4b</td>
<td>54.6b</td>
</tr>
</tbody>
</table>

\( ^a \) Per cent reflectance.

\( ^b \) Significantly different from the control at 5% significance level.
the length of storage and were a measure of the degree of browning of the radiation-sterilized sea food products.

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Reference to a company or product name does not imply approval or recommendation of the product by the US Army or Oregon State University to the exclusion of others that may be suitable.

The authors express their thanks to Lois A. Sather, in charge of the Flavorium, Department of Food Science and Technology, for conducting the many flavour panels and assisting in the interpretation of results, and also the following companies: Eastman Chemical Products, Inc., Kingsport, Tenn, and Evans Chemetics, Inc., New York, N.Y. for the antioxidant samples, and Swift and Co., Kearney, New Jersey, for the Viscomix.

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INVESTIGATIONS ON PASTEURIZATION OF COLD MARINADES BY $^{60}$Co GAMMA RAYS

W. SCHÖNBORN, H. J. KINKEL AND W. HAFFERL
BATTLE e. V., FRANKFURT/MAIN
FEDERAL REPUBLIC OF GERMANY

Abstract — Résumé — Аннотация — Resumen

INVESTIGATIONS ON PASTEURIZATION OF COLD MARINADES BY $^{60}$Co GAMMA RAYS.

Marinated herring fillets are a fish product matured under the action of acetic acid and salt and marketed in a spiced brine containing about 3% salt and acetic acid (pH 4). Since the usual addition of the preservative hexamethylene-tetramine has been restricted to a limited period of time by the new German food law, investigations were made on pasteurization by means of ionizing rays, as a new method of preservation without the addition of other preservatives.

Decay of this food product was caused by heterofermentative lactic-acid bacteria, which decarboxylated the amino acids set free from the protein; the decay was a result of carbon dioxide bombardment.

The marinades were packed into flat tins holding about 125 g, and exposed to $^{60}$Co gamma rays from an under-water source, while being cooled. The shelf life of the tinned marinades was extended by the irradiation. The period up to bombardment at 15°C was three times as long as usual in cases of irradiation with 155 krad. The critical number of 1 million germs per ml at 15°C was also reached after a period three times as long as usual upon irradiation with 160 krad. The LD$_{99}$ of three isolated strains of lactic-acid bacteria irradiated in a salt-peptone solution was 113, 165 and 144 krad, respectively. Since at 15°C the growth of the germs is retarded, while at 20°C it is practically unrestrained, the period of durability at a storage temperature of 18°C could only be doubled by irradiation with 280 krad.

The organoleptic tests were based on preference analyses by means of the nine-step Hedonic scale, and on difference tests (triangle test) and were performed by a panel. At 70 krad the taste is still acceptable, at 140 krad there is a distinct taste of rays and at 280 krad the taste is disagreeable. A distinct improvement in taste is achieved by irradiation at low temperatures (≤30°C) and by the addition of ascorbic acid, sorbitol and spices. The experiments are being continued.

RECHERCHES SUR LA PASTEURISATION A FROID DE MARINADES PAR LES RAYONS GAMMA DU $^{60}$Co.

Les filets de harengs marinés sont un produit macéré sous l'action d'acide acétique et de sel et vendu dans une saumure épicée contenant environ 3% de sel et d'acide acétique (pH 4). Étant donné que la nouvelle législation allemande sur les denrées alimentaires vient de réduire à une période limitée l'admission habituelle d'hexaméthylène-tétramine qui sert d'agent de conservation, les auteurs ont procédé à des recherches sur la radiopasteurisation comme méthode nouvelle de conservation sans addition d'agents chimiques.

La corruption de ce produit alimentaire a été causée par l'hétérofermentation due aux bactéries formant l'acide lactique, qui ont décarboxylé les acides aminés provenant des matières protéiques; cette corruption était accompagnée d'un dégagement d'anhydride carbonique.

Les marinades ont été mises dans des boîtes de conserve plates d'une contenance d'environ 125 g et exposées, pendant la réfrigération, à des rayons gamma provenant d'une source de $^{60}$Co sous écran d'eau.

L'irradiation a augmenté la durée de conservation des marinades en conserve. La période précédant la formation d'anhydride carbonique à 15°C était trois fois plus longue qu'habituellement, après irradiation à 155 krad. Le nombre critique de 1 million de germes par ml à 15°C a également été atteint dans un délai trois fois plus long qu'habituellement, après irradiation à 160 krad. La DL$_{99}$ de trois souches isolées de bactéries formant l'acide lactique irradiées dans une solution de sel-peptone était respectivement de 113, 165 et 144 krad. Comme à 15°C la croissance des germes est retardée, tandis qu'à 20°C elle n'est virtuellement pas entravée, la période de conservation à une température de 18°C ne pourrait être que doublée par une irradiation à 280 krad.

Les essais organoéléptiques, fondés sur des analyses préférentielles effectuées à l'aide de l'échelle hédonistique des qualités (neuf degrés), ainsi que sur des essais différentiels (test du triangle), ont été faits par un groupe d'experts. À 70 krad, le goût est encore acceptable; à 140 krad, un goût d'irradiation très net est perceptible; à 280 krad, le goût est franchement désagréable. Une amélioration sensible...
du goût peut être obtenue par une irradiation à basse température (−30°C) et par l'addition d'acide ascorbique, de sorbitol et d'épices. Les expériences se poursuivent.

1. INTRODUCTION

Cold marinades are very popular fish products in the Federal Republic of Germany. They consist of herring cured by the action of acetic acid and salt, and marketed in a spiced pickle containing around
3% common salt and 1.5% acetic acid with a pH value of about 4. When the authors' investigations were started the usual addition of hexamethylene-tetramine had been restricted by the country's food legislation to a limited period of time. For this reason pasteurization by means of ionizing rays was examined for its suitability as a method of preservation without preservatives.

2. MATERIALS AND METHODS

Investigations on marinated herring involve a number of difficulties: in spite of its acid content, this product is subject to variations in taste; because of the high fat content, in particular, it was likely that irradiation would entail variations in taste. Moreover, large differences in the quality of the product were to be expected as a function of size, fat content, sex, age and maturity of the herrings landed. The additions of vinegar and salt to the pickle have to be adapted to these different properties, which is done on the basis of the experience gained by the pickling expert. To illustrate these variations, Table I gives the salt content of seven batches examined, and Table II shows the fat content of twenty-eight samples. The varying fat content of the different herrings involves difficulties, especially in organoleptic investigations, because the examiner is compelled to try a large quantity of fish before he can give his opinion.

The investigations were conducted on marinated herring fillets supplied from the current production of the "Nordsee, Deutsche Hochsee-Fischerei GmbH". The pickle contained around 1.3% common salt, 0.5% vinegar and liquid spices, but no preservatives. The marinades were packed in flat tins holding 90 g fish and 45 g pickle. The tins were lined with an epoxy resin, which showed no signs of damage after irradiation with 2 Mrad.

Irradiation was done in the under-water $^{60}$Co source of the Battelle Institut. The tins to be irradiated were placed in a special container which allowed cooling. To achieve homogeneous radiation they were turned on a revolving table during the irradiation.

The dose-rate was determined with iron sulphate solution in small dosimeter tubes inserted in the tins at different places. Decrease in the dose-rate in the tins, which were about 25 mm thick, was approximately 6%, thus being negligible for the practical problem under investigation. The dose-rate figures are based on the value in the middle of the tin. At the beginning of the experiments the dose-rate was 57,000 rad/h.

The microbiological investigations were performed according to a schedule which extended over 51 weeks. They comprised examinations of the marinades for their shelf life, as a function of the radiation dose, at temperatures of 7 and 15°C. The marinades were irradiated with $^{60}$Co γ-rays of 50, 100, 200, 300 and 400 krad at 2°C. Bacterial growth, as a function of the storage time, was investigated by taking samples at fixed time intervals. A certain number of tins was stored up to spoilage of the marinades, which manifests itself by swelling of the tins. Since the large supply of samples to be investigated had to be distributed over a fairly extended period of time, the material was delivered in seven supplies.

1 The authors are grateful to Messrs. Nowack and Jendrusch.
TABLE I. COMMON SALT CONTENT OF HERRING MARINADES

<table>
<thead>
<tr>
<th>Batch (No.)</th>
<th>Date</th>
<th>Number of analyses</th>
<th>Salt content (%)</th>
<th>Mean</th>
<th>Minimum</th>
<th>Maximum</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>21/8/1963</td>
<td>8</td>
<td>1.76</td>
<td>1.76</td>
<td>2.60</td>
<td>2.9</td>
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<tr>
<td>2</td>
<td>5/9/1963</td>
<td>22</td>
<td>3.37</td>
<td>3.37</td>
<td>2.92</td>
<td>3.62</td>
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<tr>
<td>3</td>
<td>19/9/1963</td>
<td>14</td>
<td>3.07</td>
<td>3.07</td>
<td>2.63</td>
<td>3.40</td>
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<tr>
<td>4</td>
<td>2/10/1963</td>
<td>10</td>
<td>3.23</td>
<td>3.23</td>
<td>3.09</td>
<td>3.51</td>
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<tr>
<td>5</td>
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<td>4.04</td>
<td>3.78</td>
<td>4.40</td>
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<tr>
<td>6</td>
<td>25/11/1963</td>
<td>4</td>
<td>2.86</td>
<td>2.86</td>
<td>2.78</td>
<td>2.90</td>
</tr>
<tr>
<td>7</td>
<td>19/12/1963</td>
<td>2</td>
<td>2.46</td>
<td>2.46</td>
<td>2.18</td>
<td>2.73</td>
</tr>
</tbody>
</table>

TABLE II. FAT CONTENT OF 28 HERRING MARINADES

<table>
<thead>
<tr>
<th>Fat (%)</th>
<th>Sample marinades (No.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt; 10</td>
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</tr>
<tr>
<td>10.1 - 12.0</td>
<td>7</td>
</tr>
<tr>
<td>12.1 - 14.0</td>
<td>3</td>
</tr>
<tr>
<td>14.1 - 16.0</td>
<td>9</td>
</tr>
<tr>
<td>16.1 - 18.0</td>
<td>4</td>
</tr>
<tr>
<td>&gt; 18</td>
<td>2</td>
</tr>
</tbody>
</table>

(batches). Owing to the heterogeneity of these different batches, the individual values obtained from the experiments showed major variations. Nevertheless, the overall evaluation furnished mean values which may be regarded as representative of this fish product.

3. RESULTS

3.1. Microbiology

At a storage temperature of 7°C the shelf life of the unirradiated marinades up to spoilage ranged between 30 and 40 weeks. During this period the quality of the product is distinctly reduced, even without bacterial spoilage. Irradiation, therefore, does not extend the shelf life
Radiation dose (krad)

FIG. 1. Storage life extension of herring marinates at 15°C after irradiation with 60Co gamma rays (a = standard deviation)

TABLE III. BACTERIAL GROWTH IN MARINADES AT A STORAGE TEMPERATURE OF 7°C

<table>
<thead>
<tr>
<th>Radiation dose (krad)</th>
<th>Microorganisms/ml</th>
<th>After weeks (No.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>10^7</td>
<td>10</td>
</tr>
<tr>
<td>50 krad</td>
<td>10^4</td>
<td>10</td>
</tr>
<tr>
<td>100 krad</td>
<td>10^3</td>
<td>20</td>
</tr>
<tr>
<td>200 krad</td>
<td>10^3</td>
<td>25</td>
</tr>
<tr>
<td>300 krad</td>
<td>10^3</td>
<td>30</td>
</tr>
<tr>
<td>400 krad</td>
<td>10^3</td>
<td>35</td>
</tr>
</tbody>
</table>

at this storage temperature, although bacterial growth is considerably retarded by irradiation with doses of 100 krad and more (Table III).

At a storage temperature of 15°C, the average shelf life of unirradiated marinades up to spoilage is 39.5 d. The minimum value was 21 d,
the maximum value 63 d. Figure 1 shows the shelf life, in weeks, as a function of irradiation. This figure has been plotted on a semi-logarithmic scale, which is the most suitable for this illustration. An extension of the shelf life from 33 d to a period three times as long is achieved by a radiation dose of 180 krad.

A similar result is obtained on the basis of bacterial growth. For example, it may be said that, at a critical number of 1 million microorganisms/ml the shelf-life limit is exceeded. In the case of untreated marinades this limit is reached after 1.5 weeks. Figure 2 shows that this shelf life is extended to a period three times as long by irradiation with a dose of about 160 krad. When related to the critical number of microorganisms, radiation dose and shelf life are directly proportional to each other.

Figure 3 illustrates an experiment which was aimed at a more accurate determination of the radiation dose required for an extension of the shelf life. In contrast to the preceding investigations, the experiment was made on marinades of the same batch. The temperature was 18°C.

The unirradiated marinades were spoiled after 33.2 d, thus having about the same shelf life as the seven batches examined in the preceding investigations. In the narrow dose range between 120 and 280 krad, it was possible to assume a direct proportionality between radiation dose and shelf life. It is then found that a radiation dose of about 290 krad is necessary to extend the storage life at 18°C by a factor of 2.

The microflora of fresh marinades was poor in species and number of microorganisms. To determine the number of microorganisms, the total
contents of the tin (fish and pickle) were homogenized. Up to 1500 yeasts/ml of homogenized material were found; their number decreased with increasing storage time, or increased only temporarily. In addition, the marinades contained a spore former which reached a maximum number of 100,000/ml, and decreased upon extended storage; in part, this bacillus was present in the form of spores. Pediococcus cerevisiae was observed occasionally.

The microorganisms responsible for spoilage are heterofermentative Lacto bacilli [1]. These are Gram-positive immobile rod bacteria lacking catalase and urease, which are not capable of reducing nitrate. Their number was below 50/ml of fresh marinades. Their number increases as a function of storage time and temperature. The growth of these microorganisms depends on the presence of free amino acids which are decarboxylated to the corresponding amines while energy is gained. As soon as a threshold value of 0.25% free amino acids - referred to the total mass - is exceeded, the carbon dioxide released may be sufficient to effect spoilage. According to Meyer [2], the first traces of amines can be chemically identified as decarboxylation products as soon as the bacterial count reaches 10⁷ microorganisms/ml. Occasionally, there is an early peak in the bacterial number, which is followed by a renewed increase in bacterial population that finally leads to spoilage. This may be interpreted in terms of the assumption that, up to this maximum, the
free amino acids originally present have been consumed, while the liberation of any further amino acids by hydrolysis of the fish meat takes place at a low rate.

The nutrient medium most suitable for cultivation and counting of the Lactobacilli had the following composition: 6% extract of malt, 0.5% glycerol, 0.5% common salt, 0.5% peptone and 1.8% agar, left at its natural acidity of pH = 5.

Twenty strains of Lactobacilli were isolated from the marinades. By interaction with glucose all of them formed lactic acid, acetic acid and formic acid. There were major differences between the individual strains with regard to their capability of fermenting various mono-, di- and trisaccharides, as well as glycosides. There is a minor delay in their growth rate at temperatures of 15°C. Already at 20°C the growth has reached its optimum rate. Among the heterofermentative lactic acid bacteria they fit best into the group of Lactobacillus brevis, Buchneri.

The inactivation by $^{60}\text{Co}\gamma$-radiation was investigated on three isolated strains. Pre-cultivation of the strains was done according to Schmidt-Lorenz [3]. The microorganisms were irradiated in a suspension containing 1 million cells/ml common salt-peptone solution (0.85% common salt, 0.1% peptone). The Lactobacilli proved to be fairly insensitive to irradiation. The D-value (LD$_{90}$ = decimal irradiation-reduction dose) totalled 67, 84 and 77 krad, respectively; this corresponds to MLD (Mean Lethal Dose = LD$_{63}$ = D$_{0}$-value) of about 40 krad. Figure 4 shows the inactivation curves. The line for the lc strain and the B5 strain does not pass through the point "100% survival", as would be required by the 1-hit theory. Among other things, this has to be attributed to the fact that Lactobacilli form cell chains which cannot be separated into single cells, even by shaking with glass beads. Table IV shows the relative frequencies at which single cells and cell chains occur in these strains. An accurate analysis would require the determination of the number of nucleoids for each cell.

3.2. Organoleptic appraisal

Comprehensive tests have been performed to ensure that the irradiated marinades are acceptable from the organoleptic point of view. The tests included both preference analysis, with the nine-step hedonic scale [4], and also difference tests (triangle test) [5]. The panel comprised at least ten members, male and female.

At an irradiation dose of 70 krad the taste was not affected at all. At 140 krad there was a distinct irradiation flavour. Marinades exposed to a dose of 280 krad were rejected. This result is in agreement with the experience made by Wittfogel [7].

Since irradiation with doses of 70 krad is not sufficient to achieve an adequate extension of storage life, attempts were made to prevent off-flavours, caused by the irradiation, by the addition of radical scavengers, and similar measures, in order to render higher radiation doses possible. Numerous conventional additives were tried out.

Nicotinic acid in a concentration of 0.12 g/l of fish plus pickle remained ineffective.
FIG. 4. Survival curves for four strains of Lactobacilli: lc(●), 2a(x) and B5 (□) after irradiation with $^{60}$Co gamma rays (dose-rate 92 000 rad/h)

### TABLE IV. RELATIVE FREQUENCY OF THE OCCURRENCE OF SINGLE CELLS AND CELL CHAINS IN THE STRAINS lc, 2a and B5

<table>
<thead>
<tr>
<th>Strain</th>
<th>Single cells</th>
<th>Chains comprising 2</th>
<th>Chains comprising 3</th>
<th>Chains comprising 4</th>
<th>Chains comprising 5 and more cells</th>
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</thead>
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<td>1.2</td>
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<td>0.8</td>
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<tr>
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<td>0.1</td>
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<td>-</td>
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<tr>
<td>B5</td>
<td>1</td>
<td>2</td>
<td>1</td>
<td>8.5</td>
<td>9.5</td>
</tr>
</tbody>
</table>

The addition of sorbic acid in a concentration of 0.067 g/l appeared to reduce the irradiation flavour, but at the same time led to rancidity – also if combined with ascorbic acid.

The most favourable effect was observed with ascorbic acid. A concentration of 3.3 g/l was sufficient to reduce the irradiation flavour markedly. In addition, ascorbic acid was used, together with chelating agents. Citric acid (e.g. 0.5 g/l) entailed quick softening of the fish meat. A more satisfactory effect was achieved with sorbitol in a concentration of
3 g/l; this compound neutralizes the acidity of ascorbic acid by its sweetening power.

Irradiation not only effects a new unpleasant taste, but also impairs the spicy flavour of marinades. Hence, experiments have been performed where the samples were treated with higher quantities of liquid spices, or with dry spices. It was found that the conventional dry marinade spices composed of pepper, juniper berries and the grain of mustard seed, reduce and mask the irradiation flavour. To prevent harmful bacteria, such as microorganisms forming butyric acid, being entrained by the dry spices, the spices have to be sterilized beforehand. This may be done with ethylene oxide.

It was further possible to improve the taste by carrying out the irradiation at -30°C.

These results gave rise to the following combined treatment:

- The addition of 3.3 g ascorbic acid and 3 g sorbitol per litre fish plus pickle, the addition of dry spices, and irradiation at -30°C. This combination furnished the following result:
  - No difference from the unirradiated samples is observed upon irradiation with a dose of 70 krad. In most cases the irradiated product is rated even higher than the unirradiated marinades.
  - No difference from the unirradiated marinades is observed upon irradiation with a dose of 140 krad.

Exposure to rays of 210 krad partly results in variations in taste. The extent of these variations depends on the quality of the fish products. High-quality fish tolerates higher radiation doses.

Another question examined was whether the variations in taste can be reduced by irradiation at higher radiation intensities. Dose-rate dependencies have been repeatedly discussed [6], but rarely determined.

Two preparations of the marinades, i.e. the combination described above, and a sample without these additions, were submitted to Wantage Research Laboratory, United Kingdom Atomic Energy Authority, and exposed to a dose-rate of $10^3$ krad/h$^2$. At the same time, parallel samples were irradiated at a dose-rate of 33 krad/h at Battelle Institut. At all the doses applied, i.e. at 70, 140 and 280 krad, no differences in flavour were observed. In one case, where the marinades containing the additions were exposed to a dose of 140 krad, the marinades exposed to the lower dose-rate were given an even better rating. In the other five batches no statistically reliable differences [8] were observed.

4. SUMMARY

Summing up, it may be established that the shelf life of vinegar-salt-cured herring marinades can be increased from about 33 d to 99 d, without chemical preservatives, by irradiation with $^{60}$Co γ-rays of 160 krad at a storage temperature of 15°C. The taste is perfectly satisfactory if the marinades are treated, prior to the irradiation, with dry spices and 3.3 g ascorbic acid and 3 g sorbitol per litre of marinade, carrying out the irradiation at -30°C.

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2 The authors thank Messrs. F. J. Ley and L. J. Crook for their valuable assistance in the performance of this test series.
ACKNOWLEDGEMENT

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REFERENCES


STERILIZATION OF PRESERVED FISH BY GAMMA RADIATION. Experiments in which various vacuum-packed fish products (boiled, fried and stuffed fish, fried fish fillets, hot-smoked fish) were subjected to irradiation showed that doses of 1.5 to 2.0 Mrad sterilize the products but have an adverse effect on their organoleptic properties. During storage the fat of the irradiated product is damaged by oxidation, and colloidal senescence of albuminous tissues accompanied by synaeresis occurs.

To prevent these undesirable changes the author tried lowering the pH of the product and introducing carotinoids, ascorbic acid, etc., using commercial tomato sauces and vegetable dressings for the purpose. Pieces of fish (catfish, carp, cod, pike-perch) were cooked until ready for eating, placed in glass preserve jars and vacuum-sealed. For purposes of comparison, samples of the same products were autoclaved.

The fish were then subjected to doses of 0.2 to 2.0 Mrad of gamma radiation from a 60Co source at a dose-rate of 800 rad/s.

Both the irradiated and autoclaved products were analysed immediately after processing, and again after certain temperature tests and periods of storage. Microbiological, chemical, electrophoretic, spectrophotometric, physico-chemical and organoleptic tests were performed on them. It was shown that a dose of 1.5 Mrad is sufficient to sterilize such products. The bactericidal action of the radiation was more effective in these tests than in the irradiation of fresh fish. The quality of the irradiated product, both immediately after irradiation and after a year of storage, did not differ from the quality of un-irradiated fish and was better than that of the autoclaved samples. Moreover, there was less change in the quality of the fat and a smaller reduction in the content of vitamins and amino acids in the irradiated product.

Preserved fish products sterilized by gamma radiation can be kept for more than 2½ years without any substantial changes.

STERILISATION DES CONSERVES DE POISSON AU MOYEN DES RAYONS GAMMA. Les expériences d’irradiation de préparations de poisson (poisson bouilli, frit, farci, croquettes de poisson, poisson fumé à chaud) empaquetées sous vide ont montré que des dosages de 1,5 à 2,0 Mrad stérilisent le produit, mais causent une détérioration des indices organoleptiques. Dans le processus de conservation du produit ainsi irradié, on a observé une détérioration acide de la graisse et un vieillissement colloïdal des tissus albumineux, avec apparition de synéreses.

Pour prévenir ces modifications indésirables, on a essayé d’abaisser le pH du produit, d’introduire des caroténoïdes, de l’acide ascorbique, etc., en utilisant des sauces culinaires à base de tomates ou des marinades. On a fait frire des morceaux de poisson (silure, carpe, monse, sandre), puis on les a placés dans des bocaux en verre, qui on été mis sous vide et cachetés. Aux fins de comparaison, le même produit a été stérilisé en autoclave.

L’auteur a effectué des essais avec des doses de 0,2 à 2,0 Mrad de rayons gamma provenant d’une source au cobalt-60 ayant une intensité de dose de 800 rad/s.

Les produits irradiés et les produits stérilisés en autoclave ont été soumis à des analyses immédiatement après le traitement, après avoir été exposés à diverses températures et après certains délais de conservation. L’auteur a procédé à des recherches microbiologiques, chimiques, électrophorétiques, spectrophotométriques, physico-chimiques et organoleptiques. Il a constaté que la dose de 1,5 Mrad avait un effet stérilisant. En pareil cas, l’action bactéricide de l’irradiation est plus efficace que celle de l’irradiation du poisson frais. Aussitôt après l’irradiation et après un an de conservation, la qualité du produit irradié
ne différait pas de la qualité du produit non irradié et était meilleure que celle des échantillons stérilisés en autoclave. L'auteur a également observé une altération moins importante de la qualité de la graisse et une diminution plus faible de la teneur en vitamine et en aminocides dans le produit irradié.

Les préparations de poisson stérilisées par irradiation gamma se conservent sans altération notable pendant plus de deux ans et demi.

**РЫБНЫЕ КОНСЕРВЫ ГАММА-РАДИАЦИОННОЙ СТЕРИЛИЗАЦИИ.** Эксперименты облучения рыбной кулинарии (вареной, жареной, фаршированной рыбы, жареных рыбных котлет, рыбы горячего копчения), упакованной под вакуумом, показали, что дозы 1,5 - 2,0 Мрад стерилизуют продукт, но вызывают ухудшение органолептических показателей. В процессе хранения такого облученного продукта замечена окислительная порча жира и коллоидное старение белковых тканей с явлением синерезиса.

Для предотвращения этих нежелательных изменений было испытано понижение pH продукта, введение каротиноидов, аскорбиновой кислоты и др. путем использования деликатесных соусов из томата, овощного маринада. Куски рыбы (сом, кarp, треска, судак) были обжарены до кулинарной готовности, помещены в стеклянные консервные банки, вакуумированы и укупорены. Для сравнения этот же продукт был автоклавирован.

Испытывались дозы 0,2 - 2,0 Мрад гамма-лучей кобальта-60 при помощи дозы 800 рад/сек.

Использование автоклавированных продуктов ведет к значительному ухудшению качества. Вероятность сохранения жировой ткани на протяжении более двух лет минимальна.

**ESTERILIZACION DE CONSERVAS DE PESCADO POR IRRADIACION GAMMA.** La irradiación experimental de diversos productos pesqueros empaquetados al vacío (pescado hervido, frito y relleno, filetes fritos de pescado y pescado ahumado) ha demostrado que las dosis de 1,5 - 2,0 Mrad los esterilizan, pero ejercen una influencia perjudicial sobre sus propiedades organolépticas. Durante su almacenamiento, la grasa de los productos irradiados se deteriora por oxidación y se observa además un envejecimiento de los tejidos alburninos acompañado de sinéresis.

Para evitar estos cambios indeseables se redujo el pH de los productos y se introdujeron en los mismos carotenoides, ácido ascórbico, etc. por medio de salas de tomate y marinadas de legumbres. Se cocieron trozos de diversos pescados (pez gato, carpa, baccala y solloperca) hasta dejarlos listos para el consumo y se colocaron después en recipientes de cristal que se cerraron al vacío. Con fines de comparación, se trataron en autoclave muestras de los mismos productos.

Se utilizaron dosis de 0,2-2,0 Mrad de rayos gamma procedentes de una fuente de cobalto-60, siendo la intensidad de la dosis de 800 rad/s.

Tanto los productos irradiados como los tratados en autoclave se analizaron inmediatamente después de su tratamiento, y de nuevo después de ciertas pruebas de temperatura y en diferentes períodos de almacenamiento. Fueron sometidos a ensayos microbiológicos, químicos, por electroforesis, espectrofotométricos, físicoquímicos y organolépticos. Se observó que una dosis de 1,5 Mrad basta para esterilizar tales productos. La acción bactericida de la irradiación fue más eficaz en estos ensayos que en la irradiación de pescado fresco. La calidad del producto irradiado, tanto inmediatamente después de la irradiación como después de un año de almacenamiento, no se distingue de la del producto sin irradiar y fue superior a la del producto tratado en autoclave. Igualmente, la grasa de los productos irradiados experimentó menos cambios y disminuyó menos el contenido de vitaminas y aminoaídos.

Las conservas de pescado esterilizadas por irradiación gamma pueden conservarse durante más de dos años y medio sin cambios sustanciales.
снижения питательных свойств в продуктах при применении высоких доз не установлено.

Дозы радиации 1-2 Мрад являются стерилизующими для большинства видов микроорганизмов. Но такие дозы не обеспечивают инактивацию тканевых ферментов: при хранении облученной свежей рыбы и мяса продолжается автолитический процесс, ограничивающий срок хранения продуктов.

Установлено, что неприятный запах и привкус в результате облучения вызван образованием ряда веществ, являющихся продуктами распада аминокислот, жира и других компонентов продукта. Известно, что при облучении растворов аминокислот можно уменьшить выход продуктов радиолиза (например, аммиака сероводорода) снижением pH [1]. Введение в продукт некоторых антиокислителей, акцепторов свободных радикалов уменьшает образование постороннего запаха и привкуса у облучаемого продукта.

Мы поставили себе цель создать полноценный консерв гамма-радиационной стерилизации из рыбы путем подбора оптимального pH, введения в продукт природных веществ, которые применяются в кулинарии и имеют указанные свойства предотвращать нежелательные изменения основных компонентов продукта при облучении.

Были поставлены широкие опыты облучения жареной рыбы при разной глубине экскгастурирования воздуха с последующим ее хранением. Предварительно было изучено влияние содержания воздуха в банке при облучении и хранении жареной рыбы.

Рыбу помещали в стеклянные консервные банки, вакуумировали, укупоривали и облучали различными дозами гамма-радиации при мощности дозы около 800 рад/сек [2, 3, 4].

Эти опыты показали, что обжарка рыбы до кулинарной готовности надежно инактивирует тканевые ферменты и большинство микроорганизмов. Однако, обжарочное растительное масло на кусках рыбы вне зависимости от величины остаточного парциального давления кислорода быстро приобретало окислительную порчу.

Затем было испытано снижение pH путем заливки обжаренных кусков рыбы раствором уксусной кислоты разной концентрации. Эти опыты показали, что снижение pH до приемлемой для вкуса величины уменьшает образование запаха и привкуса облучения, но не предотвращает в значительной мере окислительную порчу растительного масла и жира рыбы. Тогда была поставлена серия опытов с томатными соусами, приготовленными по рецептуре, принятой в СССР. Ингредиентами заливки являются: томат-паста, уксусная кислота, сахар, вода и пряности (перец, лавровый лист и др.). В опыте варьировалось содержание томата-пасты и уксусной кислоты. Необходимо отметить, что консерв из жаренной рыбы в томатном соусе является популярным в СССР закусочным продуктом. Однако консерв автоклавной стерилизации существенно отличается от аналогичного кулинарного изделия.

Консерв гамма-радиационной стерилизации из такого кулинарного изделия при оптимальном соотношении томата-пасты и уксусной кислоты почти полностью сохранял при хранении более двух лет качество кулинарного изделия: плотное мясо, естественный цвет заливки, аромат и вкус. В нем не обнаруживалась окислительная порча жира. Куски жаренной рыбы пропитывались растворимыми веществами заливки и обвола-
кивались с поверхности томат-пастой, которая, как известно, содержит витамин C и витамины группы B, каротиноиды и другие вещества, имеющие антиокислительные свойства.

В других опытах облучали разными дозами деликатесный закусочный продукт — жареный карп в овощном маринаде. Последний представлял собой набор бланшированных овощей (морковь, петрушка, лук) соус из томата-пасты с пряностями, уксусом, сахаром. В этом опыте были использованы подобраные ранее соотношения томата-пасты и уксусной кислоты. Также как и в прежних опытах подбирались стерилизующие дозы.

ТАБЛИЦА 1. ЛОГАРИФМ ЧИСЛА МИКРООРГАНИЗМОВ В 1 г ПРОДУКТА В ЗАВИсимости ОТ ДОЗЫ РАДИАЦИИ (Мрад)

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<td>-</td>
<td>-</td>
<td>7</td>
<td>5</td>
<td>Стерильно</td>
</tr>
<tr>
<td></td>
<td>720</td>
<td>-</td>
<td>-</td>
<td>3</td>
<td>Дрожжи</td>
<td>Стерильно</td>
</tr>
</tbody>
</table>

Микробиологические определения (табл. 1) показали, что резкое уменьшение содержания микроорганизмов в результате обжарки рыбы, снижения рН продукта до 5,2 - 5,5 усилили эффективность действия радиации и даже доза 1,0 Мрад для многих образцов была стерилизующей.

Обычно обжаренные куски рыбы содержали единицы или десятки микроорганизмов в грамме тканей. Однако соус несмотря на то, что он приготавлялся варкой, содержал значительное количество микроорганизмов (дрожжей, грибков), которые попадали в него с мукой и пряностями. Определение видового состава остаточной микрофлоры показало, что при нестерильзующих дозах в продукте обнаруживаются кокки, споровые формы, термофильные микрококки, дрожжи, уксуснокислые микроорганизмы и др. Большой коллекционный материал облученных продуктов был проверен
на содержание микроорганизмов через два и четыре года после хранения при комнатной температуре — все образцы облучение дозой 1,5 Мрад были стерильными.

Спектрофотометрические определения изменения содержания каротиноидов в томатной заливке, моркови показали, что доза 1,5 Мрад снижает их содержание в продукте в меньшей степени, чем автоклавирование. В процессе 2-х летнего хранения, содержание каротиноидов в водной фазе консервов обоих методов стерилизации выравнивается, а в растительном масле (на котором обжаривалась рыба) снижается у консерва лучевой стерилизации. Видимо, каротиноиды, перешедшие в масло, защищают его от аутоокислительной порчи, что показывает величина кислотного, перекисного числа и числа прогоркания. Эти показатели были одного порядка в масле консервов двух методов стерилизации (то-есть в пределах нормы).

ТАБЛИЦА 2. РАЗРУШЕНИЕ БЕЛКА ПРИ АВТОКЛАВИРОВАНИИ И ОБЛУЧЕНИИ (доза 1,5 Мрад) (% к исходному содержанию в контрольном образце)

<table>
<thead>
<tr>
<th>Виды продукта</th>
<th>Срок хранения, сутки</th>
<th>Потери (-) и прирост (+)</th>
<th>Доза 1,5 Мрад</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>белкового</td>
<td>свободных аминокислот</td>
</tr>
<tr>
<td>Треска, жаренная в томатном соусе</td>
<td>2</td>
<td>-0,5</td>
<td>-7,0</td>
</tr>
<tr>
<td></td>
<td>360</td>
<td>-0,5</td>
<td>+10,5</td>
</tr>
<tr>
<td>Автоклавир.</td>
<td>2</td>
<td>-10,5</td>
<td>-70</td>
</tr>
<tr>
<td></td>
<td>360</td>
<td>-10,5</td>
<td>-70</td>
</tr>
<tr>
<td>Карп, жаренный в овощном маринаде</td>
<td>2</td>
<td>-1,0</td>
<td>-1,5</td>
</tr>
<tr>
<td></td>
<td>360</td>
<td>-1,0</td>
<td>+150</td>
</tr>
<tr>
<td>Автоклавир.</td>
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<td>-5,5</td>
<td>-3,0</td>
</tr>
<tr>
<td></td>
<td>360</td>
<td>-6,0</td>
<td>+50</td>
</tr>
<tr>
<td>Треска свежая, облученная</td>
<td>0</td>
<td>-2,0</td>
<td>-25</td>
</tr>
</tbody>
</table>

При гамма-лучевой стерилизации жареной рыбы в томатном соусе и овощном маринаде, как видно из табл. 2, белки и свободные аминокислоты разрушаются в 5-20 раз меньше, чем при автоклавировании.

Снижение содержания свободных сульфгидрильных групп при автоклавировании, а также нарастание летучих азотистых оснований показывает более сильное окислительное и дезамирующее действие тепла, чем радиации.

При сравнении величины распада белковых веществ свежей рыбы при дозе 1,5 Мрад, облученной под вакуумом, и жаренной рыбе в томатном соусе при той же дозе видно, что вещества, содержащиеся в томат-
ном соусе защищают их от действия ионизирующих излучений, в том числе от окисления свободных сульфгидридных групп [5]. Чрез два года хранения при комнатной температуре белковые вещества консервов практически не изменились. Незначительно возросло содержание свободных аминокислот и летучих азотистых оснований, что вызвано видимо гидролизом белка раствором уксусной кислоты заливки. Не было обнаружено изменения качества жира.

Проведенные в разные сроки дегустации образцов консервов автоклавной и гамма-радиационной стерилизации показали полную их доброкачественность. Консервы гамма-радиационной стерилизации не имели постороннего привкуса и запаха, значительно отличались от консервов автоклавной стерилизации своим естественным вкусом, видом и консистенцией кусков рыбы, характерных для исходного кулинарного продукта. При хранении более двух лет в этом продукте обнаруживалось уплотнение тканей (наиболее существенное в образцах из трески), что вызвано коллоидным старением белков мяса рыбы. Консервы автоклавной стерилизации имели все обычные свойства баночных консервов — разрушенное варкой мясо, изменившийся (коричневый) цвет заливки, переваренные овощи.

Проведенные исследования показали практическую возможность получения стойкого доброкачественного рыбного консерва гамма-радиационной стерилизацией.

**ЛИТЕРАТУРА**


**DISCUSSION**

N. GRECZ: We have found that almost any treatment or factor that protects food also makes the microorganisms more resistant to radiation. I wonder whether this is also true with respect to the mixture of oil and carotenoid compounds in your fish products?

A. V. KARDASHEV: You are quite right. However, heat treatment (cooking) of the fish and the lowering of its pH created favourable conditions for radiation sterilization. The carotenoids and other protective substances enter the oil and fat of the fish, thereby preventing spoilage through oxidation. In addition, the tins containing the fish were filled with a hot sauce and immediately irradiated.

G. MOCQUOT: Is the product about which you spoke widely consumed in the Soviet Union, or was it prepared specially for irradiation?

A. V. KARDASHEV: It is a popular tinned commodity in the Soviet Union, but the recipe was modified to allow for preservation by gamma radiation.
H. WITTFOGEL: Your finding that a gamma dose of 1.5 Mrad did not affect the acceptability of fish products in tomato sauce is in complete contrast to the results we obtained in Cuxhaven, Germany, where doses of 75-150 krad rendered marinated herring completely unacceptable.
STATUS OF VARIOUS IRRADIATED COMMODITIES (cont.)
(Session VI)

E. FRUIT AND VEGETABLES
RECENT RESEARCH ON THE IRRADIATION OF FRUITS AND VEGETABLES*

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UNITED STATES OF AMERICA

Abstract — Résumé — Аннотация — Resumen

Radiation treatments of fruits and vegetables after harvest have evoked much interest for the control of market diseases, insect infestation, delay of ripening and prevention of growth. Radiation as a fungicidal treatment is of special interest because of its therapeutic action. Unfortunately, the dose is often severely limited by host sensitivity. The tolerance to irradiation varies among species and varieties and is influenced by ripeness at time of treatment. If destined for storage, commodities may be limited to a low dose because of delayed adverse effects. The suppression of a pathogen depends primarily on its sensitivity and the extent of lesion development. Commonly a large portion of small fungus lesions are inactivated while others are delayed. To date, radiation treatments have been most promising where disease problems were most serious, as in the treatment of highly perishable commodities that are harvested when ripe and contain established disease lesions when picked.

Presumably the fungicidal effect of radiation treatments could be greatly improved if pathogens could be made more sensitive, the host more resistant, or both. Use of a localized oxygen effect, chemical sensitization of pathogens, or shallow irradiation have presented formidable difficulties. More promise has been shown by combinations of radiation and heat which provide a striking synergism when used to inactivate fungi.

Gamma-irradiation inhibits ripening of some fruits but is stimulatory to others. In those fruits which are caused to ripen more rapidly by irradiation, ethylene production is stimulated. Fruits in which ripening is inhibited by irradiation apparently have a reduced sensitivity to the ripening action of ethylene, and also produce less ethylene before ripening. At doses of 20 to 35 krad, ripening is inhibited in bananas for 4 to 15 days depending on maturity and the amount of mechanical injury to the fruit. Irradiated fruits ripen to good quality when given a standard ethylene treatment.

Peaches and nectarines subjected to doses of gamma rays that might retard rots are excessively susceptible to transit injury. Papaya fruits show promise for gamma-ray control of the Hawaiian fruit fly. Irradiated fruits have 3 to 5 days longer shelf-life than fruits subjected to ethylene dibromide fumigation.

The present outlook for the radiation treatment of various fruits and vegetables is discussed.

sation d'un effet localisé de l'oxygène, la sensibilisation des organismes pathogènes par des produits chimiques ou l'irradiation à faible profondeur soulèvent de très grandes difficultés. Il serait plus facile de combiner l'action des rayonnements et celle de la chaleur, qui se conjuguent de manière remarquable lorsqu'on les utilise pour inacter des champignons.

L'irradiation gamma inhibe la maturation de certains fruits mais stimule celle d'autres fruits. Les fruits qui mûrissent plus rapidement lorsqu'ils sont exposés aux rayonnements produisent également une plus grande quantité d'éthylène. Les fruits dont la maturation est inhibée par l'irradiation semblent moins sensibles à l'action maturatrice de l'éthylène et produisent également moins d'éthylène avant d'arriver à maturation. À des doses de 20 à 35 krad, la maturation des bananes est inhibée pendant 4 à 15 jours suivant le degré de maturation et l'étendue des dommages mécaniques subis par le fruit. Les fruits irradiés atteignent un degré de maturation satisfaisant lorsqu'ils sont soumis à un traitement standard à l'éthylène.

Les péches et brugnons soumis à des doses de rayons gamma qui pourraient retarder le pourrissement sont exceptionnellement susceptibles d'altération en cours de transport. Il semble qu'en soumettant les papayes aux rayons gamma on pourrait les protéger contre les effets de la mouche hawaïenne des fruits. Après cueillette, les fruits irradiés peuvent être conservés pendant 5 à 10 jours de plus que les fruits soumis à la fumigation par le dibromure d'éthylène. Le mémoire étudie les perspectives actuellement offertes par l'irradiation de différents fruits et légumes.
siderablemente la dosis. La tolerancia a las radiaciones es distinta de unas especies y variedades a otras y depende del grado de madurez en el momento de la irradiación. Si los productos vegetales han de ser almacenados, la dosis que se les administra suele ser baja, debido a los efectos nocivos retardados. La eliminación de un agente patógeno depende sobre todo de su sensibilidad y de la magnitud de las lesiones. Corrientemente se inactiva gran parte de las pequeñas lesiones causadas por los hongos, mientras que se retarda el desarrollo de otras. Hasta la fecha, los tratamientos por irradiación han sido más eficaces cuando las enfermedades han presentado mayor gravedad, como en el caso de los productos altamente perecederos que se cosechan en estado de madurez y presentan lesiones patológicas caracterizadas en el momento de la recolección.

Al parecer, el efecto fungicida de la irradiación se intensificaría considerablemente si fuera posible incrementar la sensibilidad de los agentes patógenos, la resistencia del portador, o ambas cosas a la vez. El empleo de oxidantes localizados, la sensibilización de los agentes patógenos por vía química o mediante irradiación en bajas dosis presentan enormes dificultades. Mejores perspectivas ofrece la combinación de la irradiación y del tratamiento térmico, cuya acción concertada, cuando se utilizan para inactivar hongos, es sumamente eficaz.

Las radiaciones gamma inhiben la maduración de algunas frutas pero estimulan la de otras. Las frutas que maduran más rápidamente por irradiación producen mayor cantidad de etileno. Las frutas cuya maduración se inhibe por irradiación tienen, en apariencia, menor sensibilidad al efecto madurador del etileno y, además, producen menos etileno antes de madurar. Las dosis de 20 a 35 krad inhiben la maduración de los plátanos de 4 a 15 días, según el grado de sazón y la importancia de las deterioraciones mecánicas sufridas por la fruta. Las frutas irradiadas sometidas a un tratamiento con etileno maduran en buenas condiciones.

Las melocotones y pêrcicos sometidos a dosis de rayos gamma capaces de retardar la putrefacción son muy sensibles a los daños debidos al transporte. La irradiación de papayas con rayos gamma para eliminar la mosca de la fruta de Hawaii presenta perspectivas alentadoras. El período de almacenamiento de las frutas irradiadas es de 3 a 5 días mayor que el de las frutas sometidas a fumigación con dibromuro de etileno. En la memoria se examinan las perspectivas que ofrece la irradiación de varias frutas y verduras.

INTRODUCTION

Postharvest treatment of fruits and vegetables by irradiation has been suggested because of several possible beneficial effects. Softening, as a consequence of irradiation might be a method of providing a more tender product in the case of dry beans [1] or prunes [2], and might permit more rapid drying of prunes [1]. The astringency of persimmons might be reduced by gamma irradiation [3]. Partial control of physiological disorders, such as scald or brown core in apples, has been reported [4]. Inhibition of sprouting of harvested garlic [5] or onion bulbs [6] or potato tubers [7] may lead to longer retention of high quality. Radiation-enhanced delays in ripening may extend the shelf life of certain fruits [8]. Insect control by radiation has been suggested by research on eliminating Oriental fruit fly from fruits of papaya, cucumber, litchi, and tomato, and seed weevils from mango fruits [9]. The greatest interest, however, has been evoked by the fungicidal properties of radiation and the shelf life extension and/or loss avoidance gained from postharvest disease control [10].

This paper discusses recent research on and the present status of irradiation of fruits and vegetables. Major attention is given to problems relating to the use of radiation as a fungicidal treatment. Also considered is the physiological response of fruits and vegetables to irradiation.

RADIATION FOR POSTHARVEST DISEASE CONTROL

It is now clearly seen that the greatest potential advantage of gamma irradiation as a fungicidal treatment is penetration of tissues
making a therapeutic treatment of the infected host possible. The pathogen growing within host tissue can be inactivated or its growth delayed sufficiently to permit increased time for marketing or reduce losses during normal marketing periods. With chemicals, a therapeutic treatment is usually impossible because there is little or no penetration into host tissues. Instead, chemical fungicides and bactericides are usually entirely protective and act to prevent infection, not to stop the disease once infection has occurred.

Both pathogen and host are subjected to the damaging events associated with irradiation. For satisfactory fungicidal treatment, the pathogen must be severely affected by a dose that does not excessively injure the living host tissue or incite other adverse changes. The effect of the radiation on lesions will be determined by the sensitivity of the fungus (Fig. 1) and the extent of its colonization of the host. Radiation-resistant pathogens may be inactivated by modest doses if infections are recent and lesions are of microscopic size. If lesions are large, however, the most sensitive pathogens may require excessive doses (Fig. 2). In such case, the only effect possible with radiation may be a short delay in lesion development [10].

Since host cells may have stopped division or growth and may be senescent while the pathogen is actively growing, the latter might be expected to be the more sensitive. As a matter of fact, however, only a discouragingly few commodities evidence a capacity to withstand satisfactorily the doses necessary for disease control [10]. At the present stage of the technology, the following characteristics of the disease and the host seem to determine the candidates for irradiation.

A. Factors affecting feasibility of irradiation for disease control.

1. Disease attributes favorable to control by radiation.

a. Disease incidence is high and causes large losses. An irradiation treatment effective for disease control will likely be costly and cause some host damage. A low disease incidence will likely rule out irradiation even if total losses are sometimes high.
FIG. 2. Relation of the amount of inoculum to the ability of gamma irradiation to stop subsequent fungus colony development. Data show doses required to inactivate every spore in populations of the sizes indicated when in vitro: (1) Trichoderma viride, (2) Phomopsis citri, (3) Penicillium italicum, (4) P. expansum, (5) P. digitatum, (6) Geotrichum candidum, (7) Monilinia fructicola, (8) Botrytis cinerea, (9) Diplodia natalensis, (10) Rhizopus stolonifer, (11) Alternaria citri, (12) Cladosporium herbarum (From Sommer, et al. [16,17]).

b. Alternative methods of control are ineffectual. Irradiation treatments may supplement but are unlikely to replace chemical control methods or good temperature management.

c. Commodities are diseased at time of harvest as a consequence of inadequate field control. Infected fruits or vegetables can be therapeutically treated by penetrating radiation, whereas chemical treatments are limited to the surface. The development of effective measures for prevention of infections in the field would probably negate the need for radiation treatment. Although fruits and vegetables may become inoculated after harvest by contamination of wounds made during harvest and handling, such infection can often be prevented by simple chemical treatments.

2. Host attributes favorable to the use of radiation for disease control.

a. Properly irradiated foods are safe, nutritious, attractive, and free from objectionable flavors and odors.

b. Textural changes do not adversely affect acceptability or result in a fragile commodity unable to resist impacts and vibrations of handling and transit.

c. Fruits or vegetables are not destined for extended storage. Radiation doses sufficient for a fungicidal treatment almost always cause some host damage which is intensified with time. If the fruit or vegetable has a short physiological life, even short delays in disease development may be important. Ripe fruit may tolerate radiation better than fruit that must ripen after irradiation.
d. The commodity may be treated without excessive special handling.

B. Improving the fungicidal efficiency of radiation.

It is now known that the lowest dose required for an effective fungicidal treatment will be, in most cases, noticeably harmful to the commodity. For this reason, considerable research has been devoted to measures designed to improve fungicidal effect, reduce host damage, or both. These efforts show various degrees of promise.

1. Oxygen sensitization. Since the dose effect is usually greater in the presence of oxygen, the fungicidal effect might be enhanced without increased host damage if the oxygen was limited mostly to the area of the disease lesion. Thus, if the commodity was initially in anoxia but air was introduced at the start of irradiation, oxygen might be limited to outer fruit tissues. Careful measurements have shown, however, that gas permeation is generally too rapid to permit the success of any such regime [11]. With the dwell periods necessary for gamma irradiation, all host tissue would be oxygenated early in the treatment.

2. Shallow irradiation. With diseases having lesions near the surface, a fungicidal radiation dose applied to a depth of 2 mm or so might be nearly as effective as complete penetration. Obviously, with limited penetration the total energy absorbed per fruit would be comparably small and host injury might thereby be minimized. With deep lesions, however, no therapeutic effect would be achieved. Furthermore, problems associated with obtaining a uniform dose distribution appear difficult at best, and impossible with many commodities.

3. Radiation-chemical combined treatments. The important postharvest rot fungi Botrytis cinerea Pers. ex Fr. and Rhizopus stolonifer (Ehrenb. ex Fr.) Lind have been shown to be strikingly sensitized to radiation by in vitro treatment with iodoacetamide [12]. In connection with fruit and vegetable diseases, however, it is doubtful whether the chemical could penetrate the colonized host tissue sufficiently to effectively sensitize the pathogen within. In some cases, however, ordinary chemical fungicides might be utilized effectively, not to sensitize the pathogen but to protect irradiated commodities from subsequent infection.

4. Radiation-heat combinations. Possibly the most promising means of increasing the utility and effectiveness of radiation is to combine it with heat [13]. In some cases the two treatments are complementary. For example, Penicillium expansum Lk. ex Thom is relatively heat resistant but radiation sensitive (Fig. 3). Probably of far more importance is a striking interaction between the two treatments. With the Prunus brown rot fungus, Monilinia fructicola (Wint.) Honey, a 5- to 10-fold synergism above the additive effects of the two treatments has been
FIG. 3. Survival of fungi after four minutes at the indicated temperatures (From Sommer, et al. [13]).

FIG. 4. Survival of M. fructicola conidia after heat (44°C for 4 min) combined with various gamma irradiation doses as influenced by sequence of treatments compared with irradiation alone. (From Sommer, et al. [13]).

observed when heat preceded irradiation (Fig. 4). Similar results have been obtained with Cladosporium herbarum Lk. ex Fr. (Fig. 5). With R. stolonifer, in contrast, inactivation synergism is greatest if irradiation precedes heat (Fig. 6). Thus, the fungus species presumably determines the sensitivity to single treatments of radiation or heat, the synergism between radiation and heat, and the sequence of treatments for maximum synergism.

Hopefully, combined treatments will be more effective than either radiation or heat alone. The much reduced
dose thereby permitted may minimize radiation-induced changes in texture, odor, and flavor. Radiation costs would presumably be reduced significantly by the ability to treat a larger volume of a commodity with a lower dose. Obviously, if host injury increased synergistically, little would be gained from the combined treatment. In limited studies, no such injury increase was seen, but evaluation of the feasibility of combined heat and radiation must await careful studies of the physiological responses of various species and varieties to combined treatments.
Since heat is seemingly most conveniently applied as a hot-water dip, combination treatments may be limited to commodities that can be wetted. Any predictions of the possible utility of heat-radiation treatments are obviously premature. Nevertheless, the initial tests have seemed promising enough to warrant intensive investigations.

C. Disease control in selected fruits and vegetables.

1. Strawberry. The strawberry appears to be the fruit most likely to benefit in the near future from irradiation as a fungicidal treatment. This is so particularly in California, where benefits are likely to be maximum because of special circumstances: relatively long producing periods in a single location (6 to 8 months); long distances to market (up to 3000 miles by rail or 6000 miles by air); and avoidance of important losses from only a few days’ delay in disease development [10].

The most important disease, by far, is gray mold caused by B. cinerea. Because small lesions are already present at harvest [14], decay may proceed without any delay for infection and colonization. Under refrigerated transit conditions the growth of the fungus is only slowed, not stopped, by the low temperatures. Furthermore, the fungus hyphae can spread rapidly from fruit to fruit where they are in contact (Fig. 7). Spread by conidia is relatively unimportant in harvested strawberries, because the time required for germination and subsequent infection to develop at low temperatures is long compared with the short postharvest life of the host.

The other major disease of strawberry fruits is "leak" caused by R. stolonifer. Infection commonly occurs in wounds incurred during harvesting and handling. Like B. cinerea, R. stolonifer may also spread from fruit to fruit by contact, quickly rotting the contents of a fruit container. For rapid development, however,
temperatures must be warm. At temperatures near optimum for growth of this fungus (25-27°C), all strawberries within a container may be reduced to a watery residue within two or three days. Unlike *B. cinerea*, *R. stolonifer* does not grow at temperatures below about 10°C. If modern handling practices provide for quick cooling and maintenance at ca. 5°C or less from the grower to the housewife's refrigerator the disease cannot occur.

With strawberries, the possibility of using radiation to extend the marketing period in the absence of refrigeration appears extremely unlikely. At elevated temperatures the physiological life of the fruit is extremely short while the irradiation-induced delay in fungus growth is small. Moreover, even in the unlikely event that radiation-resistant *R. stolonifer* could be completely controlled by radiation, the occurrence of postirradiation infections would likely result in serious losses as a consequence of the rapid rate of growth of this pathogen at near-optimal temperatures. Prevention of postirradiation infections would likely require a sophisticated (and costly) packaging program.

A third fungus species, *C. herbarum*, is common in strawberries. It not only is capable of growing at refrigerator temperatures but is radiation resistant as well. Fortunately, its growth is slow and it is evidently only weakly pathogenic. Fruit rots caused by *Phytophthora* spp. and *Rhizoctonia* spp. seldom develop vigorously after harvest.

Under California conditions almost all postharvest disease loss of strawberries is caused by *B. cinerea*. A radiation dose of 200 Krad has been demonstrated to inactivate many small lesions. Large lesions present are only delayed by irradiation, but the delay in disease development and "nesting" may amount to 5-8 days when the fruit is held at 5°C or lower. Because of the short physiological life of the commodity this short delay is believed to constitute a very effective control. Economic studies suggest that costs would not be excessive [15]. A semicommercial demonstration irradiator will soon be available in growing areas, but use must remain experimental until irradiated strawberries have been governmentally approved for human consumption.

With strawberries, the possibility of combining heat with irradiation to obtain added control or to reduce the required dose has been unpromising in preliminary tests. In the first place, heat application is difficult. Hot-water dips cannot be used, because berry juice deposited on fruit surfaces would be unsightly. Some packaging materials would be damaged by water. Uniform, rapid heating with moist air is evidently difficult. Exploratory tests with microwave heating did not produce uniform temperatures. Finally, the strawberry may be adversely affected by even relatively short periods at a high temperature.
2. **Stone fruits.** In America, cherry, peach, nectarine, plum, and apricot fruits are destroyed by two major and several minor postharvest diseases. Brown rot, incited by *M. fructicola* and closely related species, and by *R. stolonifer*, sometimes associated with other Mucoraceous species, results in widespread losses. In extended cold storage, gray mold caused by *B. cinerea* and blue mold caused by *P. expansum* may cause important damage. *C. herbarum* is of particular importance in sweet cherries, and may develop in other stone fruits if they are held in cold storage for extended periods.

The brown rot disease is destructive both before and after harvest. Fruit rot in orchards may be extensive, particularly during periods of wet weather, even if a comprehensive protective spray program is followed. Because of spread in the orchard, small lesions may be present at harvest. Since the mycelium of lesions is internal, postharvest sprays or dips are usually entirely ineffective in eradicating the fungus. However, chemical treatments are sometimes effectively applied to prevent the initiation of infections after harvest. Although lesions present at harvest may be small, the contamination of harvest and handling wounds by spores constitutes an ever-present and important means of infection.

Growth of *M. fructicola* may be extremely slow or halted by temperatures below 5°C. The brown rot disease cannot develop if good temperature management is used. However, stone fruits are sometimes harvested while still firm so as to limit transit and handling injuries and to provide added time for marketing. When these fruits are removed from refrigeration to permit final ripening, the brown rot disease is then free to develop.

*Rhizopus* rot may be, under certain conditions, the most destructive postharvest disease of peaches, and may attack other stone fruits as well. Attacked seriously are fruits that are shipped without adequate refrigeration or fruits in which cooling has been delayed. Disease development seldom occurs at 10°C or below. If fruits are shipped ripe and are kept refrigerated from grower to home refrigerator, *Rhizopus* rot should not be a problem. If fruits are harvested and marketed only partially ripe, as is common with peaches and nectarines, the disease may develop during the final ripening period. In general, however, the incidence of *Rhizopus* rot is low if the fruits have been held for a few days under refrigeration before ripening at room temperature. Germinating spores and young mycelium were recently shown to be sensitive to inactivation by chilling at 2.5°C or below.

Irradiation of stone fruits at 200 Krad soon after harvest should inactivate a large proportion of very small lesions resulting from orchard infections or the contamination of harvest and handling wounds [16]. Unfortunately, that dose softens stone fruits to the
extent that excessive fragility may prevent normal handling and transit of peaches and nectarines (Fig. 8). In sweet cherries the loss of "crispness" through softening may adversely affect consumer acceptance.

Of particular interest in connection with stone fruits are investigations of combinations of heat and radiation in which the radiation dose does not exceed 100 Krad. Such a dose limitation would suggest that many of the undesirable changes induced by irradiation could be avoided. Initial studies suggest that combined treatment enhanced fungicidal activity (Table 1).

3. Citrus. The irradiation of citrus fruits has not looked promising, because of radiation-induced changes, especially in flavor; increased sensitivity to Alternaria stem end rot (Alternaria citri Ellis and Pierce); the availability of effective chemical fungicides; and poor disease control with doses of radiation that are non-injurious to the host [17].

4. Pome fruits. Although pathogenic or nonpathogenic storage diseases of pome fruits might be controlled by radiation, apples and pears appear to be unlikely candidates for such treatment at this time. Interest in irradiation would appear to be limited by the availability of reasonably satisfactory and cheap chemical treatments, on the one hand, and the possible development of delayed irradiation injury in storage, on the other.
Table I. Effect of heat, radiation, and a combination treatment of heat followed by irradiation for control of *Monilinia fructicola* in nectarines. Twenty-five fruits per treatment

<table>
<thead>
<tr>
<th>Inoculation</th>
<th>Treatment</th>
<th>No. rotted fruits</th>
</tr>
</thead>
<tbody>
<tr>
<td>A. Data recorded after treatment and 5 days at 5°C and 10 days at 20°C</td>
<td></td>
<td></td>
</tr>
<tr>
<td>None</td>
<td>None</td>
<td>23</td>
</tr>
<tr>
<td>None</td>
<td>55°C for 3-1/2 minutes + 100 Krad</td>
<td>0</td>
</tr>
<tr>
<td>$10^2$ conidia/fruit</td>
<td>100 Krad</td>
<td>16</td>
</tr>
<tr>
<td>$10^2$ conidia/fruit</td>
<td>55°C for 3-1/2 minutes</td>
<td>22</td>
</tr>
<tr>
<td>$10^2$ conidia/fruit</td>
<td>55°C for 3-1/2 minutes + 100 Krad</td>
<td>0</td>
</tr>
<tr>
<td>B. Data recorded after treatment and 7 days at 5°C and 14 days at 20°C</td>
<td></td>
<td></td>
</tr>
<tr>
<td>None</td>
<td>None</td>
<td>0</td>
</tr>
<tr>
<td>None</td>
<td>55°C for 3-1/2 minutes + 100 Krad</td>
<td>0</td>
</tr>
<tr>
<td>$10^3$ conidia/fruit</td>
<td>100 Krad</td>
<td>25</td>
</tr>
<tr>
<td>$10^3$ conidia/fruit</td>
<td>55°C for 3-1/2 minutes</td>
<td>21</td>
</tr>
<tr>
<td>$10^3$conidia/fruit</td>
<td>55°C for 3-1/2 minutes + 100 Krad</td>
<td>2</td>
</tr>
</tbody>
</table>

5. **Tomatoes.** No detailed studies appear to have been made on the relation of radiation to individual diseases of tomato fruits. Observations of disease incidence following irradiation suggest, however, that rots incited by *R. stolonifer* and *Alternaria tenuis* Nees ex Corda may be delayed 4 to 12 days by a gamma-irradiation dose of 300-400 Krad applied at the pink to fully ripe stage.

**PHYSIOLOGICAL RESPONSES OF FRUITS TO RADIATION**

In studying the effects of ionizing radiation on fruits, it is imperative that the physiological state of the fruits be determined before treatments are made.

In many fruits the pattern of respiratory rate serves as a good index of stage of ripeness [8, 16, 19]. Such fruits belong to the climacteric class, in which there is an initial decline in respiratory rate immediately after harvest, followed by a marked increase as ripening begins, with a peak at about the time the fruits are "eating ripe." Fruits irradiated before the onset of the climacteric rise will show a response markedly different from that of fruits irradiated at any point beyond the midpoint of the rise.
Table II. Summary of fruits showing possible feasibility for irradiation technology

<table>
<thead>
<tr>
<th>Fruit Species</th>
<th>Physiological State When Irradiated</th>
<th>Recommended Dose (Gamma Rays) Krad</th>
<th>Desired Effect</th>
<th>Expected Shelf Life Extension (Days)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bananas</td>
<td>Preclimacteric</td>
<td>20-35</td>
<td>Inhibited ripening</td>
<td>4-15</td>
</tr>
<tr>
<td>Cherries (sweet)</td>
<td>Fully ripe</td>
<td>200</td>
<td>Rot control</td>
<td>3-6</td>
</tr>
<tr>
<td>Figs</td>
<td>Fully ripe</td>
<td>200</td>
<td>Rot control</td>
<td>3-6</td>
</tr>
<tr>
<td>Mangos</td>
<td>Preclimacteric</td>
<td>35</td>
<td>Insect control</td>
<td>--</td>
</tr>
<tr>
<td>Oranges</td>
<td>Fully ripe</td>
<td>200</td>
<td>Rot control</td>
<td>To 6 weeks at low temps.</td>
</tr>
<tr>
<td>Papayas</td>
<td>Preclimacteric to half-ripe</td>
<td>35-75</td>
<td>Insect control</td>
<td>3-6</td>
</tr>
<tr>
<td>Prunes</td>
<td>Fully ripe</td>
<td>300-400</td>
<td>More rapid drying, more tender product</td>
<td>--</td>
</tr>
<tr>
<td>Strawberries</td>
<td>Fully ripe</td>
<td>200</td>
<td>Rot control</td>
<td>3-6</td>
</tr>
<tr>
<td>Tomatoes</td>
<td>Pink to fully ripe</td>
<td>300-400</td>
<td>Rot control</td>
<td>4-12</td>
</tr>
</tbody>
</table>
Preclimacteric fruits show no consistency in ripening response to gamma irradiation. Bartlett pears [20] and tomatoes [21] irradiated in the preclimacteric state will either fail to ripen or ripen abnormally. Peaches and nectarines will ripen prematurely [22]. Ripening in bananas [23] is temporarily inhibited, and is normal once initiated spontaneously or via treatment with ethylene. In all these fruits, ripening proceeds normally if irradiation is done after ripening and the climacteric rise in respiratory activity has progressed to a measurable degree. It is probable that much of the confusion in the literature relative to tolerable doses for various fruits can be attributed to variations in the degree of ripeness when treatments were made. It seems clear that the success reported for strawberries [24], sweet cherries, and figs [8] is dependent on the fact that these fruits are essentially full-ripe at harvest. This phenomenon is clearly evident with tomatoes [21]. Mature-green tomatoes (preclimacteric) cannot tolerate doses that might retard rot development. However, when irradiated in the pink or full-ripe stage, tomatoes show a beneficial extension of shelf life without undue harm to quality.

The effect of ionizing radiation on ripening of fruits is not fully understood. The ethylene metabolism of fruits in response to gamma irradiation appears to be intimately related to their ripening behavior. In pears and tomatoes, the capacity for endogenous production of ethylene is suppressed by doses that retard ripening, and, simultaneously, the sensitivity of the fruits to exogenous ethylene is depressed. In peaches, lemons, and nectarines, ethylene production is stimulated, as is ripening (degreening in lemons). If the sensitivity of these fruits to exogenous ethylene is altered, the effect is masked by ethylene production induced by irradiation. With bananas, ripening is delayed by low doses of gamma rays. This delay is related to a decreased sensitivity of the fruit to ethylene, apparently, since, for optimum ripening, irradiated bananas seem to require a slightly longer exposure to ethylene than do unirradiated fruit.

The stimulation of ethylene production by plant tissues is apparently a characteristic response to gamma irradiation, and there are at least two systems operative in the production of ethylene by irradiated fruit systems [25]. One is a direct radiolytic formation of the gas from alcohols, organic acids, lipids, etc., during the time the fruit is in the irradiation field. The second system is metabolic, apparently beginning during irradiation but reaching its maximum value several days later. Evidence to date indicates that radiolytically produced ethylene does not act as a catalyst for metabolic production of the gas. However, considerably more evidence must be developed before a final conclusion can be drawn on this point.

It is now clear that gamma irradiation will intensify most if not all physiological disorders of fruits, such as chilling injury (bananas, tomatoes, and lemons) [8], high-temperature injury, etc. Therefore, it is important that careful attention be given to environmental requirements of fruits subjected to gamma irradiation.

CONCLUSIONS

Currently, few fruits or vegetables show good promise for feasibility of irradiation. Table II summarizes the most likely candidates, with the recommended physiological state, dose, and desired effect, and an estimate of expected shelf-life extension. From the discussion of the various physiological phenomena described above, it seems clear that
much additional research must be done before any firm conclusions can be drawn on the feasibility of irradiation for any fruit. Urgently needed are studies by postharvest pathologists on ways of maximizing disease control, coordinated with studies by physiologists aimed at reducing adverse host responses.

REFERENCES


DISCUSSION

K. KAINDL: To what temperature do you heat the commodity, and for how long?

N. F. SOMMER: The temperature treatment used depends on the tolerance of the commodity. For disease control after harvesting it is desirable to use the most rigorous treatment that does not cause fruit injury. Some peach varieties tolerate commercial heat treatments of 55°C for three and a half minutes if they are quickly cooled. Bing cherries were treated for four minutes at 44, 46 and 48°C with injury observed at the latter temperature.
IRRADIATION OF FRUIT AND VEGETABLES IN FRANCE. France, thanks to its varied and temperate climate and the features of its soils, affords favourable conditions for the production of fruit and vegetables. In certain cases these conditions permit harvests covering a fairly long period of time.

As a result of work on the choice of varieties, on specialization and on the improvement of growing techniques, fruit and vegetable production has expanded and yields have increased. Techniques for increasing keeping periods and preserving quality are being developed, mainly on the basis of refrigeration. In some cases these techniques are inadequate, while in others their action is restricted.

Irradiation seems capable of bringing new improvements, principally with regard to halting the germination of tubers, bulbs and rhizomes, to the conservation of fruit and vegetables - when applied together with freezing or, possibly, in a controlled atmosphere - and to the disinfection of certain commodities.

Work carried out in various countries, including France, shows the advantages of irradiation and the possibility of using it for French fruit and vegetables (strawberries, peaches, apricots, tomatoes, potatoes, garlic, onions).

The introduction of irradiation will lead to changes in the production and distribution of fruit and vegetables. Distribution will be improved and more distant sales points may be reached. The use of irradiation will not alter operations required to prepare the products for commercial purposes. The characteristics of these installations (usually gamma facilities) will depend on many variable factors. In the light of the results obtained, the cost of irradiation would appear to lie within economic limits.

The irradiation installations will operate mainly by radioisotope sources.

The annual utilization factors of the installations play an important part in the cost of irradiation. Several procedures are envisaged to render them more economic, since their operation will necessarily be seasonal.

The siting of the installations will depend on factors involving the commodity, its keeping time and its conditions of marketing. In general, for meeting germination problems, the irradiation facilities will be situated at the points of production or consumption, preferably the former. For fruits, the facilities will be sited at the point of production, preferably adjacent to packing and refrigeration plants.

IRRADIATION DES FRUITS ET LEGUMES EN FRANCE. Avec ses climats variés et tempérés et ses sols, la France réunit des conditions favorables à la production de fruits et de légumes. Dans certains cas, ces conditions permettent des récoltes plus étalées dans le temps.

Par des efforts portant sur le choix des variétés, la spécialisation, l’amélioration des techniques culturales, les productions fruitières et légumières se sont étendues et les rendements ont augmenté. Les techniques permettant l’allongement des durées de conservation et la conservation des qualités se développent, principalement le froid. Dans certains cas, ces techniques sont insuffisantes et dans d’autres leur action est limitée.

L’irradiation semble devoir apporter une nouvelle amélioration, principalement dans l’arrêt de la germination des tubercules, bulbes et rhizomes, dans la conservation de fruits et légumes conjointement avec le froid ou éventuellement en atmosphère contrôlée, et la désinfection de certains produits.

Les travaux effectués dans différents pays et en France montrent l’intérêt de l’irradiation et ses possibilités d’utilisation pour des fruits et légumes français (fraises, pêches, abricots, tomates, pommes de terre, aulx, oignons).

L'introduction de l'irradiation amènera des changements dans la production et la distribution de fruits et légumes. La distribution s'effectuera dans de meilleures conditions et des points de vente plus éloignés pourront être atteints. L'intervention de l'irradiation ne changera pas les opérations de préparation des produits en vue de leur commercialisation. De nombreux facteurs variables détermineront les caractéristiques de ces installations, en général à rayonnement gamma.
Le coût de l'irradiation apparaît rentable compte tenu des résultats obtenus.
Les installations d'irradiation seront principalement à sources de radioéléments.
Les coefficients d'utilisation annuels des installations jouent un rôle important dans le coût de l'irradiation. Plusieurs solutions sont envisageables pour améliorer leur rentabilité, car elles seront forcément saisonnières.

Leurs emplacements dépendront de facteurs dépendant du produit, de sa durée de conservation, de ses conditions de commercialisation. En général, pour les problèmes de germination, les installations d'irradiation pourront être sur les lieux de production ou de consommation, mais de préférence à la production. Pour les fruits, les installations seront sur les lieux de production, de préférence adjacentes à des stations de conditionnement et de réfrigération.

OBLEJ\n
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ЯФАНЦИи. Эти климатические условия позволяют получать урожай на протяжении более длительного времени, чем обычно.

В результате селекции сортов, специализации, совершенствования агротехники урожайность фруктов и овощей повысилась. При разработке новых методов, позволяющих улучшить срок хранения и сохранить качество, учитывается, главным образом, использование охлаждения. Однако в некоторых случаях этот метод недостаточен, а в других — его действие ограничено.

Облучение должно, по-видимому, принципиально улучшить методы предотвращения прорастания клубней, луковиц, корневищ и способы сохранения фруктов и овощей, используя также холод и дезинсекцию для некоторых продуктов.

Проводимые в различных странах и во Франции работы свидетельствуют об интересе к методу облучения и о возможностях использования его для фруктов и овощей во Франции (клубни, персиков, абрикосов, помидор, картофеля, чеснока и лука).

Применение облучения вызовет изменения в производстве и распределении фруктов и овощей. Распределение будет осуществляться в лучших условиях и сможет охватить наиболее удаленные места сбыта. Однако применение облучения не меняет процессов подготовки продуктов для коммерческих целей. Характер установки для облучения (обычно гамма-установка) будет зависеть от многих факторов.

Стоимость облучения представляется рентабельной, учитывая полученные результаты. Установки по облучению будут в основном установками с активными источниками.

Коэффициенты годового использования установок играют важную роль в стоимости облучения. Следует произвести некоторые расчеты для улучшения рентабельности установок, так как их использование будет неизбежно носить сезонный характер.

Распределение установок будет зависеть от вида продукта, от длительности его хранения и условий его продажи. В общем, что касается проблемы борьбы с прорастанием, то установки по облучению должны быть расположены в местах производства или потребления, но по преимуществу в местах производства. Для фруктов установки должны находиться предпочтительно в местах производства, расположенных ближе кондиционирования и охлаждения.

LA IRRADIACION DE FRUTAS Y VERDURAS EN FRANCIA. Por sus climas variados y templados y por sus suelos, Francia reúne condiciones favorables para la producción de frutas y verduras. En ciertos casos, esas condiciones permiten recolecciones escalonadas en el tiempo.

Gracias a los esfuerzos desplegados en la selección de variedades, la especialización y el mejoramiento de las técnicas de cultivo, las explotaciones frutícolas y hortícolas se han extendido y los rendimientos han aumentado. Las técnicas – principalmente las del frío – que permiten prolongar el periodo de conservación y mantener las calidades, se han perfeccionado, pero en unos casos son insuficientes y en otros su acción es limitada.

Parece que la irradiación permitirá nuevas mejoras, sobre todo en la prevención de la germinación de tubérculos, bulbos y rizomas, en la conservación de frutas y verduras por asociación con el frío o, eventualmente, en atmósfera controlada, así como en la desinsectación de ciertos productos.

Los trabajos efectuados en diferentes países y en Francia muestran el interés que ofrece la irradiación y la posibilidad de utilizarla para el tratamiento de frutas y verduras (fresas, duraznos, albaricoques, tomates, patatas, ajos y cebollas).

La introducción de la irradiación originará cambios en la producción y distribución de frutas y verduras. La distribución se efectuará en mejores condiciones y podrá alcanzarse lugares de venta más alejados. La utilización de las radiaciones no alterará las operaciones necesarias para la preparación de los productos con miras a su comercialización. Numerosos factores variables influirán sobre las características de esas instalaciones, en general de radiación gamma.

Dados los resultados obtenidos, las operaciones de irradiación parecen rentables.

Las instalaciones de irradiación serán principalmente a base de fuentes radiactivas.
Los coeficientes de utilización anual de las instalaciones desempeñan un papel importante en el costo de la irradiación. Se estudian diversas soluciones para mejorar la rentabilidad, pues dichas instalaciones serán forzosamente estacionales.

Su emplazamiento dependerá de varios factores relacionados con el producto, de su período de conservación y de sus condiciones de comercialización. En general, cuando se trate de problemas de germinación, las instalaciones podrán emplazarse en los lugares de producción o de consumo, de preferencia en los primeros. Cuando se trate de frutas, las instalaciones se situarán en los lugares de producción, preferiblemente contiguas a las estaciones frigoríficas y de acondicionamiento.

Cet exposé est fondé sur les données techniques connues à ce jour et a pour but de dégager les lignes générales d'action qui conditionneront la radioexposition dans les pays européens (France entre autres) de quelques fruits et légumes.

L'Europe comprend plusieurs pays dont les productions de fruits et légumes frais, déjà importantes, s'accroissent d'année en année. Ces pays approvisionnent leurs propres populations et les autres pays placés dans de moins bonnes conditions de production. Cet approvisionnement pourrait mieux être assuré avec des produits de qualité s'il était possible d'améliorer les conditions de conservation au cours de la distribution et de la commercialisation. La radioexposition est une technique qui doit apporter une amélioration pour certains légumes et fruits. La France est un des pays producteurs et en même temps un pays de large consommation. Avec ses climats variés et tempérés, ses sols divers et fertiles, elle réunit un ensemble de conditions favorables à la production de fruits et légumes. Comme ses autres partenaires européens, par des efforts dans la sélection des variétés, dans la spécialisation, l'amélioration des techniques de cultures, les productions fruitières et légumières se sont étendues et se développent et les rendements sont en continuelle augmentation. Les problèmes d'écoulement des produits et d'approvisionnement des consommateurs nécessitent le perfectionnement des moyens de conservation ou exigent d'en trouver de nouveaux, les deux points principaux étant d'avoir des produits de qualité pendant le temps le plus long et d'atteindre de nouveaux marchés ou de mieux approvisionner les marchés actuels.

Des efforts importants ont été fournis dans le domaine des techniques de ramassage, mais principalement des techniques de conservation. Pour les produits frais, la réfrigération a vu une extension dans ses applications, apportant une très nette amélioration de la conservation et par suite de la qualité des produits. La réfrigération a cependant une action de durée limitée, parfois insuffisante (germination, fruits et légumes frais). Par ailleurs, si la réfrigération ralentit l'évolution des micro-organismes ou des insectes dont sont infestés les produits, elle n'en assure pas la destruction presque totale ou totale.

RADIOEXPOSITION DES FRUITS ET LEGUMES

La radioexposition permet, soit seule, soit conjointement avec d'autres procédés, d'améliorer la qualité des fruits et légumes frais, d'en
assurer une meilleure conservation plus ou moins longue. On peut ré-partir l'utilisation de la radioexposition en trois groupes:

a) Arrêt de la germination des tubercules et bulbes (doses de 8000 à 12 000 rad);

b) Augmentation de la durée de conservation de certains fruits par ralentissement de la maturation et destruction de la flore microbienne (doses de 50 000 à 300 000 rad);

c) Désinfection des produits frais, secs ou déshydratés, soit par action létale, soit par stérilisation biologique (doses de 20 000 à 30 000 rad).

Les travaux déjà effectués et ceux qui sont exposés ici font état des applications de la radioexposition aux fruits et légumes. Aussi, nous nous étendrons peu sur les connaissances acquises.

PRODUCTIONS FRANÇAISES INTERÉSSÉES PAR LA RADIOEXPOSITION

Les productions se répartissent sur toutes sortes de fruits et légumes, mais tous ne sont pas susceptibles d'être radioexposés; une partie ne justifie pas l'utilisation de la radioexposition malgré les possibilités existantes, en raison soit de la production faible localement ou trop dispersée, soit de l'avantage présenté par d'autres procédés de conservation. Enfin, le coût de l'opération peut ne pas être en rapport avec les avantages obtenus. Par exemple, les résultats obtenus sur les légumes feuillus sont, en l'état actuel de nos connaissances, peu encourageants; par ailleurs, la radioexposition impliquerait une augmentation de prix qui, pour le moment, ne semble pas acceptable. Cette conclusion est cependant susceptible d'être révisée plus tard.

Deux autres exemples: La framboise, dont la production est concentrée dans les Alpes (Haute-Savoie) et l'Est; la consommation à l'état frais en est faible et le meilleur procédé pour la conservation est la congélation et le stockage à basses températures. Pour les châtaignes, la réfrigération est suffisante pour la conservation en vue de la consommation; pour l'industrie, la congélation reste le meilleur procédé.

En résumé, quelques produits à gros tonnages et à aires de production concentrées pourront être radioexposés, d'autres venant s'ajouter ultérieurement à eux.

Fruits frais

Nous rappelons que, pour les fruits frais, en général la radioexposition seule peut assurer une conservation. Pour obtenir une durée de conservation assez longue il faut utiliser des doses de l'ordre de 500 000 rad qui peuvent affecter la texture, la couleur, le goût du fruit. L'utilisation conjointe de la réfrigération et de la radioexposition permet d'utiliser des températures plus élevées que celles qui devraient être employées avec la réfrigération seule, températures difficiles à maintenir tout au long de la chaîne de commercialisation du producteur au consommateur, et d'utiliser des doses d'irradiation moins élevées.

Cette action combinée permet une augmentation de la durée de conservation, avec éventuellement des zones de températures de réfrigération faciles à maintenir (+5 à +7°C) et la conservation des caractéristiques et des qualités des fruits.
Depuis près de sept ans en France, des travaux sur la conservation des fruits par radioexposition ont été effectués par la Société Conservatome, qui ont permis de déterminer les données générales industrielles (maturité des fruits, conditions de ramassage, technique d’irradiation, conditions de conservation, emballages, etc.). Ces résultats doivent être appliqués pratiquement aux circuits commerciaux.

Par ailleurs, des chercheurs français étudient l’action de l’irradiation, tant sur les fruits que sur la flore présente. Il est certain que ces travaux, ainsi que ceux effectués à l’étranger, permettront d’améliorer les données industrielles. Ainsi, le laboratoire du CNRS de Bellevue, dirigé par M. Ulrich avec M. Marcellin et ses collaborateurs, entreprend des travaux sur l’irradiation des pommes (Calville, Golden Delicious), des fraises, des pêches, des abricots, sur l’action de différentes doses de rayonnement et sur quelques champignons infectant les fruits (Botrytis cinerea, Sclerotinia fructigena, Penicillium expansum, Rhizopus migrans, Trichothecium roseum, Gloeosporium peresinans).

Les fruits examinés ci-après doivent être irradiés avant un certain stade de leur évolution physiologique. Si la maturation a commencé, l’irradiation n’aura aucun effet et il semble même qu’à un certain degré de maturation celle-ci est accélérée. Les études sur différents emballages ont montré en général que l’usage d’une pellicule plastique non hermétique enveloppant les fruits dans l’emballage de transport est le mieux adapté aux fruits radioexposés. Les autres facteurs intervenant sont le laps de temps qui s’est écoulé entre la cueillette et l’irradiation, les conditions de transport entre le terrain et le lieu d’irradiation, la température du produit avant et pendant l’irradiation.

En conséquence, il convient:
- de cueillir les fruits au degré d’évolution requis,
- de réfrigérer et d’irradier les fruits le plus tôt possible après la cueillette,
- d’irradier des produits emballés en vue de leur commercialisation pour éviter toute manipulation après l’irradiation.

Pour les fruits, la combinaison de températures plus ou moins élevées et des doses entre certaines limites donnera à l’utilisateur une souplesse qui lui permettra de s’adapter à la conjoncture commerciale du moment.

abricots - La production moyenne annuelle est de 50 000 t (principalement neuf variétés) s’étageant de début juin à mi-juillet. Il est très difficile de mettre sur le marché des abricots mûrs à point; cueillis trop tôt ils sont durs et insipides, trop mûrs ils se transportent mal et se conservent peu de temps.

Les doses à utiliser sont de 150 000 à 200 000 rad et les températures de +4 à +7°C. Ces températures correspondent le mieux aux possibilités pratiques. Elles présentent, par ailleurs, l’intérêt de permettre ultérieurement le développement du parfum; après une durée de conservation prolongée à 0°C, le parfum ne se développe pas.

La durée de conservation, tous autres facteurs ne variant pas, dépend des températures et des doses utilisées. Elle peut être doublée ou triplée et être portée à 30 à 40 jours.
**Fraises** - La production moyenne annuelle est de 30 000 t s’étageant de mi-avril à mi-juin; 12% sont utilisés pour la transformation. La production est répartie entre la Vallée du Rhône, le Sud-Ouest et l’Est principalement, avec une production très localisée en Bretagne. Cette culture se déplace et est en très forte augmentation. La fraise s’altère rapidement, elle ne supporte aucune meurtrissure, manipulation brutale ou exposition au soleil et se transporte difficilement.

Les doses à utiliser sont de 150 000 à 200 000 rad, mais celles près de 200 000 rad sont préférables. Les températures peuvent varier entre +4 et +7°C, autour de cette dernière de préférence.

La durée de conservation peut ainsi être multipliée commercialement par 1,5 à 2; la durée normale sans radioexposition à 0°C étant de 7 à 10 jours.

**Pêches** - La production française comprend des variétés à chair blanche et à chair jaune; les secondes prennent de plus en plus d’extension. Elle est en continuel développement et est en moyenne de 200 000 t entre début juin et mi-août. La production se répartit comme suit: 46% dans la vallée du Rhône, 22% dans le Sud-Ouest, 32% dans la région méditerranéenne. Les variétés jaunes sont moins fragiles que les variétés blanches. La pêche s’adapte mal à une conservation limitée en frigorifique à basse température de réfrigération. Cueillie trop verte elle mâtit mal, trop mûre elle se conserve mal et dans les deux cas elle est peu appréciable.

La radioexposition permet d’élérer les températures utilisées. Les doses sont comprises entre 150 000 et 200 000 rad et les températures entre +4 et 7°C.

La durée de conservation suivant la variété, les conditions de température et de doses peut être multipliée par 1,5 à 2,5.

**Tomates** - La production est estimée à 400 000 t, dont 100 000 à 150 000 t sont transformées; la récolte a lieu de juin à septembre. Il est importé de décembre à mai environ 90 000 t. Beaucoup de précautions sont à prendre lors des manutentions, les fruits meurtris s’abîment rapidement. En fin de saison, la récolte doit se pratiquer en « vert » pour éviter les risques de maladies et d’éclatement; les tomates subissent alors un mûrissement artificiel. Les tomates conservées à des températures trop basses ne mûrissent pas totalement ou mal. La température possible se situe entre +12 et +13°C, les tomates mûrissent alors lentement; la zone comprise entre 15 et 18°C est préférable, les tomates vertes mûrissant normalement.

L’irradiation ici pourra avoir différents buts; soit permettre d’expédier des tomates conservées à des températures plus élevées pour leur assurer des qualités organoleptiques et augmenter la durée de conservation, soit, en fin de saison, augmenter la durée de conservation. Les températures à utiliser seront comprises entre +10 et +18°C et les doses entre 250 000 et 300 000 rad. Ici le choix des températures et des doses dépendra beaucoup de l’époque et des buts à atteindre.

**Autres fruits** - Les cerises (production 80 000 t), bien que pouvant être irradiées, ne semblent pas devoir être un fruit qui sera radioexposé à grande échelle. Les raisins de table sont peu conservés en France; les procédés utilisés (froid avec gaz sulfureux) sont suffisants. Quant aux...
autres fruits, ils resteront en général justiciables de la congélation (cassis, framboises), ou ne seront irradiés que dans certaines circonstances.

Les doses utilisées, par leur action désinsectisante, assureront en général en même temps que la conservation les opérations de « quarantaine » et élimineront les périodes d'arrêt des exportations dues à une infestation éventuelle.

Légumes

En l'état actuel de nos connaissances et des travaux, l'arrêt de la germination par irradiation des tubercules et bulbes est l'application pouvant être la plus intéressante.

Pour ces produits les recherches ont été nombreuses et, outre Conservatome, en France, M. le professeur Sandret, du Cerdia, poursuit avec M. Michiels des travaux sur les pommes de terre, en particulier sur les sucres solubles, essais d'utilisation industrielle, recherches sur la présence éventuelle de substances inhibitrice de la croissance et du développement des tissus végétaux, études sur les répercussions biochimiques et physiologiques de l'irradiation.

Pommes de terre - En 1964 et 1965 la production s'est située aux environs de 11 millions de tonnes. La consommation humaine est évaluée à 5 millions de tonnes. La variété Bintje représente 50% de la production. La récolte a lieu en septembre, octobre et novembre. Les pertes en cours de stockage sont élevées.

Des doses de 8000 à 10 000 rad permettent la conservation dans les conditions requises d'humidité d'une saison à l'autre. La température de stockage peut être supérieure à +12°C. La germination est complètement arrêtée.

Oignon - L'oignon de couleur de conservation représente, d'août à septembre, 250 000 t de production. La production d'ail est de 40 000 t, principalement en juillet.

Les doses à utiliser sont d'environ 12 000 rad. Il convient de procéder à l'irradiation après la récolte, pendant la dormance. Si le germe a commencé à se développer, l'irradiation le détruit et il se développe de la pourriture à l'intérieur des bulbes. A un autre stade de développement du germe, la dose de 12 000 rad n'arrête plus la germination.

À cela peut s'ajouter accessoirement la désinsectisation des légumes secs, principalement des haricots (80 000 t) et des lentilles (10 000 t produites et 10 000 t importées).

INSTALLATIONS DE RADIOEXPOSITION

Plusieurs facteurs sont à retenir dans l'étude et la conception des installations de radioexposition, dont les principaux sont: les rayonnements, les sources de rayonnement (accélérateur ou radioisotopes), le type d'installation (fixe ou mobile), la centralisation ou la dissémination des installations, la durée d'utilisation, le coût de l'opération.
Rayonnement – Nous avons à choisir entre les électrons (niveau d'énergie inférieur à 10 MeV) et le rayonnement gamma. La faible pénétration des électrons, la répartition irrégulière des doses dans le produit, les volumes unitaires des produits à irradier, leur fragilité et la nécessité en général de limiter les manipulations, donc d'avoir une seule opération d'emballage, les éliminent sauf dans des cas particuliers. Le rayonnement gamma, en raison de sa pénétration, de l'homogénéité relative très bonne de la dose dans les produits, de la possibilité d'irradier le produit emballé, sera en général le plus employé.

Sources de rayonnement – Les faisceaux d'électrons étant pratiquement éliminés, on s'adressera aux radioisotopes cobalt-60 et césium-137. Le choix dépendra du type d'installation, des conditions de son implantation, des caractéristiques qui lui sont demandées. Présentement, on peut dire que le prix n'interviendra pas d'une façon décisive lors du choix. Ces conditions de l'exploitation qui le fixeront.

Actuellement, le prix du césium-137 pour les installations envisagées, compte tenu des quantités nécessaires pour les installations (activité de l'ordre de 25 Ci/g pour le chlorure) est compétitif avec le prix du cobalt-60 (activité de l'ordre de 15 à 20 Ci/g). Si, dans des cas particuliers, il est obligatoire d'utiliser une plus haute activité spécifique (40 à 100 Ci/g), il n'y a pas d'alternative: le cobalt est le seul possible.

On peut envisager l'utilisation d'un accélérateur aménagé en émetteur gamma. Dans le domaine qui nous intéresse, le facteur décisif réside dans le fait que les installations à radioisotopes sont plus simples, très robustes et se prêtent mieux aux conditions très dures d'exploitation requises par l'irradiation des fruits et légumes.

Conception des installations d'irradiation

Il faut noter que, dans l'ensemble, l'intervention de l'irradiation ne changera pas les opérations de préparation des produits en vue de leur commercialisation. L'installation s'insèrera dans le cycle des opérations nécessaires et pourra être combinée partiellement par exemple aux opérations de réfrigération (fruits). L'utilisation de l'irradiation allant dans le sens de l'utilisation du préemballage, ces deux techniques se complètent harmonieusement.

Fruits – Pour les fraises, pêches, abricots, les opérations à réaliser totalement ou partiellement sont le triage, le calibrage, l'emballage, la réfrigération (qui peut déjà intervenir à un des premiers stades des opérations). Le traitement par irradiation s'ajoutera à ces opérations. En général, il s'insérera pendant la réfrigération. La palettisation totale ou partielle des opérations influera sur le type de l'installation et sa conception d'ensemble.

Compté tenu de la production française et de son évolution, les stations de conditionnement de ces fruits s'orientent vers des unités de 1000 à 2000 t. Les stations tendent à traiter, si possible, plusieurs variétés de fruits pour améliorer leurs coefficients d'utilisation. Cela donne une capacité horaire de 0,5 à 1 t pour les pêches. Par exemple, la capacité de l'installation se situe entre 150 000 et 300 000 Ci de cobalt-60, selon les capacités, les pointes, les durées journalières de
travail. Actuellement, le coût du fruit conditionné comprenant l'amortissement des installations, les frais d'exploitation, d'emballage, de réfrigération et autres est estimé à 0,30 à 0,50 F par kg de fruits.

Le coût de l'irradiation compensé par les avantages recueillis (diminution des pertes, conservation de la qualité, meilleure distribution) ne doit pas changer anormalement le prix de vente des fruits. Compte tenu des investissements nécessaires et de la faible durée d'exploitation (70 à 90 jours au maximum), le prix peut parfois apparaître prohibitif. Nous examinerons ce point plus loin; des solutions peuvent être prévues pour rendre ce prix normal.

Légumes - Les pommes de terre, oignons, aulx et produits similaires présentent des tonnages très importants à irradier à des doses beaucoup plus faibles (environ 10 000 rad). Ces produits subissent un ensemble d'opérations (triaje, calibrage éventuel, stockage, conditionnement). L'opération d'irradiation se situera en général avant l'opération de stockage. Les aulx et les oignons irradiés sont vendus en filets de plusieurs kilos. L'emballage peut s'effectuer avant l'irradiation ou dès la sortie de stockage pour la vente.

Les pommes de terre sont vendues en vrac, en sacs plus ou moins gros (2,5 à 10 kg - 25 kg - 50 kg). La destination (industrie, consommation), le mode d'emballage et l'époque de l'emballage influeront sur la conception de l'installation. La centralisation de ces productions permet d'envisager des unités pouvant atteindre 20 à 30 t/h. La capacité en cobalt-60 pourra osciller entre 200 000 et 300 000 Ci selon la conception et les conditions d'utilisation. Le prix de l'opération, pour une usine irradiant divers produits et fonctionnant durant toute l'année, permettrait d'atteindre un coût de traitement compris entre 0,005 et 0,007 F/kg. En admettant que l'installation ne fonctionne que trois mois par an, on arriverait à un prix estimatif de l'ordre de 0,025 F/kg. L'opération est intéressante, mais le problème d'une excellente utilisation de la source de rayonnement se pose également.

Emplacement des stations d'irradiation et utilisation optimale des sources

Pour les fruits (pêches, abricots, fraises, etc.), les installations d'irradiation seront implantées dans le complexe de l'atelier de conditionnement et de réfrigération. Les conditions techniques d'application de l'irradiation le requièrent. Elles seront donc construites sur les lieux de production.

Pour les pommes de terre, aulx, oignons, une plus grande diversité existera. En général, l'installation d'irradiation sera située dans les stations de centralisation de la récolte quand la destination définitive ne sera pas connue ou si l'utilisation a lieu sur place. Mais les autres solutions, stockage près des lieux de consommation, de transformation ou d'expédition existeront.

Une étude générale de la répartition dans le temps des productions à irradier montre une assez grande complémentarité et semble permettre une exploitation prolongée des installations. Or il n'en est rien car, sauf de rares exceptions, les diverses productions n'existent pas dans une même zone. Le problème du meilleur coefficient d'utili-
sation des sources est posé. Leur coût représente une fraction impor-
tante des investissements. La solution d'irradiateurs mobiles est
séduisante, mais elle n'est pas toujours réalisable. Chaque fois que
cela sera possible, l'irradiation d'autres produits ou matériaux dans ces
installations pourra être envisagée. Les impératifs de production et
d'approvisionnement du marché limiteront l'extension de cette solution.
Dans la phase pilote, cela est possible. Le transport des sources d'un
centre à un autre peut être envisagé, malgré le coût encore élevé de tels
transferts. Cette dernière solution intervienendra fréquemment au début
de cette nouvelle industrie, compte tenu des éléments actuels du
problème.

Cet aperçu général de l'application industrielle de la radioexposition
à un certain nombre de fruits et légumes montre l'intérêt de cette nouvelle
technique. Les informations ci-dessus indiquent les directives générales
qui seront suivies lors de sa mise en œuvre. La conjoncture au cours
des développements, l'évolution des méthodes de travail ainsi déclenchée
amèneront, pour chaque produit et chaque cas, un ensemble de données
dérivant de ces directives générales. L'étude des répartitions des pro-
ductions en France permet de situer les zones d'implantation d'un certain
nombre d'installations de radioexposition. Les autres pays européens
producteurs devront résoudre les mêmes problèmes généraux, les
conditions de production et de commercialisation étant sensiblement les
mêmes.

L'intérêt présenté en général par l'emploi des radiations ionisantes
est grand, les résultats en découlant sont très importants pour le produc-
teur et le consommateur sur les plans économiques et financiers. Il est
regrettable que cette nouvelle technique ne reçoive pas plus d'attention.
Pour permettre son application, il convient que les personnes qui tra-
vaillent à sa mise au point fassent des efforts importants et continus pour
lutter contre l'ignorance du public en général, et, dans certains cas, des
autorités.

ANNEXE

PRIX EN 1965 (francs par 100 kg)

<table>
<thead>
<tr>
<th>Désignation</th>
<th>Variation moyenne</th>
<th>Moyenne(^a)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Abricots</td>
<td>35 à 75</td>
<td>60</td>
</tr>
<tr>
<td>Fraises</td>
<td>95 à 300</td>
<td>150</td>
</tr>
<tr>
<td>Pêches</td>
<td>25 à 100</td>
<td>55</td>
</tr>
<tr>
<td>Pommes de terre(^b)</td>
<td>29 à 32/37</td>
<td></td>
</tr>
<tr>
<td>Aulx</td>
<td>180 à 250</td>
<td>200</td>
</tr>
<tr>
<td>Oignons</td>
<td>50 à 80</td>
<td>60</td>
</tr>
</tbody>
</table>

\(^a\) Ces prix moyens correspondent à des prix pondérés, compte tenu des tonnages.
\(^b\) Les prix indiqués n'ont aucune valeur d'étude; ils ont été imposés par le Gouverne-
ment en fin de saison.
DISCUSSION

K. KAINDL: Have you carried out organoleptic tests on the various irradiated products? Irradiation may lead to unwelcome changes in taste, especially in the case of garlic, which contains large amounts of sulphur compounds.

P. VIDAL: Organoleptic tests were carried out at different stages of preservation; no changes in taste were noted in the fruit under the conditions described. In the case of garlic, doses of 10-12 krad did not cause any changes in taste.

R. MOUTON: Were the control fruit shown on the slides during your oral presentation kept at the same temperature as the treated fruit?

P. VIDAL: Yes, the control fruit were stored under the same conditions as the irradiated fruit, at temperatures of 4-5°C.
Abstract — Résumé — Аннотация — Resumen

The direct effect of X-rays on freshly picked, sweet red pepper at dose levels of between 0 and 800 krad, and on the after-ripening of red pepper at dose levels of between 0 and 100 krad, was investigated.

As an effect of the irradiation of between 400 and 800 krad, the pericarps softened; the carotenoid content, however, was not substantially reduced, even at a dose of 800 krad.

During the nine weeks* storage period at room temperature, subsequent to irradiation, an increase of about 90% of the total pigment content, expressed as capsanthin, was observed in the samples not treated. The formation of the carotenoid pigments was accelerated, to some extent, by 80 rad, and substantially accelerated by treatment of 2 krad. The samples treated at the 2-krad level reached the same pigment content in three weeks as the control samples in eight weeks. In the radiation-treated samples, however, the pigment content decreased after the fourth to fifth week of storage. Dose levels above 10 krad slowed down or inhibited the formation of carotenoids during storage (after ripening).

The reducing sugar content and the rate of drying were not affected by 0 to 100-krad doses.

Since the several hundred kilorad irradiation doses needed to destroy, or substantially inhibit, the growth of moulds causing the deterioration of red pepper of high moisture content have a deleterious effect, the application of irradiation to decrease storage losses in fresh, picked red pepper does not seem to be advisable. The application, however, of the very low doses stimulating carotenoid formation does seem to be promising in view of shortening the after-ripening period and increasing the pigment content. Further investigations are needed to establish the most suitable storage conditions for the after-ripening of red peppers and the causes responsible for decrease in the carotenoid content of irradiated fruits in the second half of the storage period.
en pigments. Il serait nécessaire de poursuivre les recherches afin de déterminer les conditions d’emmagasinage les plus favorables à la maturation du piment après la récolte ainsi que les causes de la diminution de la teneur en caroténoïdes de fruits irradiés au cours de la deuxième moitié de la période de stockage.

ВЛИЯНИЕ ИОНИЗИРУЮЩЕГО ИЗЛУЧЕНИЯ НА ДОЗРЕВАНИЕ КРАСНОГО ПЕРЦА (CAPSICUM ANNUUM). Было исследовано непосредственное влияние рентгеновских лучей на только что сорванный сладкий красный перец дозами мощностью от 0 до 800 крад и влияние на дозревание красного перца доз мощностью от 0 до 100 крад.

Влияние облучения дозами мощностью от 400 до 800 крад проявилось в смягчении околоплодников, и содержание каротиноида уменьшилось незначительно даже под влиянием дозы мощностью в 800 крад.

В течение девятнадцатилетнего периода хранения при комнатной температуре, следующего за облучением, в необработанных образцах наблюдалось почти 90% увеличение общего содержания пигмента, выраженного в виде capsantina. Образование каротиноидных пигментов ускорялось до некоторой степени при обработке дозами мощностью в 80 рад и значительно ускорялось при обработке дозами мощностью в 2 крад. Образцы, обработанные дозами в 2 крад в течение 3 недель достигали такого содержания пигмента, которое достигалось контрольными образцами за 8 недель. Тем не менее, содержание пигмента в обработанных посредством облучения образцах уменьшалось после четвертой-пятой недели хранения. Дозы мощностью в 10 крад замедляют или тормозят образование каротиноидов в период хранения (после дозревания). Dозы от 0 до 100 крад не оказывали влияния на уменьшение содержания сахара и скорости высыхания.

Так как дозы облучения в несколько сот килорад, необходимые для разрушения или существенного торможения роста плесени, вызывающей порчу красного перца с высоким содержанием влажности, являются патубными, применение облучения с целью сокращения потерь при хранении свежесорванного перца кажется целесообразным. Однако с точки зрения сокращения периода дозревания и увеличения содержания пигмента использование очень низких доз, стимулирующих образование каротиноида, представляется многообещающим.

Дальнейшие исследования необходимы с целью определения наиболее подходящих условий хранения для дозревания красного перца и установления причин, вызывающих уменьшение каротиноидного содержания в облученных фруктах во второй половине периода хранения.

EFECTO DE LAS RADIACIONES IONIZANTES EN LA POSTMATURACION DEL PIMIENTO ROJO (CAPSICUM ANNUUM). Se ha investigado el efecto directo de los rayos X, en dosis de 0 a 800 krad, sobre pimientos rojos dulces recién recolectados, y sobre la postmaturación de estos pimientos, en dosis de 0 a 100 krad.

La irradiación entre 400 y 800 krad causó el ablandamiento del pericarpo, pero el contenido de carotenoides no disminuyó apreciablemente incluso a dosis de 800 krad.

Durante un período de almacenamiento de nueve semanas a la temperatura ambiente y después de la irradiación, se observó en las muestras no tratadas un aumento de un 90% del contenido total de pigmentos, expresado en capsantina. La formación de pigmentos carotenoides presentó una ligera aceleración para dosis de 80 rad y una fuerte aceleración para dosis de 2 krad. Las muestras tratadas con 2 krad alcanzaron en tres semanas el mismo contenido de pigmentos que las muestras testigo en ocho semanas. En cambio, el contenido de pigmentos de las muestras irradiadas disminuyó al cabo de la cuarta o quinta semana de almacenamiento. Las dosis superiores a 10 krad frenaron o impidieron la formación de carotenoides durante el almacenamiento (postmaturación). La disminución del contenido de azúcares y el ritmo de desecación permanecieron invariables para dosis de 0 a 100 krad.

Como las dosis de radiación (varios centenares de kildor) necesarias para impedir o inhibir en medida apreciable el desarrollo de los mohos causantes de la deterioración del pimiento rojo de gran contenido de agua tienen efectos perjudiciales, no parece aconsejable el empleo de las radiaciones para reducir las pérdidas por almacenamiento en los pimientos rojos recién recolectados. En cambio, la aplicación de dosis muy bajas, que estimulan la formación de carotenoides, parece un método interesante para reducir el período de postmaturación y elevar el contenido de pigmentos. Se precisan nuevas investigaciones para determinar las condiciones óptimas de almacenamiento de los pimientos rojos en período de postmaturación, y las causas de la disminución del contenido de carotenoides de los frutos irradiados en la segunda mitad del período de almacenamiento.

The ground pericarp of red pepper Capsicum annuum is a very popular flavouring and colouring matter used in foods. Most of the red pepper grown in Hungary is harvested in September. It is then stored in strings
or, in recent years, in bulk. During this period an after-ripening occurs, which is followed by drying and processing.

The after-ripening, or storage of the pepper, is necessary not only to increase the pigment content, but also because of the restricted drying capacity available. However, during this period, a substantial part of the pods, already infected with mould at the place of cultivation and injured during harvesting and transport, deteriorate. The colour of the infected pods also deteriorates; the ground pericarp thus becomes poor in colour.

It was therefore of great economic importance to reduce the storage losses of red pepper and, on the other hand, to accelerate after-ripening. The preliminary experiments served to establish the suitability of ionizing radiation, already in use to inhibit microbial spoilage of some fresh fruit, to decrease the danger of moulding and to study after-ripening as affected by ionizing radiation.

The samples taken for investigation belonged to the type marked No. 4725; they were harvested at the same time, at the same stage of ripeness, and were of approximately the same size.

Radiation was effected partly with a "Stabil 250"-type X-ray apparatus of 250 kV, and partly with a panoramic gamma source, containing 500 Ci $^{60}\text{Co}$ of the Plastics Research Institute, Budapest, at room temperature. The respective dose outputs of the various radiation sources were compared by means of the chemical ferrous-sulphate dosimetric method.

At each dose level a loose string, containing 18 to 25 pods, was irradiated and afterwards stored at room temperature. Both irradiated and unirradiated control samples were stored under the same atmospheric conditions.

The moisture content of the pods was established at 0 and 7 d, and from then on at every alternate week subsequent to irradiation. On each occasion the dried and ground pericarp was tested for reducing sugar, according to Bertrand, and for benzene-extracted pigment (by photometry [1]). The pigment content, based on optical density measurements at 490 nm, was expressed in capsanthin, the principal component of the pigment. For the measurements, the whole pericarp of three peppers was used, and the results represent their average values.

No colour difference between the irradiated and unirradiated pericarps could be established visually, and the pigment content, as extracted with benzene, decreased to a comparatively small extent, as an effect of irradiation, at a comparatively high dose level (Table I). This supports the findings of Lukton and Mackinney [2] on the resistance to irradiation of carotenoids in plant tissue.

The consistency of the red pepper, however, was strongly affected by high dose levels. The softening of the pericarp became apparent at 400 krad and at 800 krad, the maximum dose level applied; the initially crisp pericarp, and the inside of the peppers, became smeary and could be separated from the stalk by slight shaking. This is supposed to result from the direct degradation of the protopectin content of red pepper or from the acceleration of pectolytic enzyme activity as caused by irradiation [3]. (Owing to the low dose-rate of the radiation sources, the treatment with several hundreds of krad lasted relatively long. At 800 krad maximum level the treatment took 70 h.) Various authors observed the softening effect of high radiation levels in apple [4], in pears and peaches [3] and in tomatoes [2]. Because of these undesirable effects, the storage experiments were performed in the 0 to 100-krad region only.
TABLE I. DIRECT EFFECT OF IRRADIATION ON THE PIGMENT CONTENT OF RED PEPPER (expressed in capsanthin)

<table>
<thead>
<tr>
<th>Radiation dose (krad)</th>
<th>Pigment content</th>
<th>Pigment content (%) of control</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>capsanthin (g/kg solids)</td>
<td></td>
</tr>
<tr>
<td>0</td>
<td>2.25</td>
<td>100.0</td>
</tr>
<tr>
<td>200</td>
<td>1.94</td>
<td>86.3</td>
</tr>
<tr>
<td>500</td>
<td>1.86</td>
<td>82.5</td>
</tr>
</tbody>
</table>

During the storage tests, in an atmosphere of 35 to 55% relative humidity, the moisture content of the pericarp decreased, as can be seen in Fig. 1. No difference could be observed in the drying rate of irradiated and unirradiated samples. Under the prevailing storage conditions, the moisture content of the pods reached 75% equilibrium relative humidity [5], the critical level from the point of view of mould growth, in four weeks. The samples, initially having a moisture content above 80%, reached the equilibrium humidity of the ambient air in eight weeks.

No significant or biased difference could be observed between the respective reducing sugar contents of irradiated and unirradiated samples. During the first week of storage the reducing sugar showed a slight increase, and in the following two months decreased to a small extent (Fig. 2).

The pigment content of the red-pepper pods was, however, strongly affected by irradiation. The pigment content, as measured at the beginning of storage, was characteristic of the third harvest of the control samples; this increased during the first seven weeks, and after the seventh week exceeded the initial value by 90%. Thus, the observation made by other Hungarian researchers [6] that the pigment content of the pepper pod increases during after-ripening, was proved by the authors' experiments. After the seventh week, on reaching the air-dry state, increase in the pigment content stopped, or showed a slight decrease. During the first three weeks of storage in the samples irradiated at 2 krad, the pigment...
content increased significantly as compared to the control samples. In samples irradiated at 80 krad, the rate of increase of pigment formation was also higher than in the unirradiated samples. However, after a period
of about four weeks, the effect of radiation doses that stimulated after-ripening became unfavourable, the pigment content decreased and, in the ninth week of storage, diminished to 70-80% of that of the control samples. In samples irradiated at 10 krad, the gradual decrease commenced from the fifth week of storage, whereas in samples treated at 100 krad the increase of carotenoid content, expressed as capsanthin, stopped after three weeks. The observations, as related to the pigment content, are shown in Figs. 3 and 4.

Thus, it was proved that, with radiation doses of several hundreds or thousands of rads, the after-ripening of the red-pepper pod may be accelerated, but doses higher than these proportionately inhibit after-ripening. It is probable that decrease in the carotenoid content, beginning from the fourth to fifth week of storage in irradiated samples, and after the seventh week in unirradiated samples, is connected with oxidative changes.

The observations made during this study seem to support data found in related literature that, while small radiation doses stimulate certain physiological processes in plant tissues, the same processes are inhibited by larger doses. The extent of doses exerting a stimulating or inhibiting effect depends on a variety of conditions: the kind of plant, the physiological condition, the state of ripeness of the plant tissue, the conditions prevailing during irradiation, and the subsequent period. In a study carried out previously [7], the germination of barley was stimulated by a 1.5-krad dose, but doses above 10 krad definitely inhibited germination. Hansen and Grünewald [8] observed the acceleration of after-ripening in pears after irradiation at 15 to 20 krad. The slowing down of after-ripening, as an effect of irradiation, with doses above 100 krad was observed by several authors [9, 10].

The doses applied in this study did not affect moulding. During the nine weeks' test period, among the pods taken from strings irradiated at various levels, mouldy samples were found in equal proportion. In the majority of cases the grey-and-white mould mass of woolly texture was on the inside surface of the pod and from the outside only a partial discoloration or speck on the pericarp was visible. Notwithstanding the partial bleaching, the total pigment content, as a percentage of the solids, of mouldy pods, did not differ, beyond the margin of error, from that of the healthy pods taken from the same string at identical storage periods. Thus, there is no close connection between the colour and colouring capacity, i.e. the extractable pigment content of the ground red pepper. The reducing sugar content of the mouldy pods, however, did not amount to one third of that of the healthy pods. The most frequent moulds isolated from the mouldy pods belonged to the Fusarium, Cephalosporium, Alternaria and Stemphilium genera, respectively. Their radiation tolerance was established by irradiating colonies developed on agar plates containing pepper extract. It was found that, to achieve substantial inhibition of mould growth, a dose of 100 to 300 krad was needed, whereas to complete sterilization, a dose of between 400 and 800 krad was necessary.

Since the doses required to kill, or substantially inhibit, moulds causing the spoilage of red pepper damaged the tissue of pods and the after-ripening, the application of doses of several hundreds of krads guaranteeing pasteurization is not promising in fresh red pepper of high moisture content. However, the stimulation of carotenoid development
in the first few weeks of storage with doses of several hundreds or thousands of krads seems possible. If the after-ripening period previous to drying may be shortened by this treatment, the danger of moulding may be indirectly reduced. Further, more intensive study is needed to determine the optimum irradiation level in the case of red pepper at various stages of ripening and ambient air humidity. The lability of carotenoids in irradiated pepper during longer storage periods has to be investigated also.

REFERENCES

EXPERIENCES WITH THE IRRADIATION OF VEGETABLES IN THE NETHERLANDS

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Abstract — Résumé — Аннотация — Resumen

EXPERIENCES WITH THE IRRADIATION OF VEGETABLES IN THE NETHERLANDS. The author surveys recent experiences in the Netherlands of the effect of irradiation (electrons and gamma rays) on different vegetables. In this work main attention was given to the possibilities of prolonging the shelf life, namely, effects on the living product.

The reaction of the tomato, among others, to electrons and gamma rays is discussed. These rays cause complete loss of the internal structure. Mention is made of the strong presumption that neck-rot of the onion cannot be controlled by ionizing radiation, and some orienting trials with cut vegetables, packed in plastic and unpacked, are discussed. Possibility of the irradiation of mushrooms is reported more extensively; five favourable results are obtainable. However, an experiment with times of processing successively postponed showed that the possibilities are less than was expected initially.

Irradiation cannot be applied to "sauerkraut" due to discolourations which are rapidly manifested. Treatment of dried curly kale with 1.5-MeV electrons showed decreasing cooking time and rigidity with increasing krad doses, while samples treated with doses higher than 1000 krad became organoleptically unacceptable.

ESSAIS D'IRRADIATION DE LEGUMES AUX PAYS-BAS. L'auteur donne un aperçu d'expériences récentes faites aux Pays-Bas sur les effets de l'irradiation (électrons et rayons gamma) de quelques légumes très différents. Au cours de ces travaux, on a surtout étudié les possibilités de prolonger la durée de conservation, en d'autres termes les effets sur le produit vivant.

L'auteur examine notamment les diverses réactions de la tomate sous l'effet des électrons et des rayons gamma. Ces derniers détruisent complètement la structure interne de la tomate. Il précise qu'il y a de fortes raisons de penser que la pourriture du collet de l'oignon ne peut pas être enrayée par les rayonnements ionisants. En outre, il discute certains essais faits avec des légumes coupés, en vrac ou conditionnés dans des emballages en matière plastique. Il expose plus en détail les possibilités d'irradiation des champignons. On peut obtenir des résultats satisfaisants dans cinq cas. Toutefois, une série d'expériences consistant à différer de plus en plus le moment du traitement a montré que les possibilités réelles sont moindres qu'on ne pouvait le croire à l'origine.

Dans ce travail, l'auteur indique que l'irradiation de la choucroute ne peut pas trouver d'application étant donné la décoloration rapide que subit le produit. Le traitement, avec des électrons de 1,5 MeV, de choux frisés déshydratés a montré que l'accroissement de la dose (en kilorad) entraînait une diminution de la durée de cuisson et un amollissement du produit. Les échantillons traités avec des doses supérieures à 1000 kilorad sont devenus inacceptables du point de vue organoleptique.

ОПЫТ ОБЛУЧЕНИЯ ОВОЩЕЙ В НИДЕРЛАНДАХ. Дается обзор последних опытов в Нидерландах по воздействию облучения (электроны и гамма-лучи) на некоторые весьма различные овощи. В данной работе основное внимание уделялось возможности увеличения сроков хранения и таким образом воздействия на живой продукт.

Среди прочего рассматриваются различные реакции томатов на электроны и гамма-лучи. Эти последние вызывают полное исчезновение внутренней структуры. Упоминается о предположении, что междоузловое гниение растений не может управляться ионизирующей радиацией. Далее, рассматривается несколько ориентирующих опытов с нарезанными овощами, упакованными в пластик и не упакованными. Более широко сообщается о возможностях облучения грибов. Здесь можно получить пять благоприятных результатов. Однако эксперимент с успешно перенесенными моментами обработки показал, что эти возможности меньше, чем первоначально предполагалось.

Далее указывается, что облучение "кислой капусты" не может найти применения из-за быстро наступающего обесцвечивания. Обработка сухой капусты (curly kale) электронами...
в 1,5 Мэв показала с увеличением дозы порядка килорад уменьшение времени варки и жесткости. Однако образцы, обработанные дозами выше 1000 крад стали неприемлемыми в органолептическом отношении.

EXPERIMENTOS SOBRE IRRADIACION DE VERDURAS EN LOS PAISES BAJOS. Se describen los experimentos recientemente realizados en los Países Bajos para investigar los efectos de las radiaciones (electrones y rayos gamma) en verduras muy diferentes. En estos trabajos se han estudiado sobre todo las posibilidades de prolongar el período de almacenamiento, es decir, los efectos de las radiaciones en el producto fresco.

Se examinan entre otras cosas las diferentes reacciones del tomate a los electrones y a los rayos gamma. Estos últimos originan una transformación completa de la estructura interna. Se indica que es muy probable que la podredumbre del cuello de la cebolla no pueda combatirse con las radiaciones ionizantes. Asimismo, se examinan varias pruebas con verduras cortadas, envasadas en material plástico y sin envasar. Las posibilidades de irradiación de las setas se tratan con más extensión. En este aspecto se han obtenido resultados favorables en cinco casos. Sin embargo, un experimento con etapas sucesivas de tratamiento ha mostrado que las posibilidades reales son menores que las inicialmente supuestas.

Se indica también que la irradiación de la "sauerkraut" carece de aplicación práctica por las decoloresaciones que rápidamente se manifiestan. Se ha irradiado con electrones de 1,5 MeV colirizada deshidratada, observándose que el tiempo de cocción y la dureza disminuyen al aumentar la dosis; sin embargo, las muestras tratadas con dosis superiores a 1000 krad presentaron propiedades organolépticas inaceptables.

INTRODUCTION

The preservation of the fresh condition of food products by irradiation is achieved in two different ways. First an effect on the physiological processes, and second inhibition of the microflora or special parasite. Our main experience lies in the field of fruits. In this paper we shall try to cover our experience in the Netherlands with vegetables.

LEAFY VEGETABLES

Without entering into details, in general difficulties are experienced when irradiating leafy vegetables. The surface of the leaves is large so also is the number of spores located on them. Moreover the leafy vegetables themselves are rather susceptible to irradiation. When irradiating for example head lettuce (Lactuca sativa capitata L.) the penetrating capacity of the rays also plays an important role. Thus irradiation of lettuce at doses of 50, 100, 150 and 200 krad gave no advantages. Some lesions were found at the highest dose. Lettuce is a very important product of our country. Precooling is expected to offer much better possibilities.

MELON AND CUCUMBER

However not only leafy vegetables are susceptible to irradiation. For instance the fruits of the genus Cucumis namely the melon (C.melo L.) and the cucumber (C.Sativus L.) are also susceptible. In one experiment the melon showed some injury at 50 krad through formation of sunken spots in the peel. This fruit, therefore, certainly is not suitable for conservation by ionizing radiation. Although cucumber can endure slightly higher dosages, at about 100 krad some lesions were visible. Irradiation showed no appreciable advantage here. Much better results can be obtained by packaging in shrink film. If each individual cucumber is packed in a polythene shrink film then almost unbelievable extensions of market life are obtained.
Application of lower temperatures is not essential here. This may be illustrated by the fact that cucumbers packed in these films (0.02 mm) can be stored for not less than 14 days at 20 °C in a good condition, contrary to 3 days with the unpacked samples. With this method negligible losses in weight are found, no discolorations were noted and a taste panel could not detect any decrease in the organoleptic properties of the fruit. These surprising results proved very beneficial in the export of our cucumbers to Great Britain. Already 1 year after this finding not less than 20 percent of these products are shipped to this country in shrink film.

ONION

A product very often mentioned in the irradiation literature normally in connection with the inhibitory effect of ionizing radiation on sprouting is the onion. No special attention was drawn to this aspect. Sprouting of the onion is not a serious problem in our country. However, the incidence of neck rot in the onion is a difficult and in fact up to now still incompletely solved problem. Neck rot is a parasitic disease. Already during growth the plant is infected by the mold Botrytis allii. At harvest the fungus is already located in the centre of the bulb. Especially in a wet season much neck rot is found. An attempt has been made using X-rays to come to a control of this disease. The experiment was set up in cooperation with the I.P.O.1, using the variety "Stuttgarter Riesen". It was found, however, that the onion is very susceptible to irradiation. Former trials with 3 MeV electrons had already shown using the variety "Rijnsburger" that starting from 50 krad the first effects of injury can be observed in the form of glassiness. Therefore, for this experiment increasing values from 40 krad were applied. Also here the first serious injuries were found at 100 krad. Nevertheless the trial was continued with artificially infected onions. Irradiation was done with 120 and 220 krad, and after storage took place at 10 °C. After two months it turned out that both doses had been too high. The picture of the lesions was much like that of neck rot, especially on the highest-dosed onions. At cutting the tunics were glassy and this glassiness could often be found as far as the middle of the onion. Now experiments with Botrytis allii grown on an artificial medium in Petri dishes have shown that mold growth can certainly be expected to take place even above 300 krad. As this experiment showed already 120 krad to be inapplicable one is obliged to conclude that irradiation does not offer a solution of the neck rot problem.

TOMATO

The first trials with tomatoes (Lycopersicum esculentum Mill.) were done to get information of the effect of irradiation on colour and firmness. For this purpose fruits were taken in the turning and in the orange-red stage. The doses given were 50 and 200 krad. The fruits were rolled during the radiation with 3 MeV electrons. Storage was at room temperature for 12 days. After this period pressure tests were done by measuring the compressibility between parallel surfaces using 2 kg for 2 min. The control fruits were found to be softer than the irradiated ones. Colour was determined visually. The unripe orange colour was retained longest by tomatoes irradiated to 200 krad, whilst on the ripe tomatoes the orange-red stage was

1 IPO Institute for Pathological Research, Wageningen.
Irradiation of tomatoes with 1 and 3 MeV electrons gave little perceptible difference.

For the purpose of taste evaluations the variety Moneymaker was irradiated with 3 MeV electrons by doses of 50 and 200 krad. The fruits were stored at 10 °C. The evaluations were done on two dates. After 12 days storage preference was given to the control. The tomatoes which had received the highest dose had a tough peel. After 19 days storage the irradiated fruits were judged to be just better. The high-dosed tomatoes had the best taste. However, also here the peel was tough. It should be noted that a storage temperature of 12 °C would be better than 10 °C. For some time the trials with tomatoes were not continued. It was only in the summer of 1965 that in connection with a special problem work with tomatoes was continued. Then it was the aim to study whether irradiation would lead to an improvement of the "cuttingproof" properties, (in German called "Schnittfestigkeit" i.e. the property of tomatoes that after cutting the fruits the pulp does not run out). In order to irradiate the interior of the fruit X - rays were used. The variety Ailsa Craig was irradiated with 150 krad.

This trial showed that the fruits completely lost their cuttingproof property after 1 day, independent of their stage of ripeness. At this dose of 150 krad a slight decrease in taste was found. The result, somewhat opposite to the former, therefore, was a reason to continue with the experiments with 1.7 MeV electrons and increasing doses. Here no loss of the "cuttingproof" property was found. To make certain that there is a real difference between the effect of electrons and X - rays a more extended experiment was set up with 3 varieties (Ailsa Craig, Extase and Moneymaker), comparing 1.7 MeV electrons with X - rays at different doses (10 - 150, and 350 krad). This trial revealed many differences in effect between the two types of irradiation.

1. On colour. The tomatoes treated with electrons showed differences in the colour of the peel, namely the higher the doses the paler the colour. The X - ray-treated tomatoes only showed small differences in the colour, with an exception for the 350 krad dosed fruits. Contrary to this the pulp does show a paler colour with increasing doses.

2. On firmness. Both electrons and X - rays gave a decrease in the firmness of the fruits after one day. After 6 days the electron treated fruits had more or less retained this firmness. The X-ray treated fruits, however, continued during these 6 days to decrease in firmness. This was especially noticeable at the doses of 150 krad and above.

3. On taste. It is the impression that the organoleptic qualities decline slightly more after X - irradiation.

4. On "cuttingproof". Even a 350 krad electron dose has no influence on the "cuttingproof". X - rays induce even at very low doses an immediate loss of this property.

Out of this investigation it appears that X - irradiation of tomatoes is not useful. However, it is still not certain if electrons will be of some use. Firstly the peel becomes tough and secondly there is the danger of a loss in taste above a dose of 100 krad. Finally irradiation of tomatoes might become less interesting as recently another method, a treatment of lecithin-pimaricin emulsion, offers better possibilities of prolonging the shelf life, with a brighter appearance of the fruits, less decay and maintenance of the typical taste. This last method in all probability will lend itself to prepackaging which is getting more and more important. It is, therefore, the intention to compare electron irradiation with the lecithin-pimaricin combination.
Very spectacular results were obtained with mushrooms (*Agaricus bisporus* Sing). At the 6th International Mushroom Congress in June 1965 we had the opportunity to speak about these investigations. As this lecture will be published in Mushroom Science VI we can refer to this. Mention may be made of the following. The first experiments in 1963 showed that irradiation inhibited the opening of the caps. As closed caps are desired in our country this was found to be a very favourable irradiation effect. Further work showed that this effect on the caps was reproducible. However, it is advisable not to give doses above 350 krad in order to avoid the risk of brown discolorations. In fact it is not necessary to give such high doses as with 100 krad; the same results can be obtained provided a good penetration of the mushroom is realized. This is important for, the lower the dose can be kept. From this, it follows that 3 MeV electrons will give better results than 1 MeV and that 3 MeV has a slightly poorer effect than X-rays even if the mushrooms are spread out in one layer. This inhibition on the caps is a good example of a pure physiological action on the mushroom itself. As might be expected it was found that the strongest effect on the caps and the longest storage results in general can be obtained if the time between picking and irradiation is kept as short as possible. Already one day's delay will give considerable less keepability. The length of storage is not limited by the caps but by other factors which make the mushroom unacceptable. This effect on the caps, however, is not the only positive result. A number of other actions of irradiation are also favourable. The already mentioned extension of the shelf life is one. When comparing the colour between treated and control samples it is observed that the irradiated mushrooms are slightly whiter. Further not only cap opening is inhibited but also the undesired elongation of the stalks. This is especially evident when comparing samples of non-irradiated packed mushrooms with treated ones. After some time the packed material presses against the plastic film. All these factors result in an extended shelf life. In one experiment, after having given a dose of 100 krad not less than 12 days storage was possible at 15°C. In most cases, however, before the end of this period the mushrooms are getting moldy. This occurs earlier in the unirradiated samples. So we now have a whole series of positive points in favour of radiation. Our last experiment, however, puzzled us somewhat. Anyone who works on irradiation of foodstuffs knows the danger of impairing the quality. Therefore several taste evaluations had been carried out with a large number of people. Here the mushrooms had always been cooked in a pan and evaluated immediately afterwards. These tests always showed the irradiated mushrooms to be slightly better than or equal to control. So we concluded that irradiation also led to a preservation of taste and flavour. As a final experiment we decided to set up a trial with processed mushrooms in order to compare all different quality aspects of irradiated and non-treated samples. Further it was decided to examine whether the quality of mushrooms stored for some days would indeed get a better evaluation than the corresponding control. Therefore the period between irradiation and processing was regularly extended by one day. Storage of the fresh mushrooms was done at 10°C. X-rays were applied. The doses given were 100 and 200 krad. The full glass jars, filled with 250 g processed mushrooms each, were placed at 15°C in the dark. After 3½ months' storage the different evaluations were done.

Effect on colour: It was observed that the right white colour decreased with the increase of the time elapsed between harvest and irradiation. Irradiation itself had no influence on this tendency.

Effect on flavour: Also the right flavour decreased with an increase of the time passed between picking and irradiation. No special effect of irradiation was found. Only on the 4th day of processing irradiation had an impairing effect at the higher dose of 200 krad.
Effect on firmness: The firmness was measured by the I.M.C. tenderometer (type 384) without using weights. The values found indicated that independent of irradiation after the second day of processing the mushrooms had become more firm.

Effect on taste: The taste evaluations were carried out by 7 persons. It may be of interest to report that the panel raised no objection against the increase in firmness indicated by the tenderometer. However, also here was found at an increase of days of storage a convincing decrease of the evaluation of taste. In this course irradiation had a more favourable than negative effect. The mushrooms processed after the 4th day of storage gave an unacceptable quality.

Summarizing the results of this trial the conclusion can be drawn that all factors belonging to the conception of quality focus into the same direction namely a decrease in the appreciation at an increase in time between picking and processing. This loss in quality takes place almost independent of the irradiation. So this trial indicates that although the caps remain closed after radiation it is advisable not to wait too long with processing for the sake of quality. As already stated these results are rather puzzling. Does it make a difference whether fresh mushrooms are cooked in an open pan or processed in closed jars? If this is true we will have to deal with the problem that seemingly good mushrooms can be offered which will reveal an unacceptable quality after processing. This discrepancy between taste evaluations will still have to be solved.

CUT VEGETABLES

Attention has also been paid to the possibilities of prolonging the shelf life of fresh cut vegetables by ionizing radiation. Some orientating tests in previous years have indicated favourable possibilities with a limited number of products. Repeated experiments this spring with these promising products will be discussed here. Red cabbage (Brassica oleracea L. var. Pabla DC), onion (Allium cepa L.), leek (Allium porrum L.), swede (Brassica napus L. var. napobrassica (L.) Rchb.), and carrot (Daucus carota L.) are concerned. All were irradiated with gamma-rays produced by a Co 60 source (95 krad/h). Packaging took place in polythene bags (0.04 mm) both with completely sealed bags and perforated with 2 holes of 5 mm. They were stored at 15° C. Every trial was terminated by an organoleptic evaluation.

The red cabbage was irradiated with 0-50-100 krad. After 4 days' storage only small differences were found with the cabbages in the sealed bags between control and irradiated samples, with a tendency for the 100 krad dosed to be best. Perforation gave worse results than the control. Considerable discolourations were found here.

The onions were examined after 9 days. Irradiation was carried out with 0-25-50 krad. The appearance of the irradiated samples was better. The panel unanimously found that the irradiated onions packed in sealed film offered the best preservation of flavour.

The leek was irradiated with 0-50-100 krad. The samples were held at 15° C for 9 days. Again it was found that the sealed irradiated leek had the better taste. The colour of the control was greyish.

The swede, after having received doses of 0-50-100 krad, was inspected after 9 days' storage. Here the samples in the perforated bags were compared. Both taste of the irradiated swede and the appearance were evaluated to be better.

The carrots were given 0-50-100-200-300 krad. After 8 days the samples were compared. Unanimously, preference was given to the irradiated sealed carrots. The control was discoloured and had a deviating taste.

The results with these 5 cut vegetables are favourable to very favourable. Therefore, continuation will be worth while.
SAUERKRAUT

Similar tests were also done with "sauerkraut" viz. packed in completely closed cellulose acetate (0.045 mm) bags, in bags provided with 8 holes and unpacked. In former experiments discolourations were always obtained. Here, a study was made to see whether the discolourations were caused by gases produced during irradiation which are unable to escape from the sealed package. The result of this study showed that in all cases discolourations occurred in the irradiated samples. The conclusion drawn from this is that the purple-brown discolourations are not formed by the irradiation produced ozone but probably by the hydrogen peroxide (H₂O₂). In other experiments where hydrogen peroxide has been added to unirradiated "sauerkraut" an immediate discolouration was produced. Consequently the irradiation of "sauerkraut" is not possible, probably owing to the hydrogen peroxide.

AIR-DRIED CURLY KALE

Finally we have to report the experiments of my colleague Ir. J.C. Mettvier Meijer who irradiated dried curly kale (Brassica oleracea laciniata (L.)) in order to study the influence of this treatment on the cooking time, taste, flavour, and texture. Irradiation was done with 1.5 MeV electrons and doses of 0-300 - 1000 - 3000 - 7000 krad.

It was found that increasing doses resulted in a decrease of the cooking time (control*24 min., 1000 krad-15 min., 7000 krad-3 min.). With the cooked product it was noted that owing to the shorter times required especially at the higher doses the samples remained a fresher green colour. At the highest doses this green became unnatural for a cooked product. At equal cooking times all samples had the same normal colour. After cooking for 25 min. the texture decreased with an increase of dose. The pressure was measured by the I.B.V.T. meter. The control gave a value of 38, the dosage of 1000 krad 32 and at 7000 krad only 16 was found. The organoleptic tests showed that with up to 1000 krad an acceptable taste is maintained. With 3000 krad a slight change in flavour was observed. Therefore, it is concluded that if the acceptable 1000 krad is applied the cooking time can be reduced from 24 min. to 15 min. Further work with other dried vegetables is in progress.

ACKNOWLEDGEMENT

The radiation facilities were rendered until September 1964 by one of the Shell laboratories (The "Van de Graaff Lab.", 3 MeV) at Amsterdam. For their ready assistance to place their source at our disposal we express our sincere acknowledgement. In nearly all later treatments use was made of the Van de Graaff generator (1.7 MeV) at I.T.A.L. in Wageningen. As all radiation experiments took place in close cooperation with the I.T.A.L. staff we feel thankful for the continued interest and the valuable technical advice we always experienced.

DISCUSSION

R.S. KAHAN: How long ago did you start your onion experiments? It has been known for a long time that irradiation would help only in the

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2 I.B.V.T. meter is a pressure meter developed at the author's Institute.
prevention of sprouting in onions, and that doses slightly higher than those required for sprouting control caused increased sensitivity to neck rot infection. There was therefore little chance of your preventing neck rot infection by means of high doses.

O. L. STADEN: I do not know exactly when these experiments were started. Neck rot disease is a big problem in the Netherlands and, since the fungus is located in the centre of the bulb, irradiation would be an ideal method of combating the parasite. This is why we decided to try it, in spite of the small chances of success.

R. S. KAHAN: What was the advantage of storing tomatoes at 12°C rather than at 10°C?

O. L. STADEN: At temperatures below 12°C the tomatoes do not develop normally; they do not achieve their normal red colour, and changes in taste occur after a time.

R. S. KAHAN: The changes in quality of irradiated mushrooms that you observed during storage are probably long-term effects induced by irradiation. Such effects have been reported for many other crops.

O. L. STADEN: I agree. With regard to these effects, we are unable to suggest what mechanism is involved.

A. S. KOVACS: How do you explain the differences between the effects of various treatments on what you call in your paper the "cutting-proof" properties (Schnittfestigkeit) of the tomatoes?

O. L. STADEN: A reason for the difference in effect between electrons and gamma radiation may be their different penetrating capacities. The electrons only go through the outer surface, while the gamma radiation achieves complete penetration. If the rather loose interior of the tomato is only slightly damaged, the enzymes that split the cellular walls are liberated and decomposition, and hence loss of texture, takes place.

D. S. MALLA: In experiments that I have carried out, untreated sauerkraut packed in polyethylene bags and exposed to daylight became discolored; sauerkraut packed in the same way but not exposed to daylight showed no, or only very slow, discoloration. In your presentation you said that discoloration of sauerkraut irradiated in cellophane bags might have been caused by H₂O₂ production.

O. L. STADEN: During transport of the sauerkraut from the irradiation source to our laboratory there must have been times when the packed samples were exposed to daylight, although they were later stored in the dark. I cannot therefore say whether different results would have been obtained if the irradiated sauerkraut had been kept continuously in the dark. From the fact that both unpacked and packed irradiated sauerkraut became discolored we simply deduced that volatile gases did not induce this browning, but more probably the irradiation-induced H₂O₂.

A. MATSUYAMA: Japanese workers have observed that higher dose-rates are more effective in inhibiting the sprouting of onions. Have you made similar observations?

O. L. STADEN: No, we have not varied the dose-rate.

A. MATSUYAMA: We have observed browning of the inner bud of onions after irradiation even to low doses. Have you noticed this?

O. L. STADEN: Yes, we first observed transparency of individual scales, caused by the breakdown of cell sap into intercellular fractions, followed by browning.
M. INGRAM: You are evidently implying that the fundamental change is a loss of permeability in the cell membranes of the dormant shoot. We have used simple measurements of the conductivity of plant tissue (in peas) to reveal this change; and so has Dr. J. P. Skou at Risø, who has published several papers about it. The change usually increases susceptibility to fungal attack.

O. L. STADEN: Yes, I agree.
REVIEW OF THE STATUS OF IRRADIATION EFFECTS ON CITRUS FRUITS

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UNITED STATES OF AMERICA

Abstract — Résumé — Аннотация — Resumen

REVIEW OF THE STATUS OF IRRADIATION EFFECTS ON CITRUS FRUITS. The United States fresh-market spoilage losses valued at the 1959-1963 retail prices were estimated for oranges and grapefruit to be $8.4 and $5.4 million, respectively. Stem-end rots and green and blue molds cause the greatest post-harvest decay losses to citrus. No single radiation dose can be given that will be the minimum required for protecting citrus fruits against spoilage. Radiation doses required for retarding old or established infections are higher than for the retardation of incipient infections. The flux, as well as the dose of gamma radiation, influences the control of infections.

Fresh citrus fruits undergo metabolic changes which ultimately lead to senescence. Some of these changes include varied activities in the levels of respiration, organic acids, sugars, pectic substances and color. In many respects the loss of cellular vitality in senescence resembles the effects of radiation injury.

Irradiation causes changes in the pectic components of fruits. In general, an increase occurs in the water and ammonium oxalate-soluble fractions and a decrease occurs in the sodium hydroxide-soluble fraction. A large increase of water-soluble pectin is found in the juice extracted from irradiated fruits. Apparently this increases results from movement of the water-soluble pectin from other parts of the fruit. A marked increase in the viscosity of the juice results.

Peel injury is sometimes found following irradiation and storage of the fruit. The percentage of fruit showing peel injury, and the severity of the injury, increase the higher the storage temperature and the longer the storage duration.

Oranges and grapefruit may be irradiated with doses of up to 200 krad without any appreciable deleterious effects on organoleptic qualities.
ОБЗОР ВЛИЯНИЯ ОБЛУЧЕНИЯ НА ПЛОДЫ ЦИТРУСОВЫХ. Убытки в результате порчи свежих апельсинов и грейпфрутов в США оценивались соответственно в 8,4 и 5,4 млн. долларов в разнichenных ценах 1959-1963 гг. Затяжное конца стебля и зеленая и голубая плесень вызывают самые большие потери цитрусовых после их сбора. Нельзя называть какую-либо одну дозу облучения, которая являлась бы минимальным, необходимым для защиты плодов цитрусовых от порчи. Для приостановки действия старых или установившихся инфекций требуются более высокие дозы облучения, чем для приостановки начинаяшихся инфекций. Для борьбы с инфекциями имеет значение поток, а также доза гамма-излучения.

Свежие плоды цитрусовых претерпевают метаболические изменения, которые в конечном итоге приводят к старению. Некоторые из этих изменений связаны с дыханием, органическими кислотами, сахарами, пектиновыми веществами и цветом. Во многих отношениях утрата клетками жизнеспособности при старении напоминает эффекты радиационного поражения.

Облучение вызывает изменения в пектиновых веществах фруктов. В основном, происходит увеличение фракций, растворимых в воде и в оксалате аммония, и уменьшение фракции, растворимой в гидроокиси натрия. Большое увеличение растворимого в воде пектина обнаружено в соке, полученному из облученных фруктов. По-видимому, это увеличение является результатом перемещения растворимого в воде пектина из других частей фруктов. Это приводит к заметному увеличению вязкости сока.

Иногда после облучения и хранения фруктов обнаруживается повреждение кожицы. Процент плодов с поврежденной кожей и степень такого повреждения тем больше, чем выше температура хранения и больше продолжительность хранения.

Облучение апельсинов и грейпфрутов дозами до 200 крад не вызывает каких-либо заметных изменений органолептических качеств.

There is a widespread interest in the use of gamma radiation for the extension of shelf life of citrus fruits. This technology offers promise for reducing the spoilage loss of fruit from the time of harvest until it reaches the consumer. While the organisms causing decay can be inactivated by giving adequate exposure to gamma rays, it is necessary to limit the dosage so that not more than minor changes occur in the physical and chemical properties of the fruit.

There is wide variation in the sensitivity of organisms to radiation. This is not confined to differences between organism species, but the
stage of development of the infection on the fruit and the extent of the
infection will influence the amount of radiation required for inactivation.
The changes in fruit respiration, texture, flavor, acidity, color, etc.,
are usually intensified as the radiation dose is increased.

I. Spoilage

While citrus fruits are not as perishable as peaches, strawberries and
certain other common fruits, nevertheless there is a sizable loss of fruits
in the marketing channels. Droge (1) estimated for 1959-63 the retail
value of the annual fresh market spoilage losses in the U. S. for oranges
at $8 400 000 and for grapefruit $5 400 000.

Some of the more common causes of citrus fruit spoilage are shown in
Table I. These fruit diseases and controls are discussed by Pratt (2),
Klotz (3) and Rose et al. (4). Stem end rot and green and blue molds cause
the greatest post-harvest decay losses to citrus.

Various methods are used presently for control of the diseases and
reduction of losses during transit and handling in the markets. Immersion
of fruits in 45° to 49°C water or in soap-fungicide solutions at similar
temperatures have been used. Grierson et al. (5,6) have shown reasonably
good control of fruit decay with Dowicide A-hexamine. Biphenyl impregna-
tion of fruit wrappers and pads placed in shipping cartons has helped
reduce the losses. The biphenyl volatizes slowly and inhibits development
of blue and green molds and stem-end rots. At temperatures below 10°C
the stem-end rots are arrested. Black rot of oranges and alternaria rot
of lemons are reduced by adding to the wax emulsions 200 ppm 2, 4, 5-T or
500 ppm 2, 4-D.

Low temperature storage of lemons and grapefruit for better disease
control is limited when rind injury must be avoided. Lemons cannot be
stored at temperatures below 14°C without the development of rind injury
(7). Some grapefruit must not be held at temperatures below 10°C in order
to prevent pitting.

No single radiation dose can be stated that will be the minimum re-
quired for protecting citrus fruits against spoilage. A number of factors
determine the required radiation dose. Higher radiation doses are needed
to retard old or established infections than young or incipient infections.
The several decay causing organisms vary in radiation resistance. The
flux as well as dose of gamma radiation apparently influence the control
of infections.

Sommer et al. (8) studied several important citrus fruit decay species
and showed these to have radiation resistance in the following increasing
order: Trichoderma viride, Phomopsis citri, Penicillium italicum, Peni-
cillium digitatum, Geotrichum candidum, Diplodia natalensis, Alternaria
citri. A. citri is far more resistant to radiation than any of the others.
A radiation dose may be sufficient to prevent development of the organisms
most commonly causing spoilage, but secondary decay may result from the
more radiation resistant species.

Sommer et al. (8) determined the radiation dose that inactivated all
of the cells in a fungus population and referred to this as the "colony
inactivation dose" (C.I.D.). The dose inactivating any per cent of the
populations was approximated from results obtained. Figure 1 shows the
dose required to inactivate all cells in 80 per cent (C.I.D. 80) of
various sized populations. As the size of the spore population increased,


there was a marked increase in the radiation dose required to inactivate all spores.

Uniform quantities of conidia obtained from 7-day-old cultures of Penicillium digitatum and P. italicum were added to Tochinai's medium (9). The viable spore suspensions were irradiated at several levels and after 18–20 hours the percentages of germinating spores were determined (Table II). Germination was inversely proportional to the radiation dose. Following a gamma radiation dose of 300 000 rep there were 12.4% germinating spores in the P. digitatum suspension, and with a dose of 280 000 rep 4.5% germinating spores in the P. italicum suspension. While a spore of P. italicum may have germinated following a dose of 467 000 rep, colonies were not formed when conidia were irradiated above a dose of 103 000 rep.

Kahan and Monselise (10) inoculated Valencia-type oranges with P. digitatum spores. The fruit had been held in cold storage 10 to 14 weeks prior to inoculation. The fruits were subjected to a low flux of approximately 0.05 krad/minute gamma radiation doses of 45 to 175 krad and stored at 4° to 6°C. The unirradiated fruits were spoiled in 4 to 5 days after inoculation. For the irradiated fruit a linear relation was found between shelf life and the dose. Each 14.1 krad gave an additional day of storage life.

Beraha (11) reported that the flux or intensity as well as the delivered dose of gamma radiations influenced both rate of development and total incidence of blue mold of oranges and green mold of lemons. Decay on oranges was not completely controlled by 182 krad dose delivered at 3 krad per minute (Figs. 2, 3). However, effective control was obtained when delivered at 20 krad per minute over a dose range of 157 to 182 krad. At a flux rate of 40 krad per minute, control was effective when the dose range was 125 to 137 krad.

1 rep=roentgen-equivalent-physical which corresponds to the amount of radiation that would bring about the same absorption of energy per unit of air or tissue as from 1 roentgen or x-rays. Its equivalent in ergs ranges from 83 to 100 per gram of water.

2 krad is equivalent to 1 000 rad. The rad is the unit which specifies the radiation dose in terms of energy absorption per unit mass. It represents an energy absorption of 100 ergs per gram of material.
Table I. Summary of the common citrus fruit diseases causing spoilage losses

<table>
<thead>
<tr>
<th>Causal Agent</th>
<th>Common Name</th>
</tr>
</thead>
<tbody>
<tr>
<td>Phomopsis citri Faw.</td>
<td>Stem end rot</td>
</tr>
<tr>
<td>Diplodia natalensis Pole-Evans</td>
<td>Stem end rot</td>
</tr>
<tr>
<td>Penicillium digitatum Sacc.</td>
<td>Green mold</td>
</tr>
<tr>
<td>Penicillium italicum Wehmer</td>
<td>Blue contact mold</td>
</tr>
<tr>
<td>Alternaria citri Ellis and Pierce</td>
<td>Black rot of orange &amp; Alternaria rot of lemons</td>
</tr>
<tr>
<td>Phytophthora citrophthora (Sm. &amp; Sm.) León.</td>
<td>Brown rot</td>
</tr>
<tr>
<td>Phytophthora parasitica Dastur</td>
<td>Brown rot</td>
</tr>
<tr>
<td>Sclerotinia sclerotiorum (Lib.) Dby.</td>
<td>Cotteny rot</td>
</tr>
<tr>
<td>Pleospora herbarum (Pers.) Rab.</td>
<td>Pleospora rot</td>
</tr>
<tr>
<td>Botrytis cinerea Pers.</td>
<td>Gray mold rot</td>
</tr>
<tr>
<td>Geotrichum candidum Ferr.</td>
<td>Sour rot</td>
</tr>
<tr>
<td>Collectricium gloeosporioides Penz.</td>
<td>Anthracnose</td>
</tr>
<tr>
<td>Gleosporium limetticulum Clausen</td>
<td>Anthracnose of limes</td>
</tr>
<tr>
<td>Trichoderma viride Pers.</td>
<td>Trichoderma rot</td>
</tr>
<tr>
<td>Septoria citri</td>
<td>Septoria spot</td>
</tr>
</tbody>
</table>

The radiation dose required for sufficient inactivation of organisms to provide adequate protection for fruits during marketing is quite different from the radiation dose required for complete destruction of the organisms. Saravacos et al. (12) reported that the minimum lethal radiation doses for fungi varied between 450 krad (Rhodotorula), 2 000 krad (Penicillium), and 6 000 krad (Alternaria). These would be excessive doses for treatment of fruits without appreciable harmful effects on their texture and flavor.
II. Chemical changes

Although fresh citrus fruits do not ripen after removal from the tree, they do undergo metabolic changes which ultimately lead to senescence. Some of these changes include varied activities in the levels of respiration, organic acids, sugars, pectic substances and color changes. Low storage temperatures have been recommended to extend the shelf-life and lessen the spoilage of citrus fruits. (13, 14, 15). Varner (15) stated that in many respects the loss of cellular vitality in senescence resembles the effects of radiation injury. Neary (16) theorized that there is "some intrinsic process of biological ageing, enhanced by radiation, which operates from the start of life and is virtually complete by the time the changes of old age begin to appear".

1. Respiration

Respiratory rates have been used as an index of the metabolic activities of fruits during ripening and senescence (17), mechanical injury (18), chilling injury (19), and controlled atmospheres (20). Augmented respiratory activities during and after irradiation of citrus fruits have been observed. Irradiation caused increased respiration in both green and ripe freshly harvested Shamouti oranges, with the maximum increase occurring during the first 24 hours following irradiation (21). Kahan (22) irradiated Shamouti-type Jaffa oranges and found an increase in respiration for a few days followed by a decline approaching that of the control. High respiratory activities proportional to the radiation dosage were obtained with Temple oranges as shown in Fig. 4 (23). The maximum rise in CO₂ production occurred 2 days after irradiation, followed by a gradual decline as the storage period was extended to 9 days. However, the irradiated fruits exhibited higher rates of respiration as compared to the non-irradiated fruits at the end of the storage period. Similar trends in the respiratory activities of irradiated Duncan grapefruit and Avon lemons were observed (24, 25). Maxie and coworkers (26) found that doses of 100 krad or less induced a rise in the CO₂ evolution as well as ethylene production from Eureka lemons resembling the autogenous climacteric pattern common to many
fruits but atypical of citrus fruit, Fig. 5. The peak in ethylene production by the irradiated lemons followed that of CO₂ by one or two days. Measurement of the ethylene content in the internal atmosphere of the lemon fruits showed that radiation stimulated ethylene production within 30 minutes after removal from the gamma field. Maxie et al. (27) proposed two mechanisms for the production of ethylene in irradiated lemons: (a) non-enzymatic, which involves the radiolytic conversion of fruit constituents during irradiation and is not dependent on atmospheric oxygen; and (b) enzymatic, which is oxygen-dependent, beginning during irradiation and reaching its maximum several days after irradiation. Eureka lemons and Valencia oranges subjected to 50 to 800 and 400 to 1600 krad, respectively, exhibited an immediate rise in respiration rate which continued to increase with prolonged exposure (28). However, the respiration response was not linear with dose, suggesting a transition zone in the tissue tolerance for irradiation.

Irradiation induced augmented levels of acetate metabolism and mitochondrial activities in plant tissues. Massey (29) found that in carrot tissues: (a) metabolism of glucose and pyruvate was slightly affected by radiation; and (b) the effect of radiation on acetate metabolism was more pronounced and was in line with the overall respiratory response. Irradiation stimulated the catabolism of acetate to CO₂ and reduced the anabolism of acetate into cellular insoluble materials. Lipids and amino acids syntheses were sensitive to radiation damage and contributed to the acetate pool. Romani (30) observed losses of mitochondrial protein and increased mitochondrial activities over several days post irradiation of pear tissues.
Table II. Germination of gamma-irradiated conidia of *Penicillium digitatum* and *P. italicum* in Tochinai's medium after 18-20 hours at 24°C

<table>
<thead>
<tr>
<th><em>P. digitatum</em> dosage (rep)</th>
<th>Spores germinating (% of control)</th>
<th><em>P. italicum</em> dosage (rep)</th>
<th>Spores germinating (% of control)</th>
</tr>
</thead>
<tbody>
<tr>
<td>970 000</td>
<td>0.0</td>
<td>940 000</td>
<td>0.0</td>
</tr>
<tr>
<td>483 000</td>
<td>7.2</td>
<td>467 000</td>
<td>&lt; 1</td>
</tr>
<tr>
<td>300 000</td>
<td>12.4</td>
<td>280 000</td>
<td>4.5</td>
</tr>
<tr>
<td>193 000</td>
<td>16.2</td>
<td>199 000</td>
<td>10.1</td>
</tr>
<tr>
<td>100 000</td>
<td>25.0</td>
<td>156 000</td>
<td>15.8</td>
</tr>
<tr>
<td>50 000</td>
<td>47.3</td>
<td>103 000</td>
<td>25.4</td>
</tr>
<tr>
<td>9 700</td>
<td>53.1</td>
<td>49 600</td>
<td>51.5</td>
</tr>
<tr>
<td>0</td>
<td>100</td>
<td></td>
<td>100</td>
</tr>
</tbody>
</table>

Table III. Effects of irradiation and storage duration at 16°C on mean per cent reflectance at 675 nm in Leslion lemons

<table>
<thead>
<tr>
<th>Dose (krad)</th>
<th>Days After Irradiation</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td></td>
<td>16.6</td>
<td>22.8</td>
<td>25.7</td>
<td>27.2</td>
<td>34.2</td>
<td></td>
</tr>
<tr>
<td>25</td>
<td></td>
<td>17.2</td>
<td>23.2</td>
<td>28.1</td>
<td>30.0</td>
<td>36.9</td>
<td></td>
</tr>
<tr>
<td>50</td>
<td></td>
<td>28.9</td>
<td>28.5</td>
<td>30.3</td>
<td>32.6</td>
<td>36.6</td>
<td></td>
</tr>
<tr>
<td>75</td>
<td></td>
<td>26.9</td>
<td>35.4</td>
<td>35.6</td>
<td>35.1</td>
<td>39.0</td>
<td></td>
</tr>
</tbody>
</table>

The oxidative capacities of cytochrome oxidase, catalase, and acid phosphatase enzymes were only slightly affected. The enhanced mitochondrial activity may be associated with the repair of radiation damage in pear tissues. Similar changes in the mitochondrial activities and acetate metabolism may be contributing to the increased CO₂ evolution from irradiated citrus fruits.

2. Color

The external color of some citrus species is influenced with irradiation. Lemon fruits subjected to gamma irradiation doses of 200 krad or more exhibited browning of the skin within a few days (26). Low levels of irradiation accelerated the rate of chlorophyll disappearance in lemons. Maxie et al. (26, 31) stated that irradiation with doses of 100 krad or less degreened Eureka lemons in about 8 days at 20°C. The effects of irradiation on the degreening of Leslion lemons were observed (32). However, this augmented degreening effect was evident up to 6 days' storage at 18°C, after which the non-irradiated fruits degreened to comparable rates with the irradiated fruits. The percentage reflectance at 675 nanometers (Table III) was used to follow color changes in the fruits (higher reflectance values indicate chlorophyll disappearance).

Degreening of limes was retarded when the fruits were irradiated with 30 krad and stored at 24° - 35°C and 45 - 65% relative humidity (33). High pasteurization levels above 100 krad of irradiation induced a browning of the external color of Persian limes (34). Maxie et al. (35) stated that California Navel oranges subjected to 200 and 300 krad and stored for 2 months at 0°C were decidedly more orange in color. On the other hand, irradiated Florida Navel and Temple oranges, exhibited a bleaching of the orange color with a resultant yellow-orange color after storage for 30 and 35 days at 10°C respectively (26, 32). Effects of irradiation on color...
Table IV. Effects of irradiation on color specifications of Navel and Temple oranges stored at 10°C

<table>
<thead>
<tr>
<th>Trichromatic Coefficients</th>
<th>Navel Storage Duration (Days)</th>
<th>Temple Storage Duration (Days)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>30</td>
<td>35</td>
</tr>
<tr>
<td></td>
<td>Dose (krad)</td>
<td>Dose (krad)</td>
</tr>
<tr>
<td></td>
<td>0</td>
<td>200</td>
</tr>
<tr>
<td>x</td>
<td>0.376</td>
<td>0.372</td>
</tr>
<tr>
<td>y</td>
<td>0.359</td>
<td>0.362</td>
</tr>
<tr>
<td>Purity</td>
<td>0.267</td>
<td>0.263</td>
</tr>
<tr>
<td>Brightness</td>
<td>62.5</td>
<td>66.5</td>
</tr>
<tr>
<td>Dominant wavelength</td>
<td>586</td>
<td>581</td>
</tr>
<tr>
<td>Color</td>
<td>Y-0</td>
<td>Y-0</td>
</tr>
</tbody>
</table>

Y= Yellow, Y0= Yellow-Orange, 0= Orange

specification of Navel and Temple oranges according to the Maxwell color mixture diagram (36) are shown in Table IV.

The flesh color of both Eureka and Lisbon irradiated lemons developed translucent appearance followed by a brownish cast within 1-2 weeks after irradiation (37). This condition was particularly noticeable in fruits subjected to 200 and 300 krad. Similar effects were obtained with Persian limes (34).

3. Ascorbic and Citric Acids

The major chemical component of nutritional importance in citrus fruits is ascorbic acid (vitamin C). This acid is present chiefly in the reduced form. Irradiation effects on the content of ascorbic acids varies with the dose level and type of fruit. Losses in the reduced form of the acid were reported for Avon lemons (25) Lisbon lemons (37) and Eureka lemons (38) at the low and high levels of pasteurizing irradiation. On the other hand, studies with irradiation effects on whole oranges indicated an immediate slight loss in the reduced form of the acid followed by recovery within 24 hours (35, 38). While Romani et al. (38) stated that with a 400-krad exposure, a dose at the upper radio-pasteurization level, the short term loss in reduced ascorbic acid was limited to 15%, Saravacos and Macris (39) found that the loss was about 6%. There were no differences in the reduced ascorbic acid content between Navel oranges irradiated with a dose of 200 krad and non-irradiated fruits at the end of 90 days' storage at 0°C (35). Losses in vitamin C were obtained when orange juice was subjected to irradiation doses of less than 1 x 10⁶ (40) and doses of 1.5 x 10⁴ to 6 x 10⁴ rep (41). However, the destruction of vitamin C could be minimized by irradiating highly concentrated orange juice at low temperature (42). It was also found that the extent of the destruction of this acid was dependent on its initial content in the concentrated juice.

Changes in citric acid levels upon irradiation followed closely that of ascorbic acid. Irradiation induced a significant decline in the percentage of citric acid in lemons (25, 37). However, there were no observed losses in the levels of this acid in oranges (43, 44).
DENNISON and AHMED

4. Pectins

The effects of irradiation on pectic enzyme activities and pectic substance changes in plant tissues have been investigated. Valencia oranges exposed to gamma irradiation, prior to any storage period, show an increase in pectinesterase activity in the juice (45). However, with storage at 20°C there was a reduction in the enzyme activity proportional to the irradiation level and to the duration of the storage period. Similar trends in pectinesterase activities of irradiated Marsh grapefruit were obtained (46). Irradiation-induced changes in pectic substances in the different component parts of the fruits of Valencia oranges and Duncan grapefruit indicated generally an increase in the water- and ammonium oxalate-soluble fractions and a decrease in the sodium hydroxide-soluble fraction (47). These changes are shown in Table V.

Table V. Irradiation effects on the distribution of the pectic fractions (% on dry wt. basis) in the component parts of oranges and grapefruit

<table>
<thead>
<tr>
<th>Component part of fruit</th>
<th>Pectin as anhydrogalacturonic acid soluble in H$_2$O</th>
<th>(NH$_4$)$_2$C$_2$O$_4$ - H$_2$O</th>
<th>NaOH</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Dose (krad)</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>0 150 300</td>
<td>0 150 300</td>
<td>0 150 300</td>
</tr>
<tr>
<td>Peel</td>
<td>2.79 4.04 5.40</td>
<td>7.31 9.09 9.76</td>
<td>9.41 5.77 3.99</td>
</tr>
<tr>
<td>Valencia Oranges</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Membrane</td>
<td>3.57 6.10 7.80</td>
<td>6.04 7.75 8.54</td>
<td>13.24 5.68 4.83</td>
</tr>
<tr>
<td>Juice Sacs</td>
<td>4.74 4.55 5.07</td>
<td>2.87 3.32 3.46</td>
<td>5.14 4.70 4.57</td>
</tr>
<tr>
<td>Seeds</td>
<td>2.56 3.32 3.01</td>
<td>1.75 1.22 1.14</td>
<td>1.83 0.61 1.35</td>
</tr>
<tr>
<td>Juice</td>
<td>.29 .65 .77</td>
<td>.04 .06 .07</td>
<td>.06 .08 .06</td>
</tr>
<tr>
<td>Duncan Grapefruit</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Peel</td>
<td>3.43 4.01 4.50</td>
<td>8.08 10.14 10.31</td>
<td>5.63 5.40 4.43</td>
</tr>
<tr>
<td>Membrane</td>
<td>4.55 5.98 6.96</td>
<td>7.22 7.48 8.18</td>
<td>11.15 5.60 3.34</td>
</tr>
<tr>
<td>Juice Sacs</td>
<td>4.05 4.15 4.46</td>
<td>2.47 2.99 2.91</td>
<td>3.50 3.71 3.25</td>
</tr>
<tr>
<td>Seeds</td>
<td>3.46 3.93 3.50</td>
<td>.94 .52 .59</td>
<td>1.82 1.28 1.04</td>
</tr>
<tr>
<td>Juice</td>
<td>.42 .99 1.22</td>
<td>.04 .06 .08</td>
<td>.04 .04 .04</td>
</tr>
</tbody>
</table>

A sizable increase in total pectic substances due to irradiation was observed in the juice of Valencia oranges and Duncan grapefruit (47). This increase was reflected from the excessive water-soluble pectic fraction in the juice of the irradiated fruits. Apparently irradiation induced depolymerization of pectic substances present in other components of the fruit with a resultant increase in the water-soluble fraction in the juice. Such a change in pectic fractions is illustrated in Fig. 6. Higher juice yields with increased viscosities were obtained from irradiated Pineapple oranges and Duncan grapefruit as compared to the non-irradiated fruits (24). These probable beneficial effects of irradiation are shown in Tables VI and VII.

The differential responses of pectic enzymes and pectic substances may explain some of the textural changes in irradiated plant tissues. Gamma-irradiation of pectic substrates increased the activity of pectinesterase while reducing that of polygalacturonase and pectin transeliminase enzymes (48). Irradiation-induced softening of apple and carrot tissues (49), and pears and peaches (50) were found to correspond to an increase in pectic and pectate fractions and a decrease in the protopectin fraction of the fruit. Al-Jasim and Markakis (51) indicated that calcium dislodgment
FIG. 6. Irradiation effects on the total, water-, ammonium oxalate-, and sodium hydroxide-soluble pectic fractions (mg/100 g) in the juice of Duncan grapefruit and Valencia oranges

Table VI. Effects of irradiation and storage period on juice properties extracted from Pineapple oranges stored at 2°C

<table>
<thead>
<tr>
<th>Storage Days</th>
<th>12</th>
<th>20</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dose (krad)</td>
<td>0</td>
<td>200</td>
</tr>
<tr>
<td>Juice Yield</td>
<td></td>
<td></td>
</tr>
<tr>
<td>% weight</td>
<td>50.1</td>
<td>52.3</td>
</tr>
<tr>
<td>% volume</td>
<td>47.9</td>
<td>49.9</td>
</tr>
<tr>
<td>g/fruit</td>
<td>89.8</td>
<td>99.1</td>
</tr>
<tr>
<td>ml/fruit</td>
<td>85.9</td>
<td>94.6</td>
</tr>
<tr>
<td>Viscosity (cps)</td>
<td>15.0</td>
<td>22.4</td>
</tr>
</tbody>
</table>

Table VII. Effects of irradiation and storage period on juice properties extracted from Duncan grapefruit stored at 18°C

<table>
<thead>
<tr>
<th>Storage Days</th>
<th>10</th>
<th>20</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dose (krad)</td>
<td>0</td>
<td>200</td>
</tr>
<tr>
<td>Juice Yield</td>
<td></td>
<td></td>
</tr>
<tr>
<td>% weight</td>
<td>58.7</td>
<td>61.9</td>
</tr>
<tr>
<td>% volume</td>
<td>56.3</td>
<td>59.5</td>
</tr>
<tr>
<td>g/fruit</td>
<td>274.9</td>
<td>291.7</td>
</tr>
<tr>
<td>ml/fruit</td>
<td>263.5</td>
<td>280.3</td>
</tr>
<tr>
<td>Viscosity (cps)</td>
<td>25.7</td>
<td>53.0</td>
</tr>
</tbody>
</table>

from plant tissues by irradiation dosages of 200-600 krad may contribute to the radiation-induced softening of fruits and vegetables. Kertesz and coworkers (52) stated that pectin is degraded by electron bombardment or gamma irradiation. The calculated threshold value for gamma-irradiation-induced degradation of pectin in solution was about 3 800 R.  However, sugars such as sucrose, glucose, and fructose added to pectin solutions

3R=roentgen measures the radiation passing through a sample of air in terms of the no. of ionizations produced per unit volume. The total energy absorption associated with a dose of 1 R is usually accepted as 83-84 ergs/g of water.
provided a protective action against degradation. The protection was complete when the sugar concentration and the solution acidity were high enough to allow jelly formation. Jellies prepared with sucrose and irradiated with up to $2 \times 10^3 \text{ R}$ showed no weakening. This degradation threshold at $3 \times 800 \text{ R}$ of a pectin solution and complete protection against over $2 \times 10^3 \text{ R}$ in jellies indicate the wide range of radiation sensitivity which pectins in plant tissues might be expected to show.

III. Physical Changes

1. Peel Injury

Pitting around the stem end as a result of irradiation has been observed on Navel, Pineapple, Temple and Valencia oranges (23, 32, 53, 54). Pineapple and Valencia oranges were more susceptible to peel injury than the Navel or Temple oranges. The injury was manifested by the development of dry sunken areas turning to brownish color as the storage period of the irradiated fruits was extended. The depth and the area of the peel exhibiting the injury varied proportionally to the irradiation dosage. However, the irradiation-induced peel injury was modified by the storage temperature following irradiation. At least 97% of the irradiated Pineapple oranges were free of peel injury when they were stored for 3 weeks at $2^\circ\text{C}$ (53). As the storage temperature as well as storage duration were increased, the percent of fruits exhibiting peel injury and its severity were augmented. The effects of irradiation on peel injury of Pineapple oranges are shown in Table VIII.

2. Gas pockets

Maxie et al. (35, 55) found that lemons irradiated with dosages above 200 krad developed severe cavities (gas pockets) when stored 3 or more weeks at $15^\circ\text{C}$, but not at a storage temperature of $20^\circ\text{C}$. Development of the cavities along the segment membranes might have been due to pectin degradation in these areas or to the differential pressures of the internal atmosphere gases present at different locations in lemon fruits (35). Avon and Leslion lemon fruits grown under Florida conditions showed gas pocket development upon irradiation levels of 200 krad or above, and storage at $10^\circ\text{C}$ for four weeks (56).

IV. Organoleptic Evaluations

The effects of irradiation on the organoleptic characteristics of oranges and grapefruit are modified by the storage temperatures and periods under which irradiated fruits are held. In general, these fruits may be irradiated with dosages up to 200 krad without any appreciable deleterious effects on their organoleptic evaluations. Maxie et al. (35) found, with the exception of 300 krad dose, no differences in the taste panel evaluations of the sections and juice from Navel oranges stored up to 10 weeks at $0^\circ\text{C}$. The overall flavor scores, especially those treated at the lower levels of irradiation, generally improved with time after irradiation (35). Florida grown Navel oranges were subjected to 0, 100, 200 and 300 krad and stored at $10^\circ\text{C}$ (54). The irradiated oranges were rated less acceptable than the non-irradiated fruits one day following irradiation. However, after 13 and 28 days' storage at $10^\circ\text{C}$, there were no statistical differences in the quality attributes as judged by the taste panel members. Navel oranges irradiated with 200 and 300 krad were rated less acceptable after 2, 11 and 25 days' storage at $2^\circ\text{C}$. Temple oranges irradiated with dosages above 100 krad and stored at $2^\circ\text{C}$ for 7 and 13 days, were awarded a lower
Table VIII. Effects of irradiation and storage on mean percent peel injury of Pineapple oranges

<table>
<thead>
<tr>
<th>Dose (krad)</th>
<th>Storage Duration (Weeks)</th>
<th>2°C Storage</th>
<th>10°C Storage</th>
<th>20°C Storage</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>N</td>
<td>S</td>
<td>M</td>
<td>S</td>
</tr>
<tr>
<td>0</td>
<td>100</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>100</td>
<td>100</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>200</td>
<td>100</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>300</td>
<td>100</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>0</td>
<td>100</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>100</td>
<td>43</td>
<td>50</td>
<td>7</td>
<td>0</td>
</tr>
<tr>
<td>200</td>
<td>50</td>
<td>40</td>
<td>10</td>
<td>0</td>
</tr>
<tr>
<td>300</td>
<td>27</td>
<td>63</td>
<td>10</td>
<td>0</td>
</tr>
<tr>
<td>0</td>
<td>100</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>100</td>
<td>17</td>
<td>76</td>
<td>7</td>
<td>0</td>
</tr>
<tr>
<td>200</td>
<td>20</td>
<td>40</td>
<td>40</td>
<td>0</td>
</tr>
<tr>
<td>300</td>
<td>0</td>
<td>47</td>
<td>47</td>
<td>7</td>
</tr>
</tbody>
</table>

N= None, S1= Slight, M= Moderate, S= Severe

rating for texture, flavor and general acceptance quality attributes. However, there were no discernible differences among all irradiated Temple oranges which were stored at 10°C for similar storage periods (54). Similar trends were found for irradiated Duncan grapefruit when stored at 18° and 15°C. No differences in quality factors were observed when the fruits were stored at the higher temperature for 11 and 19 days. Storage at 15°C for 12 and 20 days resulted in a less favorable acceptance for the 300 krad level. On the other hand, oranges and grapefruit irradiated with 5 x 10 rep possessed an off-taste in oranges but grapefruit enjoyed a good ranking (57, 58).

Taste panel evaluations of single strength juice prepared from whole Navel oranges exposed to 3 x 10⁴, 6 x 10⁴, and 1 x 10⁵ rep indicated less bitterness in the juice prepared from oranges exposed to the lowest level (41, 59). Irradiation at 6 x 10⁴ rep and higher increased bitterness over the controls. At the sterilizing dose of 10⁶ rep, fresh orange juice forms strong off-flavor. Lyophilized pure orange juice in pellet form irradiated with 3.2 x 10⁵ rep and reconstituted was comparable to the controls with no detectable off-flavor (60). Levels of irradiation higher than 0.5 x 10⁶ rep produced an unacceptable off-flavor in the frozen concentrated orange juice (61), but no significant differences in flavor developed in the concentrated juice held at 4.5°C for 30 days (62).

Lemon juice concentrate was acceptable at 10⁶ rep, but the fresh juice was not as stable to ionizing radiation (59).

Fruit salads, consisting mainly of peeled citrus fruit sections, showed off-flavor after irradiation with 100 krad, whereas 500 krad were required for significant extension of shelf life (58). Application of additives and irradiation in frozen state failed to eliminate off-flavor.

Cold pressed lemon oil showed little or no organoleptic change after irradiation with 10 and 1 000 krad (58).
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DISCUSSION

J. J. MACFARLANE: I was particularly interested in your observations in view of the results obtained during our own investigations on peel injury in irradiated citrus. Our researches are concerned with the use of radiation as a commodity treatment against the Queensland fruit fly. So far we have found that Washington Navel oranges, harvested early in the season, are most sensitive to peel injury; a radiation dose as low as 7.5 krad can cause a definite increase. Have you observed a comparable susceptibility to peel injury in your work?

E. A. DENNISON: We have not employed doses as low as 7.5 krad. From our investigations I would not anticipate any apparent peel injury with our fruits at such low doses.

D. K. SALUNKE: How do you explain the increase in juice yield following the irradiation of citrus fruit?
E.A. DENNISON: Irradiation causes tissue changes including, it is believed, changes in permeability, as a result of which juice is more easily pressed from the fruit tissue.

D.K. SALUNKE: Why did the viscosity of lemon juice increase after irradiation of the fruit?

E.A. DENNISON: Studies of juice viscosity were made with oranges and grapefruit, and irradiation of the fruit was found to cause an increase in the viscosity of the juice pressed from both fruits. Irradiation causes an increase in the water-soluble pectin from the various tissues, and it is believed that there is a movement of water-soluble pectins from the membrane and juice sac tissues into the juice. It is the water-soluble pectin in the juice that causes the increase in viscosity.

F. DE LA CRUZ: Have you used chromatographic techniques, in addition to taste panels, to evaluate possible differences in the aroma of irradiated lemons and oranges?

E.A. DENNISON: We have just started using chromatographic techniques to determine differences in aroma, but we do not yet have any results to report.
IRRADIATION OF TROPICAL FRUITS AND VEGETABLES

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BOMBAY, INDIA

Abstract — Résumé — Аннотация — Resumen

IRRADIATION OF TROPICAL FRUITS AND VEGETABLES. Experiments have been carried out on delayed ripening, through the use of cobalt-60 gamma radiation of mangoes, showing a delay of up to six days by an optimum dose of 25 krad when irradiated in air, carbon dioxide or, preferably, nitrogen atmosphere.

The effect of radiation on the skin of the fruit is more prominent in terms of inhibition in chlorophyll disappearance and carotenoid formation than in ripening changes in the meat of the fruit.

These studies have been extended to mangoes skin-coated with an emulsion made of an acetylated mono-glyceride preparation. Skin-coated fruits show physiological damage due to the excessive inhibition of respiration, which is offset by a spurt in respiratory activity when irradiated in air or nitrogen. An added delay of six days in ripening is achieved by combined skin-coating and irradiation. Other fruits studied include guavas, sapotas (sapodillas) and tomatoes, with all of which a delay in ripening of about five days could be effected with a dose of 20-25 krad. Fruit like chillies, bananas and oranges do not show any delay in ripening on exposure to radiation, there being slight enhanced ripening with oranges.

Semi-dried bananas (40% moisture), irradiated by 0.5 Mrad, keep well for at least three months, compared with the dehydrated (10% moisture) product which, besides being highly susceptible to mould infection, possesses poor attributes of colour, flavour, retention of nutrients and reconstitutability.

Suitable combinations of heat treatment and irradiation have been successfully employed for the sterilization of mangoes, guavas, sapotas and apples where, usually, canned products with better texture, flavour and retention of nutritive qualities, could be obtained with treatment at 70°C for 10 min and 400 krad. Likewise, excellent-quality canned peas are obtainable with the combined use of 800 krad and 100°C for 5 min.

Orange juice could be radiation-sterilized by a combination of 400 krad and subsequent mild heat treatment at 50°C for 15 min.

Sprouting could be inhibited in potatoes (10 krad) and onions (6 krad), resulting in shelf-life extension of 32 and 24 weeks, respectively, over the 8 weeks for the unirradiated controls.

Basic researches relating to radiation preservation of fruits and vegetables include studies on (a) sensitization to radiation of spoilage microorganisms (Micrococcus radiodurans, Streptococcus faecalis) by previous ultrasonic treatment, (b) sensitization to heat of spoilage organisms, such as Saccharomyces cerevisiae and spores of Bacillus cereus and Bacillus subtilis by previous radiation treatment; (c) effect of irradiation on changes in the pectic constituents of fruit, like the apple; and, (d) radiation sensitivity of carotenoids in oranges.

IRRADIATION DE FRUITS ET LÉGUMES TROPICAUX. Des expériences ont été faites en vue de retarder la maturation de la mangue à l'aide des rayons gamma du cobalt-60; elles ont montré qu'il est possible d'obtenir un retard allant jusqu'à six jours en irradiant les fruits dans l'air ou dans une atmosphère de gaz carbonique ou, de préférence, d'azote; la dose optimale est de 25 krad.

Les rayonnements ont plus d'effet sur la peau du fruit quant à l'inhibition de la disparition de la chlorophylle et de la formation de caroténoïdes, que sur la chair du fruit en ce qui concerne sa maturation.

Des expériences ont, en outre, été faites sur des mangues dont la peau avait été enduite d'une émulsion à base d'une préparation de monoglycérides acétylés. Ces fruits ont subi des dommages physiologiques dus à une inhibition excessive de la respiration, qui est éliminée par l'irradiation dans l'air ou dans une atmosphère d'azote qui provoque une recrudescence de l'activité respiratoire. Des expériences avec d'autres fruits (guavas, sapotilles et tomates) ont montré que l'on pouvait retarder la maturation de cinq jours environ par une irradiation à 20-25 krad. Par contre, les piments de Guinée, les bananes et les oranges ne sont pas retardés dans leur maturation par les rayonnements; la maturation de l'orange est même légèrement accélérée.
La banane semi-déshydratée (40% d'eau) irradiée à 0,5 Mrad se conserve bien pendant au moins trois mois, alors que le produit déshydraté (10% d'eau), outre sa grande susceptibilité aux moisissures, ne possède que de médiocres qualités en ce qui concerne la couleur, le goût, la rétention des éléments nutritifs et la reconstitution.

Une combinaison judicieuse du traitement thermique et de l'irradiation a donné de bons résultats pour la stérilisation des mangues, des goyaves, des sapotilles et des pommes: en général, pour les produits en boîtes, un traitement à 70°C pendant dix minutes, avec irradiation à 400 krad, a permis d'obtenir une meilleure consistance, un goût plus agréable et une plus forte rétention des qualités nutritives. De même, on peut obtenir des petits pois en boîte d'excellente qualité en combinant une irradiation à 800 krad avec un traitement thermique de 5 minutes à 100°C.

Le jus d'orange peut être radioradié par irradiation à 400 krad suivie d'un traitement thermique de 15 minutes à 50°C.

La germination peut être inhibée chez la pomme de terre (10 krad) et l'oignon (6 krad); on porte ainsi à 32 et 24 semaines respectivement la durée de conservation, contre huit semaines pour les produits témoins non irradiés.

Les études fondamentales sur la radioconservation des fruits et légumes portent sur les domaines suivants: a) sensibilisation aux rayonnements des micro-organismes corrupteurs (Micrococcus radiodurans, Streptococcus faecalis) par traitement préalable aux ultrasons, b) sensibilisation à la chaleur d'organismes corrupteurs tels que Saccharomyces cerevisiae et les spores de Bacillus cereus et Bacillus subtilis, par irradiation préalable; c) effets de l'irradiation sur les modifications des composants pectiques de fruits comme la pomme; d) radiosensibilité des caroténoïdes de l'orange.
IRRADIACION DE FRUTAS Y VERDURAS TROPICALES. Se han hecho experimentos sobre la maduración retardada del mango, utilizando las radiaciones gama de una fuente de cobalto-60. Se han obtenido retrasos de 6 días como máximo, empleando una dosis óptima de 25 krad en una atmósfera de aire, de anhídrido carbónico o, de preferencia, de nitrógeno.

Los efectos de las radiaciones en la piel del fruto se reflejan más en la inhibición de la desaparición de la clorofila y de la formación de carotenoides que en la variación del grado de madurez de la carne del fruto.

También se ha estudiado la conservación de mangos después de recubrir su piel con una emulsión a base de monoglicérido acetilado. Los frutos con la piel recubierta presentan lesiones de tipo fisiológico, debido probablemente a la inhibición excesiva de la respiración, lo cual es compensado por la gran intensificación de la actividad respiratoria que experimentan los frutos irradiados en atmósfera de aire o de nitrógeno. También se han estudiado otros frutos, como guayabas, zapotes, (zapotillos) y tomates, en todos los cuales se ha conseguido retrasar la maduración en unos cinco días, administrando dosis de 20 a 25 krad. En los frutos tales como chiles, plátanos y naranjas la irradiación no retarda la maduración; en las naranjas, ésta es ligeramente estimulada.

Los plátanos semidesecados (40% de humedad) irradiados con 0,5 Mrad se conservan en buenas condiciones durante tres meses, por lo menos, mientras que los frutos deshidratados (10% de humedad), además de ser muy propensos a la infección por mohos, poseen mediocres propiedades de color, sabor, retención de elementos nutritivos y reconstitución.

Combinando adecuadamente el tratamiento térmico y la irradiación se ha conseguido esterilizar mangos, guayabas, zapotes y manzanas; así se han obtenido en general productos enlatados de mejor textura, sabor y retención de propiedades nutritivas de mejor calidad sometiéndolos durante 10 minutos a 70°C y 400 krad. Análogamente, se obtienen guisantes enlatados de excelente calidad sometiéndolos a 800 krad y a 100°C durante cinco minutos.

El zumo de naranja se puede radioesterilizar por tratamiento combinado: 400 krad y calentamiento consecutivo moderado (50°C durante 15 minutos).

Se ha conseguido inhibir la germinación de patatas (10 krad) y la de cebollas (6 krad), prolongándose el período de conservación hasta 32 y 24 semanas, respectivamente; para los productos testigo sin irradiar dicho período es de ocho semanas.

Las investigaciones fundamentales relativas a la conservación por irradiación de frutas y verduras comprenden estudios sobre: a) sensibilización a las radiaciones de los microorganismos causantes del deterioro (Micrococcus radiodurans, Streptococcus faecalis) por tratamiento previo con ultrasonidos; b) sensibilización al calor de organismos nocivos tales como Saccharomyces cerevisiae y esporas de Bacillus cereus y Bacillus subtilis por irradiación previa; c) efectos de la irradiación en las alteraciones de los componentes pécticos de frutos tales como la manzana; d) radioresistencia de los carotenoides de la naranja.

INTRODUCTION

Fruits and vegetables can be preserved by various methods, such as refrigeration, dehydration, freezing, concentration, canning, etc. Although these processing methods are in widespread use, radiation preservation methods have come in for increasing attention during recent years because of their many advantages. Ionizing radiations are (a) lethal to microorganisms, parasites and insect pests; (b) can be applied without causing appreciable rise in temperature; (c) can be penetrating, so that products can be pre-packed before treatment; and (d) where preferred, can be used for processing in the uncooked state.

With fruits and vegetables, gamma radiation has been successfully used for reducing the microbial load, as in pasteurization, for sterilization by judicious combination treatments, and for controlling physiological changes, as in the delayed ripening of fruits or the sprout inhibition of tubers and bulbs. However, although the main need for the study and application of radiation processing procedures is in tropical regions, where problems of handling, packaging, transportation and storage are frequently inadequate, and where damage to perishable foods can be more severe,
most of the researches hitherto have been in the developed countries which have prevailing temperate climatic conditions.

This paper covers various aspects of the radiation preservation of certain fruits and vegetables, which have been extensively studied in recent laboratory-scale experiments and which, it is expected, will now be extended to large-scale feasibility trials. Related basic programmes of research are also summarized.

RADIATION-INDUCED DELAY IN RIPENING

Difficulty in transportation between centres of production and consumption is a handicap reflecting in loss of farm produce and unequal distribution which, in turn, cause pockets of glut and scarcity. In glut areas, due to lack of facilities for prompt utilization, the grower suffers a double loss due to wastage and price reduction. Transportation of perishables under prevailing tropical heat also contributes to higher losses and, although fruits are transported raw, ripening takes place rapidly and unevenly during transit, with attendant softening and rotting of the tissues. Refrigeration practices are as yet limited because of the high capital and running costs involved. It would, therefore, go a long way in the conservation of supplies if the fruits were kept in the raw state for the maximum length of time, an objective which irradiation could achieve, as has been shown recently in a number of reports on other fruits [1-3].

For the study of delay in ripening, fruits like mangoes [4], sapotas (sapodillas), guavas and tomatoes were used. Alphonso mangoes (Mangifera indica), picked on the previous day and conveyed by truck from growing areas within 250 miles of Bombay, were bought from the market, selection being restricted to mature, unripe fruits, uniformly olive-green in colour. Irradiation was done on the same day in a Gammacell 220 (AECL: 22,500 Ci cobalt-60) at a dose-rate of 25 krad/min. Uniformity in the dose was achieved by rotating the positions of the mangoes with respect to each other. Total radiation doses administered were 12, 25, 50, 75, 100 and 200 krad.

Initial experiments were carried out to ascertain the optimum radiation dose required to delay ripening of the fruit. Mature, olive-green, Alphonso mangoes, were, therefore, irradiated by different doses, viz. 12, 25, 50, 75, 100 and 200 krad, one dozen mangoes being taken for each treatment and for the control, unirradiated, lot. The fruits were stored at room temperature (25-30°C) for a period of 20 d to study the ripening process, the parameters for which were green colour and fruit pressure. It was observed that, at 25 krad, there was a maximum delay in ripening of about 6 d, 12 krad, as well as 50 and 75 krad showing earlier ripening. That doses higher than 25 krad showed earlier ripening may be due to activation or distortion of the respiratory enzyme system. There is also the possibility of ethylene production being stimulated by the higher doses of radiation. Further studies are in progress.

Observations were also made, on the twelfth day of storage, on the skin colour of the fruit, as influenced by the effect of different radiation doses. A maximum greenish tinge in the fruit was observable at a 25-krad dose of irradiation. It was also seen that, with increase in the radiation
dose, there was progressive deterioration of the mangoes, as evidenced by more spotting and earlier spoiling; fruits irradiated by 100 krad and 200 krad showed maximum spotting and complete blackening.

Irradiation under different gaseous atmospheres

There are reports pointing to modification in radiation damage by irradiation under a nitrogen atmosphere [1, 5, 6]. It was therefore of interest to carry out irradiation under gaseous atmospheres, such as nitrogen and carbon dioxide, and to compare with irradiation under air. Reduction, if any, in damage in the former case can best be seen by using radiation doses not tolerated by the mangoes under the usual conditions of irradiation.

Mangoes were kept under an atmosphere of nitrogen or carbon dioxide in a desiccator for 3 h to equilibrate with the respective gas; they were then quickly transferred to 250-gauge polythene bags and heat-sealed with the appropriate gas being simultaneously blown in and exhausted from the bags. The bags were carefully examined for leaks and only the properly sealed ones were used for irradiation studies. The bags were cut open after irradiation and the fruits studied for storage behaviour in ordinary atmosphere.

As observed earlier, a dose of 200 krad causes blackening and spoilage in mangoes. Green mangoes (12 in each lot) were therefore exposed to a 200 krad dose under air or nitrogen atmosphere. It was observed that in the latter case there was considerable improvement in fruit colour and quality, following irradiation, when compared to the former. Thus, examination of several fruits taken after 10 d irradiation, showed that the control unirradiated fruit was ripe and yellow in colour, while that irradiated under air had turned completely black; the nitrogen-irradiated lot was still green in colour and apparently unaffected by the high radiation dose. On cutting, the inside of the fruit irradiated under air showed blackening, white fibrous texture and large gas fissures, whereas the unirradiated control, and the fruit irradiated under nitrogen, had an orange colour with the taste of ripe fruit and a normal appearance with the taste of unripe mango, respectively.

It seemed likely that, even with the optimum radiation dose of 25 krad, a nitrogen atmosphere may exert a beneficial effect. Therefore, in the next series of experiments, 15 fruits per lot were irradiated by 25 krad under air, nitrogen or carbon dioxide. Ripening was observed to be delayed by irradiation and the number of fruits ripening with time was nearly the same with the various atmospheres for irradiation. However, there was a marked difference in the rate at which the fruits spoiled, irradiation under nitrogen atmosphere giving minimum spoilage during storage at room temperature. Thus, as compared to a spoilage of 100% on the 15th day for the control samples, for the air-, carbon dioxide- and nitrogen-irradiated samples, the spoilage was 67%, 64% and 42% respectively, 22 d after storage at room temperature.

Total acceptability rating for nitrogen-irradiated mangoes was more than for other treatments (Fig. 1). An analysis of the scores for the various attributes of colour, flavour, texture and taste, also showed that nitrogen-irradiated mangoes rated highest for colour and taste and had a high rating for flavour. Irradiation under carbon dioxide, although some-
what effective in minimizing spoilage, resulted in low acceptability rating on storage.

Changes, during storage, in total carotenoids and ascorbic acid in the variously treated fruits were also followed. Ascorbic acid values in nitrogen-irradiated mangoes were higher than in other treatments, and compared with those for controls. Since carotenoid development is associated with ripening, the delay in ripening due to irradiation was reflected in the lower values for total carotenoids. However, it is interesting to note their increased formation in fruits irradiated with nitrogen, especially during the later period of storage.

Examination of changes in acidity, total and reducing sugars and starch, during ripening of control and irradiated mangoes showed delayed reduction in acidity in irradiated fruits as may be expected. Similar delay was also observed in total sugar formation and starch disappearance. The differences due to treatments were, however, small, especially after 5 to 8 d storage.

Observations on fruit pressure and skin colour during ripening also tied up with the definite delay in ripening due to irradiation.

Changes in skin colour, however, were not apparently consistent, and did not always seem to correlate well with the stage of ripening, since fruits with ripe flesh exhibited green skin and firm texture. In other words, chemical indices for ripening pointed to a delay of 2 to 3 d only, due to irradiation, although, judging from skin colour and fruit firmness, this delay was for 6 d. The effect of radiation on fruit skin seems to manifest itself prominently in terms of inhibition of chlorophyll disappearance and of the enzyme system responsible for the breakdown of the pectins in the middle lamella of the skin.

The production of ozone during irradiation is now well recognized. It may be expected that such a reaction inside the fruit tissues, by irradiation of the oxygen present there, will have a harmful effect on the tissue cells [1]. Replacement of intracellular oxygen by an inert gas, like nitrogen, could thus be helpful in reducing radiation damage.
Radiation effects on skin-coated Alphonso mangoes

Extension in the storage life of fruits has been achieved by skin-coating with different protective materials [8, 9]. Similar to the effect of radiation together with gas- or cold-storage, radiation treatment, combined with skin-coating, may be expected to give added extension to the shelf-life of fruits. Skin-coating does not entail big layouts, as in cold- or gas-storage installations, and hence studies were undertaken on the combined effects of radiation and skin-coating on the extension of storage life, organoleptic qualities and control of respiration, in Alphonso mangoes.

The skin-coating for these studies was prepared, using a commercial preparation of distilled acetylated monoglyceride, "Mavacet", type 7,001, oleic acid, triethanolamine and liquor ammonia. The constituents, in suitable proportions, were emulsified with 450 ml water at 70°C in a Waring blender to give an approximately 6% emulsion. The fruits were dipped in this emulsion and dried under a fan.

Respiration was studied at constant temperature by determining the carbon dioxide absorbed by standard baryta solution in Pettenkauffer tubes. The same fruit was used each day for this purpose in any one experiment. The non-coated, unirradiated, control mangoes reached a climacteric after nine days (Fig. 2), the rate rising steeply with ripening from the seventh day. In contrast to this, the skin-coated fruits did not show any rise in respiration above 5 mg CO₂/kg h for the first three days and reached the initial respiration rate of 15 mg CO₂ of the non-coated fruit on the fifth day. Thereafter, there was a steady increase up to 35 mg CO₂ on the ninth day. Thus, skin-coating results in a definite decrease in respiration as compared to controls, throughout [7].

The respiration rates of mangoes irradiated (25 krad) under air or nitrogen are shown in Figs. 3 and 4, respectively. There was a sharp rise in respiration rate immediately after irradiation, reaching a maximum (70 mg CO₂) after 24 h of radiation treatment, after which respiration was reduced on the second and third day. The skin-coated mangoes also showed a rise in respiration after irradiation, but to a much smaller extent, the climacteric being on the same day as for the uncoated fruits.

The pattern of respiration with mangoes irradiated (25 krad) under carbon dioxide was different, in that not much rise in respiration was seen immediately after irradiation (Fig. 5), the non-coated showing a rise of up to 30 mg CO₂ as compared to 15 mg for the skin-coated fruits.

Organoleptic ratings, after 20 d storage at room temperature, of skin-coated mangoes irradiated (25 krad) under different gaseous atmospheres are shown in Fig. 6. The unirradiated control and those irradiated under air, nitrogen and carbon dioxide have a total rating of 2.9, 7.5, 7.5 and 5.8, respectively. The controls had developed off-flavour and taste right from the beginning of the experiment, whereas those irradiated under CO₂ had pronounced off-flavour and taste at the beginning of the experiment which decreased during the storage period, with corresponding increase in acceptability. The skin-coated mangoes irradiated under air or nitrogen, did not develop any off-flavour and were very acceptable. It seems, therefore, that physiological degradation in

1 Distillation Products Industries, Rochester, N. Y., United States of America.
FIG. 2. Respiration of unirradiated mangoes with and without skin coating.

The respiration of single marked mangoes, skin-coated or uncoated was measured daily. Skin coating is seen to suppress respiration.

FIG. 3. Respiration of mangoes with or without skin coating, irradiated in air.

Enhanced respiration obtained under the stress of irradiation becomes subdued from the second day. This corresponds to ripening changes in the fruit as studied by changes in acidity, sugars and starch. Skin-coated mangoes also show enhanced respiratory activity after irradiation, though to a lesser extent.

FIG. 4. Respiration of mangoes with and without skin coating, irradiated in nitrogen.

Enhanced respiration is observed immediately after irradiation in mangoes with and without skin coating. Suppression of respiration in unirradiated skin-coated mangoes, is offset by radiation treatment conferring improved organoleptic qualities.
FIG. 5. Respiration of mangoes with and without skin coating, irradiated under carbon dioxide atmosphere. There is suppression of respiration due to carbon dioxide atmosphere. The initial spurt in respiratory activity due to irradiation is minimum, compared to Figs. 3 and 4. Skin-coated mangoes, irradiated in carbon dioxide atmospheres also show suppressed respiratory activities, resulting in impaired organoleptic qualities.

FIG. 6. Organoleptic tests for skin-coated mangoes stored for 20 d at ambient temperatures (25–30°C) after irradiating (25 krad) under different gaseous atmospheres. The maximum rating of 9 (like extremely) is further divided for the parameters of colour, flavour, texture and taste, each carrying a maximum of 2.25. Results show unirradiated, skin-coated controls to be unacceptable as compared to those irradiated in air or nitrogen, which are highly acceptable. Irradiation under carbon dioxide reduces organoleptic quality to some extent.

skin-coated control mangoes can be offset by irradiation under either air or nitrogen.

Organoleptic changes closely followed the trend in respiratory pattern. Mangoes, which had average respiration less than optimal for the first five days, showed degradation in taste and flavour. There is a possibility, therefore, that organoleptic changes are profoundly influenced by the inhibition of respiration at the beginning of the storage period; this latter is offset by irradiation, with corresponding improvement in taste and flavour.

Observations on the effect of irradiation under different gaseous atmospheres on skin colour, taste, flavour and fruit pressure, showed that the coated, unirradiated fruits did not ripen, even on the 15th day of storage. Mangoes irradiated under nitrogen and air ripened well on the 15th day, with good taste and flavour even on the 20th day.

A study of the changes in acidity, sugars and starch during storage of the variously treated fruits also showed poor ripening characteristics in
the control fruits, even on the 20th day, indices for ripening like decrease in acidity and starch and increase in sugars being observable in the case of mangoes irradiated under air or nitrogen from the 15th day onwards. Thus, a combination of skin-coating and irradiation show additive increase in storage life of about six days over and above that obtained by irradiation alone. It would seem that physiological damage due to the suppression of respiratory enzymes caused by skin-coating can be overcome by the spurt in respiratory activity resulting from radiation. It is of interest to note that skin-coating helps to keep the respiratory activity of irradiated mangoes to the optimal minimum, reducing physiological losses and increasing shelf-life.

Preliminary studies carried out on other fruits, like sapotas (sapodillas), guavas and tomatoes, showed that a delay in ripening of about 5 to 6 d could be achieved by an optimum irradiation dose of 20-25 krad, as judged by skin colour, flavour and fruit pressure. Firmer fruits being more amenable to transportation, the radiation treatment of these fruits would conserve fruit supply by way of less damage and fungal attack.

Encouraging results were not obtained, however, with green chillies, bananas, and oranges which did not show any delay in ripening on exposure to doses ranging from 5 to 200 krad, and subsequent storage at room temperature. Local varieties of bananas, red or green skin, blackened appreciably at higher radiation doses, while oranges showed quicker degreening when irradiated in the range 25 to 100 krad [10].

DEHYDRO-IRRADIATION OF BANANAS

While bananas in themselves did not give satisfactory results with irradiation, semi-dried bananas (40% moisture) were found to keep well for at least three months at room temperature (28 - 30°C) as compared to the dehydrated fruits which, besides being highly susceptible to mould infection within 1 to 2 weeks, possessed poor attributes of colour, flavour, retention of nutrients and reconstitutability. For these experiments, four locally available varieties (Vasai varieties, green, red, and yellow skinned, and Rajeli) of bananas were dehydrated to 35 to 40% moisture, packed in polythene bags and irradiated by doses in the range of 100 to 1000 krad. Rajeli bananas, which have a yellow skin and firm texture, were found to be best for dehydro-irradiation, after a preliminary treatment of fumigation with sulphur-dioxide to retain their original colour.

RADIATION CANNING OF FRUITS AND VEGETABLES

A suitable combination of heat treatment and irradiation has been successfully employed for the sterilization of mangoes, sapotas [11], guavas and apples, where, usually, canned products with better texture, flavour and retention of nutritive qualities could be obtained with treatment at 70°C for 10 min and a 400-krad radiation dose.

Sterilization by irradiation alone would require a high dose of radiation and would not, even then, satisfy the requirement for enzymatic inactivation. Hence, a radiation-sterilized product, apart from causing
Mangoes, control and heat-treated for different periods at 50°, 60° and 70°C, were cut into small pieces and respiration of 1-g samples studied in a Warburg apparatus. Data show inactivation of respiratory enzymes after heat treatment at 70°C for 10 min.

Undesirable organoleptic changes would, during storage, deteriorate further, due to the action of various enzymes. A food product with satisfactory quality can therefore best be stabilized, both microbiologically and enzymatically, only by a combination process of heat and radiation.

Respiratory enzymes of Alphonso mangoes were inactivated to different degrees at 50, 60 and 70°C (Fig. 7). Thus, mangoes heated at 50°C for 1 and 2 h did not show any decrease in respiration; on the contrary, there was a slight increase, suggesting that this may be the optimum temperature for the enzymes to act. Treatment at 60°C for 1 and 2 h caused a steady decrease in the respiratory rates, while at 70°C for 10 min, respiration was nil.

The mango or sapota slices were packed in sanitary cans, topped with 40% sugar syrup, heated at 70°C for 10 min and evacuated at 28 in. for about 6 min to exhaust most of the air from inside the fruit tissues. The vacuum slices were next sealed in cans, using a vacuum double steamer at 20 in. vacuum.

To ascertain the radiation dose required to obtain a sterile product, a batch of cans inoculated with 10 000 Saccharomyces cerevisiae yeast cells and approximately 500 Bacillus subtilis spores were also heated at 70°C for 10 min and irradiated with different doses of radiation. It was observed that such cans irradiated by 400 krad were sterile, even after six weeks of incubation at 30° or 37°C. The combination process with low heat treatment, followed by sterilization at a low radiation dose is therefore effective, even with initially high microbial load of the product. The combination method affords some improvement in texture with both fruit products, and in colour with sapotas.

Since the susceptibility to irradiation of desirable attributes may vary with the nature of the fruits and vegetables, it may be expected that procedures for the combination of radiation and thermal processing have to be standardized in each case. In other studies with guavas, apples and peas it has been observed that the combination procedure results in distinctly superior products compared to the heat-sterilized ones. This was
especiall\(^y\) the case with peas, where a comparison of thermally (115°C, 40 min) and radio-sterilized (800 krad followed by 100°C, 5 min) peas showed that the latter had a better retention of chlorophyll and were more acceptable organoleptically.

**Radiation-sterilized orange juice**

Effective sterilization of orange juice has been achieved by subjecting it to a radiation dose of 800 krad, or to a radiation dose of 400 krad, followed by incubation at 50°C for 15 min [12]. The drastic reduction in the required dose is brought about by the sensitization of the spoilage microorganisms to heat by the previous radiation treatment. Sterilization by the combination method helps in the retention of ascorbic acid, thiamine and riboflavin to a greater extent than with radiation alone, since thereby a lower dose is required to sterilize the product.

Changes in colour brought about by irradiation under nitrogen and air have also been studied, showing darkening of orange juice as measured tintometrically, after two weeks' storage, on irradiation by various doses under different gaseous atmospheres. Darkening induced by irradiation in air is inhibited by radiation treatment under nitrogen.

**IRRADIATION OF POTATOES AND ONIONS**

At doses of 10 krad for potatoes and 6 krad for onions, sprouting could be inhibited, resulting in shelf life extension to 32 weeks and 24 weeks, respectively, over the 8 weeks found for the unirradiated products when stored at room temperature. The dose required to inhibit sprouting was found to depend upon the variety and length of storage time before irradiation, but in all cases the doses mentioned above were enough to meet the requirements for sprout inhibition.

**BASIC RESEARCHES**

Among basic researches in progress relating to the preservation of fruits and vegetables, the following may be mentioned:

(a) **Sensitization to radiation of spoilage microorganisms by previous ultrasonic treatment**

*Micrococcus radiodurans* (radiation-resistant) and *Streptococcus faecalis* (relatively radiation-sensitive), were chosen as representative food-borne organisms. Cells from 24-h cultures were washed, suspended in buffer, sealed in ampoules and irradiated by various doses with and without previous ultrasonic treatment at 300 kc. The sensitizing action of the ultrasonic treatment on both the organisms is shown by the change in the slope of the survival curve (Fig. 8). Reduction in the D-values (90% mortality) in the case of *M. radiodurans* was from 580 krad to 290 krad, whereas, with *S. faecalis*, the reduction was from 37 krad to 22 krad [13]. This marked effect of ultrasonic treatment in enhancing the radiation sensitivity of microorganisms points to its possible practical
FIG. 8. Sensitization of *Micrococcus radiodurans* and *Streptococcus faecalis* to radiation by previous ultrasonic treatment

5 x 10^7 cells/ml suspended in phosphate buffer were treated in a G.E. ultrasonic generator at 300 kilocycle frequency for 20 min and subsequently irradiated by various doses of radiation. Sensitization is observable in both cases from the change in the slope of the survival curves.

value in radiation sterilization of liquid foods, such as fruit juices, milk, etc.

(b) Sensitization to heat of spoilage organisms by previous radiation treatment

Post-irradiation heat treatment of spoilage organisms sensitizes them to even sub-lethal temperatures. This can be seen from Fig. 9, where the survival of *S. cerevesiae* cells, suspended in mango juice (mango pulp dispersed in twice its volume of water) with or without heat treatment at 50°C for 15 min after irradiating with different doses of radiation, are shown [11]. There is an appreciable drop in the D-values when the radiation effect alone is compared with the combination of irradiation and heat. It seems that the organism becomes very sensitive to this low temperature after irradiation, which property can be well utilized to sterilize mango juice at a low radiation dose.

Similar work was carried out, with respect to their radiation sensitivity, with and without post-irradiation heat treatment, on spores of *Bacillus subtilis* and *Bacillus cereus* suspended in pea extract. Various doses of radiation were combined with subsequent heating at 80, 90 or 100°C for 5 min. Preliminary results indicated sensitization to post-irradiation heat treatment in both cases. The original D value of 400 krad
FIG. 9. Radiation sensitivity of *Saccharomyces cerevesiae* suspended in mango juice

Mango juice with $10^8$ yeast cells/ml after irradiation without and with heat shock at 50°C for 15 min was placed on yeast agar medium by pour-plate method. Colonies were counted after incubation for 48 h at 30°C. From the slope of the curve B, it is seen that radiation sensitizes the organism to the sublethal temperature of 50°C.

for the irradiated treatment alone was reduced to 300, 200 and 125 krad for 80, 90 and 100°C heat treatment for 5 min, subsequent to irradiation, in the case of the spores of *B. subtilis*.

(c) Radiation effects on the pectic substances of apples

Pectin was extracted from ripe ready-to-eat apples when bought, and after storage for 15 d at room temperature. Fruits, irradiated with different doses of radiation (20-100 krad), were also used at the beginning, and after 15 d storage, for pectin extraction. The prepared pectin samples were analysed for methoxyl content, equivalent weight, acetyl value, uronic acid and pH. The methoxyl content, equivalent weight and acetyl value progressively diminished with the radiation dose, the pH remaining the same. There seemed to be some degradation in polygalacturonic acid.

To study the protective effect, if any, of the fruit constituents, pectin solution (0.1%) was irradiated alone and in combination with sucrose (15%) or glucose and fructose (7.5% each) by different doses (8, 12 and 24 krad). Degradation was assessed by decrease in relative viscosity. An observed 20% degradation with the pectin solution at the highest dose was reduced to 7% by sucrose and to 3% by the invert sugar.

In preliminary studies on the effects of aspartic and glutamic acids in 24 mg% and 7 mg% concentrations, changes due to irradiation in a relative viscosity of 0.1% pectin solution were minimized to some extent. Further work is in progress.

(d) Radiation sensitivity of carotenoids from fruits and vegetables

The conjugated double-bond system and beta-ionone rings in the carotenoid structure provide sites for free radical chain reactions induced by radiation. A knowledge of radiation chemistry of carotenoids is,
therefore, important in interpreting the changes due to pasteurization or sterilizing doses of radiation.

Studies on carotenes from orange juice and mango pulp have indicated that the radiation lability of carotenes differs from fruit to fruit and is markedly influenced by pH and chemical composition of the fruit. Different pigments were isolated from non-irradiated (control) as well as irradiated (1 Mrad) samples on deactivated alumina columns. Various fractions were compared with respect to their elution patterns and spectral characteristics. Except for beta-carotene, other fractions are yet in the process of being identified.

Of the six fractions obtained from the control samples of orange juice, two fractions were absent in irradiated ones showing their complete destruction by radiation. However, different fractions undetectable in control samples were present in irradiated ones. The origin of these fractions formed during radiation is not clear.

The properties of four different fractions of carotenes from irradiated samples of mango pulp were similar to those of control; radiation caused 31% (beta-carotene), 56%, 22% and 31% destruction, respectively, in these four fractions.

ACKNOWLEDGEMENT

The authors' thanks are due to their colleagues in the Division of Biochemistry and Food Technology, who have shared in the experimental work reported here.

REFERENCES

A.S. KOVACS: Have you investigated differences in the effects of radiation with different varieties of mango?

A. SREENIVASAN: We are aware of the need to extend our studies on Alphonso mangoes to other commercially important mango varieties. After the experience gained over three seasons with this variety, we have begun studies on Dasseri mangoes, which have the peculiar characteristic of retaining their green skin colour, even in the fully ripe stage. Since delayed ripening in the Alphonso mango, through judicious use of gamma radiation, is associated with the retention of chlorophyll in the skin, we felt that the study of the Dasseri mango would be particularly interesting. We also intend to study other economically important mango varieties.

V.I. ROGACHEV (Chairman): You have touched on the effect of radiation on the respiration of fruit and vegetables. Further clarification of this problem is vital to the use of radiation to extend the storage life of these commodities. Investigations carried out in the Soviet Union have shown how important this work is, particularly in connection with the observed changes in immunity under the influence of irradiation. It should be stressed that not only quantitative changes occur in respiration intensity, but also (and sometimes even to a greater extent) qualitative shifts in the mechanism of the oxidation-reduction processes. It would also be interesting to carry out such investigations on tropical fruit.

A. SREENIVASAN: We have standardized a technique for isolating mango mitochondria in the intact, fully respiring state with a maximum oxidative phosphorylation rate, and are now looking into the changes in the respiratory enzymes due to irradiation.
SUMMARY

V. I. ROGACHEV
(Chairman)

From the very interesting papers presented at this session we can draw a number of general conclusions.

It is clear that the irradiation of fresh fruit and vegetables is not as simple a matter as it appeared initially. There has been a considerable expansion in physiological and biochemical research into changes in the ripening of stored irradiated fruit.

Methods of extending the storage life of fruit and vegetables are also being studied intensively. This problem is being considered not only from the technological point of view, but also from that of the interaction between plant organisms and microbial microflora. In this connection there is a growing interest in clarifying the immunological questions at issue, including the study of microflora toxigenicity, of the active response of the plant organism to the intrusion and development of the pathogen, and of the passive immunity associated with the structural and anatomical properties of fruit and vegetables.

It is to be hoped that, by intensifying and co-ordinating our efforts to understand the processes that occur in the living cell under the effects of irradiation and microflora, we shall soon achieve the practical realization of the possibilities offered by ionizing radiation in this sphere.
PROGRAMMES AND FACILITIES FOR FOOD IRRADIATION

(Session VII)
UNITED STATES ATOMIC ENERGY COMMISSION
RADIATION PROCESSING OF FOODS PROGRAMME

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Abstract — Résumé — Аннотация — Resumen

UNITED STATES ATOMIC ENERGY COMMISSION RADIATION PROCESSING OF FOODS PROGRAMME. The current progress of the United States Atomic Energy Commission's Radiation Processing of Food Programme, with emphasis on the clearance of such foods for general human consumption, product development, facility design, process conditions and economics, and commercial aspects are discussed.

Semi-production processing for a number of products has now become feasible. The goal is to test laboratory data under near-commercial-scale process conditions, and to obtain cost data. Either completed, or nearing completion, are semi-production facilities capable of processing various foods in quantities of thousands of pounds per hour. Among them are the Marine Products Development Irradiator, the Mobile Gamma Irradiator and the Grain Products Irradiator, for bulk and packaged grain. Plans for a Hawaiian Development Irradiator are also discussed.

Activities in the United States, which are related to the commercialization of radiation processing of foods, including the use of radiation for processing fresh fish and fruits, sterilized meats and other food products, are discussed. For example, a project is under way in which several agencies of the United States Government are attempting to establish a co-operative programme with industry, aimed at the development of a pilot-plant meat irradiator. These efforts are directed towards the establishment of a large facility operated by industry which would: (a) provide necessary radiation-sterilized meats for the armed services; (b) establish process conditions and economics; and (c) introduce some of the product into the civilian economy, for commercial purposes.
PROГРАММА КОМИССИИ ПО АТОМНОЙ ЭНЕРГИИ США ПО РАДИАЦИОННОЙ ОБРАБОТКЕ ПИЩЕВЫХ ПРОДУКТОВ. В этой работе описываются последние результаты осуществления программы Комиссии по атомной энергии США в области радиационной обработки пищевых продуктов, особенно в области проверки пригодности таких продуктов для общего потребления населением, создания новых пищевых продуктов, конструкций установок, технологических процессов и экономики, а также коммерческого производства.

В настоящее время стала возможной полупромышленная обработка пищевых продуктов, особенно в области проверки пригодности таких продуктов для общего потребления населением, создания новых пищевых продуктов, конструкций установок, технологических процессов и экономики, а также коммерческого производства.

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PROGRAMA DE IRRADIACION DE ALIMENTOS DE LA COMISION DE ENERGIA ATOMICA DE LOS ESTADOS UNIDOS. En la memoria se exponen los progresos realizados en la ejecución del programa de irradiación de alimentos que lleva a cabo la Comisión de Energía Atómica de los Estados Unidos, prestando particular atención a cuestiones tales como las autorizaciones para el consumo general de los alimentos irradiados, la preparación de los productos, el diseño de las instalaciones, las condiciones de tratamiento, así como los aspectos económicos y comerciales.

Es posible ya el tratamiento en escala semiindustrial de toda una serie de productos. El fin que se persigue es estudiar los resultados de las pruebas de laboratorio en condiciones casi comerciales y obtener datos sobre costos. Se han realizado ya, o están a punto de realizarse, instalaciones de producción en escala semiindustrial capaces de tratar diversos alimentos a razón de varios millares de libras por hora. Entre ellas cabe citar un dispositivo de irradiación gamma y un dispositivo de irradiación de granos envasados y a granel. En la memoria se describen asimismo los planos para la construcción de un dispositivo de irradiación de productos alimenticios en Hawái.

Se reseñan las actividades desarrolladas en los Estados Unidos para comercializar la irradiación de alimentos tales como frutas y pescados frescos, Carnes cemeterizadas y otros productos. Con la participación de varios organismos oficiales de los Estados Unidos se está ejecutando un proyecto encaminado a establecer un programa de cooperación con la industria para construir una planta experimental de irradiación de carne. La finalidad de estos trabajos es la construcción de una gran instalación explotada por la industria que producirá carne radioesterilizada para las fuerzas armadas, definirá las condiciones y los aspectos económicos del tratamiento y destinará parte de su producción al mercado civil con fines a su comercialización.

INTRODUCTION

The United States Radiation Processing of Foods programme has two distinct, but parallel, efforts. The first, under the direction of the United States Department of Army, is concentrating on the radiation sterilization of meats, such as ham, pork, chicken and beef. With this process, packaged meat can be held for indefinite periods of time, in good quality, at ambient temperatures. The other phase of the national programme is carried out by the United States Atomic Energy Commission (USAEC). The objective under this programme is to develop radiation-
Pasteurization techniques, whereby the fresh shelf life of foods, such as fruit and marine products, can be extended significantly, with resultant reductions in spoilage, and extension of marketing times.

In this paper the authors review the general status of the Atomic Energy Commission's programme and discuss product development, radiation facilities, and current efforts directed to commercialization of the process. A paper on Wholesomeness and Public Health Research in the United States Atomic Energy Commission Food Irradiation programme, by Whitehair, is published in these Proceedings [1].

The USAEC programme is concentrating on a limited number of marine products, fresh fruits and vegetables which maintain good quality with radiation processing. It is to be observed that some of the food products selected for study at the start of the USAEC programme have not shown good response to radiation preservation; further study has therefore been terminated. These food products included pears and grapes, where the adverse effects included incomplete maturation and textural damage. Studies on peaches were not continued as a result of radiation-induced structural changes. Subsequent studies indicated that the dose could be sharply reduced by a combination process, using heat. Studies involving peaches are now being intensified. This fresh approach has applications to other types of fruit. With these changes, recent research results indicated the desirability of adding selected new food products for study. For example, a relatively low dose of radiation, approximately 35,000 rad, applied to the Gros Michel bananas in the green state is quite effective in inhibiting ripening. Further studies are required on this variety of banana, as well as on newer varieties, and this work is under way. Economic analyses of potentially competing processes, including atmosphere control, must also be made to comprehend the practical value of this process more fully.

The poultry industry in the United States needs an extension of the shelf life of fresh chicken to enhance marketing conditions and a method to control Salmonellae effectively in frozen processed chicken. Because of the importance of chicken as a food commodity in the United States, this product has been added to the programme during the past year.

This movement in the study of specific food products is to be expected and is a natural consequence of a research and development programme as complex as the radiation preservation of foods. In the management of the USAEC programme, an attempt is therefore made to maintain enough flexibility to permit the inclusion of new products which show an opportunity for early commercialization. This must be balanced against the basic objective of the USAEC programme, which is to demonstrate a technology for radiation processing of foods against a limited number of specific food items. With the successful achievement of this mission, it can be expected that the development of radiation processing for additional new foods will be carried out by the food industry in the United States.

In the remainder of this paper and in Tables I and II, the authors summarize the current status of work on food products being studied in the USAEC's programme.

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1 Work on specific products is discussed in the papers by Slavin et al. [2], Sommer and Maxie [3] and Dennison and Ahmed [4] in these Proceedings.
<table>
<thead>
<tr>
<th>Product</th>
<th>Desired end point</th>
<th>State of Technology</th>
<th>Technological outlook¹</th>
<th>State of wholesomeness</th>
<th>Completion of wholesomeness (fiscal year)</th>
<th>Petition submission date² (clearance expected 12 to 18 months later)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Strawberries</td>
<td>RS, SLE</td>
<td>Advanced</td>
<td>Excellent</td>
<td>Near completion</td>
<td>1966</td>
<td>1966</td>
</tr>
<tr>
<td>Sweet cherries</td>
<td>RS</td>
<td>Relatively new</td>
<td>Fair</td>
<td>Do</td>
<td>1966</td>
<td>1967</td>
</tr>
<tr>
<td>Pears</td>
<td>RS, DM</td>
<td>Advanced</td>
<td>Poor</td>
<td>Do</td>
<td>1966</td>
<td>(?)</td>
</tr>
<tr>
<td>Plums</td>
<td>RS</td>
<td>New</td>
<td>Fair</td>
<td>Do</td>
<td>1966</td>
<td>(?)</td>
</tr>
<tr>
<td>Prunes</td>
<td>RS</td>
<td>Do</td>
<td>Good</td>
<td>Do</td>
<td>1966</td>
<td>1967</td>
</tr>
<tr>
<td>Peaches</td>
<td>RS</td>
<td>Advanced</td>
<td>Uncertain²</td>
<td>Completed</td>
<td>---</td>
<td>(?)</td>
</tr>
<tr>
<td>Apricots</td>
<td>RS</td>
<td>New</td>
<td>Poor</td>
<td>Near completion</td>
<td>1966</td>
<td>1967</td>
</tr>
<tr>
<td>Nectarines</td>
<td>RS</td>
<td>Advanced</td>
<td>Good</td>
<td>Completed</td>
<td>---</td>
<td>1967</td>
</tr>
<tr>
<td>Apples</td>
<td>DIS</td>
<td>New</td>
<td>Fair</td>
<td>Near completion</td>
<td>1966</td>
<td>(?)</td>
</tr>
<tr>
<td>Oranges</td>
<td>RS</td>
<td>Advanced</td>
<td>Good</td>
<td>Completed</td>
<td>---</td>
<td>(?)</td>
</tr>
<tr>
<td>Lemons</td>
<td>RS</td>
<td>Dropped</td>
<td>Poor</td>
<td>Do</td>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td>Grapes</td>
<td>RS</td>
<td>Do</td>
<td>Do</td>
<td>Do</td>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td>Tomatoes (ripe)</td>
<td>RS, DM</td>
<td>New</td>
<td>Fair</td>
<td>Not initiated</td>
<td>(?)</td>
<td>(?)</td>
</tr>
<tr>
<td>Bananas²</td>
<td>DM</td>
<td>Do</td>
<td>Excellent</td>
<td>Do</td>
<td>1967</td>
<td>1969</td>
</tr>
<tr>
<td>Papayas</td>
<td>DIS, SLE</td>
<td>Relatively new</td>
<td>Do</td>
<td>Do</td>
<td>1967</td>
<td>1969</td>
</tr>
<tr>
<td>Mangoes</td>
<td>DIS</td>
<td>Do</td>
<td>Do</td>
<td>Do</td>
<td>1967</td>
<td>1969</td>
</tr>
<tr>
<td>Pineapples</td>
<td>DIS</td>
<td>New</td>
<td>Good</td>
<td>Partly completed</td>
<td>(?)</td>
<td>(?)</td>
</tr>
<tr>
<td>Figs</td>
<td>DIS</td>
<td>Do</td>
<td>Do</td>
<td>Not initiated</td>
<td>1967</td>
<td>1969</td>
</tr>
<tr>
<td>Onions</td>
<td>SI</td>
<td>Near completion</td>
<td>Do</td>
<td>Do</td>
<td>1966</td>
<td>1967</td>
</tr>
<tr>
<td>Potatoes</td>
<td>SI</td>
<td>Completed</td>
<td>Do</td>
<td>Completed</td>
<td>---</td>
<td>(4)</td>
</tr>
<tr>
<td>Wheat and wheat products</td>
<td>DIS</td>
<td>Do</td>
<td>Excellent</td>
<td>Do</td>
<td>---</td>
<td>(4)</td>
</tr>
</tbody>
</table>

Legend:
RS=Reduced spoilage.
SLE=Storage life extension.
SI=Sprout inhibition.
DIS=Disinfestation.
DM=Delayed maturation.

¹Economic aspects not considered.
²Approval normally requires 12 to 18 months, and may require additional work during that period.
³Pending FDA action.
⁴FDA approval.
⁵Improving due to promising combination treatment with heat.
⁶Main variety studied to date (Gros Michel variety).
TABLE II. ITEMS FROM THE FOOD IRRADIATION PROGRAMME APPROVED OR SUBMITTED TO THE FOOD AND DRUG ADMINISTRATION (FDA) AS OF MAY 1966

<table>
<thead>
<tr>
<th>Product and purpose of irradiation</th>
<th>Radiation source</th>
<th>Dose (permissible range) (megarad)</th>
<th>Petitioner</th>
<th>Date of filing (F) or FDA approval (A)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bacon; purpose: sterilization</td>
<td>Cobalt 60</td>
<td>4.5-5.6</td>
<td>Army</td>
<td>2/8/63-A</td>
</tr>
<tr>
<td></td>
<td>Electron beam (5 Mev)</td>
<td>4.5-5.6</td>
<td>General Electric Co.</td>
<td>8/23/63-A</td>
</tr>
<tr>
<td></td>
<td>Cesium 137</td>
<td>4.5-5.6</td>
<td>AEC</td>
<td>1/30/64-A</td>
</tr>
<tr>
<td></td>
<td>X-rays from electron beam (5 Mev)</td>
<td>4.5-5.6</td>
<td>Radiation Dynamics Inc.</td>
<td>12/15/64-A</td>
</tr>
<tr>
<td>Wheat and wheat products; purpose:</td>
<td>Electron beam (10 Mev)</td>
<td>4.5-5.6</td>
<td>Army</td>
<td>4/15/65-A</td>
</tr>
<tr>
<td>Insect disinfection</td>
<td>Cobalt 60</td>
<td>.02-.05</td>
<td>Brosneth et al</td>
<td>8/21/63-A</td>
</tr>
<tr>
<td></td>
<td>Cesium 137</td>
<td>.02-.05</td>
<td>AEC</td>
<td>10/2/64-A</td>
</tr>
<tr>
<td></td>
<td>Electron beam (5 Mev)</td>
<td>.02-.05</td>
<td>High Voltage Engineering Corp.</td>
<td>12/12/63-F</td>
</tr>
<tr>
<td>White potatoes; purpose:</td>
<td>Cobalt 60</td>
<td>.005-.010</td>
<td>Army</td>
<td>6/30/64-A</td>
</tr>
<tr>
<td>Sprout inhibition</td>
<td>Cesium 137</td>
<td>.005-.010</td>
<td>AEC</td>
<td>10/2/64-A</td>
</tr>
<tr>
<td></td>
<td>Cobalt 60</td>
<td>.005-.015</td>
<td></td>
<td>1/25/65-F</td>
</tr>
<tr>
<td></td>
<td>Cesium 137</td>
<td>.005-.015</td>
<td></td>
<td>Put Do</td>
</tr>
<tr>
<td>Oranges; purpose: Inhibition of surface and subsurface microorganisms.</td>
<td>Cobalt 60</td>
<td>.075-.200</td>
<td>Joint Army/AEC</td>
<td>12/11/63-F</td>
</tr>
<tr>
<td></td>
<td>Cesium 137</td>
<td>.075-.200</td>
<td>Do</td>
<td>Do</td>
</tr>
<tr>
<td>Packaging materials: purpose: Food contactants for use in radiation preservation of prepackaged foods.</td>
<td>Gamma emitters</td>
<td>21.0</td>
<td>AEC</td>
<td>8/10/64-A</td>
</tr>
<tr>
<td>Packaging materials: purpose:</td>
<td>Do</td>
<td>21.0</td>
<td>Do</td>
<td>2/11/65-F</td>
</tr>
<tr>
<td>(Same as above)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Vegetable parchment paper; purpose:</td>
<td>Cobalt 60</td>
<td>26.0</td>
<td>Army</td>
<td>3/8/65-A</td>
</tr>
<tr>
<td>Food contactant for use in radiation preservation.</td>
<td>Cesium 137</td>
<td>26.0</td>
<td>Do</td>
<td>Put Do</td>
</tr>
<tr>
<td></td>
<td>X-rays from electron beam (5 Mev)</td>
<td>26.0</td>
<td>Do</td>
<td>Put Do</td>
</tr>
<tr>
<td>Packaging materials: purpose: Food contactants for use in radiation preservation of prepackaged foods.</td>
<td>Cobalt 60</td>
<td>26.0</td>
<td>Do</td>
<td>12/8/64-F</td>
</tr>
<tr>
<td></td>
<td>Cesium 137</td>
<td>26.0</td>
<td>Do</td>
<td>Put Do</td>
</tr>
<tr>
<td>Strawberries</td>
<td>Cobalt 60, Cesium 137</td>
<td>0.1-0.25</td>
<td>AEC</td>
<td>4/29/66-F</td>
</tr>
<tr>
<td>Marine Products</td>
<td>Cobalt 60, Cesium 137</td>
<td>0.1-0.2</td>
<td>AEC/Army</td>
<td>9/15/65-F</td>
</tr>
<tr>
<td></td>
<td>X-ray 5 MeV</td>
<td>Electron beam 10 MeV</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

1 Nine classes of materials: nitrocellulose-coated cellophanes; glassine papers; wax-coated paperboards; polypropylene films; ethylene-alkene-1 copolymer films; polyethylene films; polystyrene films; rubber hydrochloride films; vinylidene chloride copolymer films.

2 Maximum.

3 Polyethylene terephthal film, resins and polymeric coatings for polyolefins film.

4 Six classes of plastic materials: polyolefins, polyvinylidene chloride copolymers; polyvinyl chlorides; polystyrenes, polyesters, polyamides.
The results of work on the radiation pasteurization of some 16 species of marine products continue to be very favourable [5]. The authors are at present engaged in laboratory research and developmental activities necessary for the successful commercialization of the process.

The effect of the quality of the fish before irradiation, on the quality of the processed product and shelf life has been studied at several laboratories. The findings for sole, haddock and cod have established that fillets cut from fish held on ice for periods of up to seven to nine days are suitable for radiation processing. Based upon this information, and upon data from a survey of fish quality in the North-eastern United States, it is estimated that over 50% of the ground fish now being received in large fishing ports, such as Boston, Mass., is of a quality suitable for radiation processing.

Research results also indicate that it may be possible to process fish successfully with multiple radiation doses, thereby effectively reducing the bacterial load. These findings have a direct bearing on the possible future success of irradiating fish at sea immediately upon catch. Such a procedure is considered to be a desirable step in the further improvement of the quality of fish processed, using radiation.

Investigation into the beneficial effects of coupling radiation processing with heat treatment continues to look encouraging as a means of increasing the shelf life and still maintaining good quality. The use of this coupling technique may have special application in the processing of marine products, such as crab meat, which is normally marketed as a cooked product.

Packaging material studies have been completed and it can be reported that most commercial plastic films are suitable materials for packaging radiation-processed fish. In addition to maintaining necessary characteristics, upon exposure to radiation, these packaging materials are excellent barriers against bacterial recontamination.

During the past year, laboratory investigations were expanded to include developmental work on handling, shipping and storing radiation-processed fish under commercial conditions. Radiation-processed fish has been shipped in commercial channels from the east coast of the United States to the west coast, for quality evaluation. Haddock fillets, given a radiation dose of 250 krad, were used. The fillets were packed in ice. The non-irradiated controls were acceptable up to 11 d, while the irradiated fish had a 17-d storage life. These tests demonstrate the feasibility of transcontinental shipments of radiation-processed fish to distant markets. It is intended to expand such shipping and storage tests in conjunction with industry. At present, the authors work with ten large food companies, with up to 2000 outlets each, which will be used to store, ship and evaluate marine products.

An important recent accomplishment, which will lead towards ultimate commercialization, is the submission of a petition to the United States Food and Drug Administration for the clearance of radiation-processed fish fillets. Important commercial species included are cod, haddock, flounder and sole. This petition has been accepted for filing by the United States Federal Drug Administration (USFDA). Results are now awaited.
of the large-scale commercial shipping and storage tests which will be used in the evaluation of the petition.

For the future, the technological investigations required for commercial development will continue to be emphasized and the co-operative industrial studies outlined above will continue to be expanded. It is realized that certain aspects of basic research must be pursued also, including the important development of data to support petitions to the USFDA for the clearance of specific classes of food products.

FRUIT TECHNOLOGY

Research results reported by investigators carrying out work under the USAEC programme continue to be optimistic for the ultimate use of radiation for the commercial processing of fresh fruits. Selected work of particular interest in this regard is described below.

A marked delay in the onset of ripening of bananas, of the Gros Michel variety, was effected by using radiation doses of 10-35 krad. Radiation-processed bananas ripen to excellent quality when subjected to standard ethylene treatment. A secondary beneficial effect occurs when the fruit reaches full ripeness. Non-irradiated samples proceed rapidly into senescent breakdown, while irradiated lots remain at the optimum eating condition for two to three days. As the Gros Michel variety is being replaced in Central America by more disease-resistant varieties, such as the Valery, it is important to expand research and economic studies to include these.

The United States Department of Agriculture regulates the quarantine of agricultural products suspected of carrying pests into the United States. Clearance has been given for the importation, from the State of Hawaii to the United States' mainland, of experimental lots of papaya, eggplant and pepper fruits processed by radiation for the control of Hawaiian fruit-fly infestation. Disinfestation, under current practice, is carried out by using chemical fumigation treatment. This is a significant development from two points of view: it will further the objectives of the programme being carried out in Hawaii, directed to the radiation-processing of tropical fruits, and it is a tentative recognition by United States quarantine officials that low-dose radiation processing is an adequate means of controlling the fruit fly. It is probable that similar approval will be granted for the importation of mango fruits processed by radiation for the control of the mango-ved weevil.

Work at the University of Hawaii indicated a three to four-day shelf-life extension in papayas subjected to a radiation dose of 75 krad when coupled with the standard hot-water treatment. Investigators at the University of Florida report control of anthracnose in mangoes, using a radiation dose of 200 krad. Work in progress with ten varieties of mangoes at the Puerto Rican Nuclear Centre indicates shelf-life extension of over ten days, using radiation doses of up to 250 krad. An organoleptically acceptable shelf-stable product can probably be attained at less than 100 krad.

The results of investigations at the University of California and the University of Michigan indicate that radiation-processed strawberries are not susceptible to infection during their subsequent shelf life to any greater
degree than the controls. This will eliminate the possible requirement for using protective wraps for strawberries processed by radiation under commercial conditions.

The results of two years of work at the University of California, with tomatoes irradiated from the "pink" to the "full-ripe" stage, demonstrate a shelf-life extension of 8 to 15 days. This may mean an extended radius of marketing from central warehouses, as well as an extended retail period. The results have special significance when it is recognized that the present trend in the United States is to pick tomatoes in the "pink" stage. These results differ appreciably from earlier work, in which unsuccessful attempts were made to delay the ripening of green tomatoes. Tomatoes harvested at the "pink" to "full-ripe" stage offer a better quality of fruit than tomatoes picked green, and allowed to ripen, during the period of distribution and marketing. The potential of this application is highly interesting, since fresh tomatoes are a large-volume vegetable commodity in the United States.

Two other developments should be mentioned, namely, modification of the adverse effects of radiation on fruit. Sweet-cherry fruit, dipped in calcium chloride before irradiation, do not show the severe loss in texture usually seen in this species. The calcium chloride apparently exerted a protective effect on the structural component, calcium pectate. The irradiation of some fruit fungi at a dose lower than usual (75 krad), followed by a brief hot-water treatment (about 55°C), had a marked lethal effect on the organism. This combination treatment may reduce the radiation dose required for the control of the fungi to levels that do not harm the texture of fruit, such as peaches. The most effective sequence for the use of heat and radiation varies with the specific plant pathogen.

Much of the progress achieved on the radiation-processing of fresh fruit has developed from an increasing understanding of the radiation biochemistry, pathology and physiology of the products under study. Continued, and perhaps even more rapid progress can be expected as fundamental information grows.

However, many critical areas still remain to be explored. In addition to basic research work on food quality, increasing effort must be directed to understanding the effects of harvesting, handling, packing, transporting and marketing practices on radiation-processed fruits.

IRRADIATOR PROGRAMME

Concurrently with the work on food-product development, a major effort has been devoted to the development and provision of a group of radiation facilities (Table III). These irradiator are designed to support research, as well as extend laboratory technology to near-commercial-scale production operations. The experience gained in the design, construction and operation of these facilities will contribute to understanding the requirements of commercial production facilities. As a by-product, this effort has also yielded, radiation engineering data on source and irradiator design which is being applied to radiation processing facilities for other applications than to food.

When the USAEC's programme on the radiation-processing of food was started its contractor, Brookhaven National Laboratory, undertook to
design an irradiator which would be easy and safe to operate and install at sites where the research was to be carried out. The latter factor was considered essential, to avoid the transportation of food products from the harvest area to a point remote from the research centre for irradiation. By integrating the irradiator into the research centre, delays in irradiation and in-transit damage are avoided and improved control and handling practices are attained. Experience obtained in using the research irradiators has fully demonstrated their operational utility, as well as the value of having them available as an integral part of the research activity.
<table>
<thead>
<tr>
<th>TYPE</th>
<th>DESCRIPTION</th>
<th>LOCATION</th>
<th>PURPOSE</th>
<th>REMARKS</th>
</tr>
</thead>
<tbody>
<tr>
<td>a. Research Irradiators (4 total)</td>
<td>35,000 curie $^{60}$Co source; capacity of 75 lbs/hr at 1 megarad dose, underwater irradiation in closed containers</td>
<td>MIT, University of Florida, University of Washington, University of California</td>
<td>Immediate research support at the research site</td>
<td>All in operation</td>
</tr>
<tr>
<td>b. Marine Products Development Irradiator (MPDI)</td>
<td>250,000 curie $^{60}$Co source; capacity 1000 lb/hr at 0.5 Mrad; 4 pass quadrant irradiator</td>
<td>USDI Laboratory, Gloucester, Mass.</td>
<td>Semi-commercial seafood irradiation testing; cooperative industry programs</td>
<td>Operable in early 1965</td>
</tr>
<tr>
<td>c. Mobile Gamma Irradiator (MGI)</td>
<td>Truck-mounted, 60 ton unit; 100,000 curie $^{60}$Co; capacity 1000 lb/hr at 0.2 Mrad</td>
<td>West Coast (California initially)</td>
<td>Wide-scale demonstration of feasibility of fruit irradiation; economic determinations. Industry participation invited</td>
<td>Operable in June 1966</td>
</tr>
<tr>
<td>d. Grain Products Irradiator</td>
<td>30,000 curie $^{60}$Co source; capacity 5000 lb/hr bulk grain or 2800 lb/hr packaged product at 25 000 rad dose</td>
<td>USDA Labs, Savannah, Georgia</td>
<td>Bulk or packaged product disinestation; Industry participation invited</td>
<td>Operable in June 1966</td>
</tr>
<tr>
<td>e. On-Ship Irradiator</td>
<td>30,000 curie $^{60}$Co source; transportable 17 ton unit, capacity at 150 lb/hr at 0.1 Mrad</td>
<td>USDI, Gloucester, Mass. USDA, Seattle, Wash. Louisiana</td>
<td>Placement on fishing vessels for immediate irradiation after catch</td>
<td>Two units operable</td>
</tr>
<tr>
<td>f. Portable Irradiator</td>
<td>Under design. To be a $^{137}$Cs source of 150,000 curies; portable, trailer mounted unit of about 18 tons</td>
<td>On-site at industry locations</td>
<td>Demonstration unit for use by interested food processors</td>
<td>Completion scheduled for October 1966</td>
</tr>
<tr>
<td>g. Hawaii Development Irradiator</td>
<td>250,000 curie $^{60}$Co source; with capacity of 4000 lb/hr at doses of 100,000 rad</td>
<td>Honolulu, Hawaii</td>
<td>Semi-commercial irradiation of tropical fruits; economic determinations; test marketing in cooperation with industry</td>
<td>Completion scheduled for January 1967</td>
</tr>
</tbody>
</table>
Four of these pool-type units, each containing about 35 000 Ci $^{60}$Co, are installed and in use at the University of California, Davis, the Massachusetts Institute of Technology, Cambridge, the University of Florida, Gainesville, and the University of Washington, Seattle (Fig. 1). Four other similar units are in the planning stage, or have been installed at other sites, with nominal AEC support in the form of the radiation sources.

In accordance with the concept that the radiation processing of food should be accomplished as soon as possible after harvest, or catch, the authors have recently completed the construction of three on-ship irradiators (Fig. 2). These are versatile units which are safe and easy to operate and which have the added advantage of being readily transportable. The on-ship irradiator is a compact, 17-ton unit loaded with 30 000 Ci $^{60}$Co,
and primarily intended for use on board ship to irradiate fish immediately after catch. Under commercial fishing operations in the United States, ships stay at sea for periods of up to 14 days. As a result, on return port the product is often of low to medium quality, depending on the time of catch and the refrigeration conditions employed. Research results have shown that the use of a low dose of radiation immediately after catch helps to maintain quality. To further this work, one of these units is now installed on board a fishing vessel operated by the United States Department of Interior's Bureau of Commercial Fisheries Laboratory at Gloucester, Mass. A second unit will be installed on board a fishing vessel for operation by the Louisiana State University for shrimp and oyster studies.

The authors are planning to construct another unit, of the same general type, for co-operative demonstration studies with private companies in the United States. This unit will contain 150 000 Ci $^{137}$Cs, and will be the first large-scale $^{137}$Cs irradiator in use in the United States.

The USAEC has also designed and constructed irradiators for semi-production processing (a) to provide a means of studying radiation processing under near-commercial-scale operating conditions; (b) to provide large quantities of food products for test purposes; and (c) to obtain data on the economics of radiation processing. Experience gained in building the United States Army Radiation Laboratory at Natick, Mass. served as the basis for the design of these pilot plants.

The first of these large-scale units, which became fully operational and licensed for use in early 1965, is the Marine Products Development Irradiator (MPDI), located at Gloucester, Mass. (Fig. 3) [6]. The unit is operated for the USAEC by the Bureau of Commercial Fisheries Laboratory of the Department of Interior. Built at a cost of approximately $600 000, the MPDI contains 250 000 Ci $^{60}$Co and has a throughput of one ton of fish per hour at a pasteurizing radiation dose of 250 000 rad. The facility's purpose is to provide marine products for large-scale shipping, storage, and distribution tests, to obtain a better understanding of the economics of radiation processing, and to assist the fishing industry in commercializing the process.

In June 1964 the USAEC initiated the design, construction, and test operation of a grain products irradiator and a mobile gamma irradiator (Figs. 4 and 5) [7, 8]. The Grain Products Irradiator is located in Savannah, Georgia, and will be operated by the Stored-Product Insects Research and Development Laboratory of the United States Department of Agriculture (USDA). Although it contains a source of only 25 000 Ci $^{60}$Co, novel design and high efficiency permit a throughput of 5000 lb/h of bulk grain, or 2800 lb/h of packaged products irradiated to a dose of 25 000 to 50 000 rad for insect disinfestation. The USDA is making available to the project some of the grain-handling mechanisms, storage facilities, and ancillary laboratory facilities. The irradiator became operational in June 1966 and is intended to be available for limited commercial testing by private industry, as with the MPDI.

A preliminary design and feasibility study of a truck-mounted irradiator, using either a $^{60}$Co or an electron machine, has been completed. This has been followed by the design and construction of a Mobile Gamma Irradiator (MGI). The MGI design has been optimized for the processing of fruit contained in their standard field lugs. The irradiator contains approximately 100 000 Ci $^{60}$Co and has a product throughput for
FIG. 3. Marine Products Development Irradiator

FIG. 4. Bulk Grain Irradiator
strawberries of, for example, 1000 lb/h, or half a railroad boxcar per ten-hour day. Accordingly, daily shipments can be made of boxcar lots of strawberries, both radiation-processed and controls, and the effects of transit and storage evaluated and compared. The unit became operational in May 1966 and is being used, initially, in the State of California. The University of California, Davis, will operate the unit, and it is anticipated that private fruit growers and distributors will participate in end-product testing programmes.

In April 1966 the USAEC submitted a formal petition to the USFDA for the clearance of strawberries for general human consumption. This step, coupled with favourable economic projections, and the expected success of large-scale feasibility tests, could result in limited commercialization of the radiation processing of strawberries by the middle of 1967. This action, of course, would be dependent on a decision by United States industry to undertake commercial activities in this area.

The last large-scale unit at present under design and construction is a semi-production irradiator to be located in Honolulu, Hawaii. This is a co-operative project, the USAEC providing an irradiator, with its attendant equipment, and the State of Hawaii providing a site, building, laboratories, and other support facilities. The irradiator is to be operated by the State Department of Agriculture. The radiation processing of tropical fruit, such as papaya and mango, shows good promise for shelf-life extension and insect sterilization for quarantine control, respectively. Accordingly, a versatile unit is required which is capable of handling a variety of fruit at widely varying doses. A $^{60}$Co source of approximately 250 000 Ci enables a throughput of some 4000 lb/h of product at doses of
about 75,000 rad. This irradiator is scheduled for completion early in 1967 (Fig. 6).

Three agencies of the United States Government, the USAEC, the Department of Defense, and the Department of Commerce, are considering the initiation of a co-operative industry-government project for the construction and operation of a one to five million pound per year meat sterilization facility. As an inducement for the United States industry to provide the major part of the capital funds for the construction of the facility, the USAEC has offered to support the costs of the engineering design and the radiation source, and the Department of Defense will guarantee procurement of a percentage of the product of the plant for a specified period of time. The exact commitment is still under review, and will be a key factor in the willingness of industry to participate.

The main objective of such a co-operative programme is to establish a commercial basis for radiation-processed meats. The specific goals of the project are:

(a) The construction of a facility, to be in operation in 1968, in which laboratory techniques will be scaled up to semi-processing conditions;
(b) The provision of sufficient radiation-sterilized foods to meet the proposed commitment of the Department of Defense;
(c) Determination of processing costs and the economics of radiation-sterilized meats and poultry, with attendant extrapolation to full-scale commercial production conditions; and
(d) The introduction of a portion of the throughput into the civilian economy to induce further commercialization.

To date, interviews have been conducted with a large number of food companies, many of whom have expressed specific interest in the project.
Consequently, there is good reason to expect the eventual participation of the United States industry in the successful achievement of the project.

The foregoing summarizes the present status of the research and development programme on product and process development of the USAEC as well as on supporting radiation facilities.

COMMERCIALIZATION

In considering commercialization in the United States, it must be noted that the food industry in the country was stimulated a number of years ago to look into the possibilities of the radiation processing of food. A good deal of interest was generated and a number of companies investigated the suitability of the process for their product. Generally, they found that the process was not yet ready for commercial use and that it would not be ready before a great deal of research had been done which, together with obtaining USFDA clearance, would take a number of years. Consequently, they largely stopped their own private activity and assumed the posture of watching and waiting.

Today, specific steps are being taken to develop full industry participation with the Government to bring this important new food-processing technology into commercial use.

It is recognized that there are many factors which tend to inhibit commercialization. Here there is temptation to make an analogy to the numerous problems that affected the development of Appert's process of thermal canning. Some of the present problems pertaining to the radiation processing of foods are: (a) Quality of the product; (b) Competing processes; (c) Better processing cost data; (d) Clearances in sufficient number from the pertinent government agencies to support commercialization; and (e) The education of industry and the public.

These problems tend to inhibit enthusiasm for the process, and it is necessary to overcome them. Some products are showing more immediate promise than others and are attracting the direct interest of industry. Strawberries and some fishery products are examples of this.

The most effective means for achieving commercialization is to obtain industry participation in the development stage. Participation need not wait for a fully developed process. Significant contributions can be made by a commercial firm during the developmental period. At this time, assistance can be given by industry, for example, in connection with USFDA petitions. This type of industry participation is currently the goal of the USAEC. As part of this, financial participation by industry is also expected.

It is recognized that a particular company may be reluctant to pioneer a process which will be equally available to its competitors. There should be an opportunity for proprietary rights.

A commercial organization is unlikely to spend its money on a process which it cannot, as yet, legally carry out. Hence, clearance by the USFDA and other agencies is crucial for developing commercial interest. This does not preclude interesting a company before clearance is obtained. In fact, as noted elsewhere, this is desirable. However, due to develop-

APPERT, François (Nicolas) – discoverer of the thermal processing of food in 1809.
mental expense and the general lack of proprietary rights, clearance of a reasonable number of selected foods is an area where the United States Government can and should act.

Recognizing the various problems, the authors are taking steps to try to overcome them. The United States Department of Defense is seeking radiation-sterilized meats and has proposed the building of a meat irradiator having a capacity of one to five million pounds per year to be operated directly by industry.

The USAEC and the Bureau of Commercial Fisheries have made the Gloucester Marine Products Development Irradiator available to the fishery industry for product irradiation to enable it to evaluate the process.

The USAEC, directly and through its contractors, has been in contact with chicken processors, and has been working closely with large producers of bananas and also with strawberry producers.

In addition, surveys have been conducted to ascertain interest in and the potential use of the radiation preservation of fishery products and certain fruit. The Department of Commerce conducted a study of the broad application of the process.

One food company in the United States has applied for clearance of a process involving the improvement of dehydrated vegetables by radiation.

CONCLUSION

In conclusion, the USAEC research and development work continues to show increasing promise for commercialization. In the United States, commercial interest will be dependent upon progress made in obtaining clearance of radiation-processed food for general human consumption. While important problems remain to be solved, no evidence exists which would preclude their solution and the subsequent development of the first new food-processing method since the time of Appert.

REFERENCES

M. de PROOST: What fruit do you think is likely to be the subject of the first commercial application of food irradiation in the United States?

K. SHEA: I have already mentioned strawberries as a serious candidate, but disinfestation of mangoes to control the seed weevil is another promising process. At present there is no way of controlling these weevils and as a result Hawaiian mangoes may not be imported to the mainland of the United States. The shelf life of papayas grown in Hawaii can be prolonged by three or four days by a combination of heat (55°C) and radiation (75 krad), and at the same time this process would control the fruit fly, which at present must be destroyed by chemical means. A corollary advantage of the prolonged shelf life is that it might allow the fruit to be shipped economically by sea, rather than by air as at present.
THE UNITED STATES ARMY FOOD IRRADIATION PROGRAMME

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Abstract — Résumé — Аннотация — Resumen

THE UNITED STATES ARMY FOOD IRRADIATION PROGRAMME. The United States Army ten-year food irradiation programme is a mature, comprehensive, scientific and technological effort that has produced sufficient results to warrant the confidence it now enjoys. Modern, highly-effective facilities are now available to expedite all phases of the work. Highly-qualified research personnel have been drawn into the programme over the years, and with present fine resources and the talent bank, all aspects of interest - sources, doses, radiation effects, and product development - are receiving intensive study.

The paper covers (1) the scope and essential findings of the United States Army wholesomeness studies; (2) acceptance-testing procedures and typical hedonic ratings; (3) the status of gamma-ray and accelerated electron irradiation. Reference is made to (a) food item(s) cleared by the United States Food and Drug Administration (FDA); (b) petitions accepted and pending; and (c) special objectives of electron irradiation studies.

The influence on product quality of conditions current during irradiation is discussed, with emphasis on nutritive and sensory improvements stemming from low (cryogenic) temperatures and from high dose-rate irradiation.

The place of radiation pasteurization in the Army programme is described, especially with regard to poultry product improvements achievable by this means.

The work on packages and packaging for irradiated foods, now under development, is reported. Studies (and FDA clearances) of rigid containers, parchment liners and of resinous can linings are reviewed. The promising leads in flex-pack development are of much interest.

An important section of the paper concerns the efforts of other Federal Agencies, such as the United States Atomic Energy Commission, the United States Department of Interior, Bureau of Fisheries, and the United States Department of Agriculture. A perspective on the interrelationships of these efforts with the United States Army programme is given.

In conclusion, future plans are briefly described. Highlights of the new five-year research and development programme are set forth. Of special interest is the industrial food irradiation pilot plant, now in the planning stage.

LE PROGRAMME D'IRRADIATION DE DENREES ALIMENTAIRES DE L'ARMEE DES ETATS-UNIS.
Le programme d'irradiation de denrees alimentaires de l'Armee des Etats-Unis represente un effort scientifique et technique d'ensemble dont les resultats suffisent a justifier la confiance dont il jouit a l'heure actuelle. On dispose maintenant d'installations modernes tres efficaces pour exécuter toutes les phases des travaux. Un personnel de chercheurs hautesement qualifies a ete affecte a ce programme au cours des dernieres annees et, avec les remarquables resources en personnel de valeur dont on dispose actuellement, toutes les questions présentant un interet - sources, doses, effets des rayonnements et mise au point du produit - font l'objet d'une étude intensive.

Le present memoire porte sur les domaines suivants: 1) portee et conclusions essentielles des etudes faite par l'Armee des Etats-Unis sur la comestibilité; 2) tests d'acceptabilité et évaluations éthédonistiques des types des qualités; 3) applications actuelles de l'irradiation par les rayons gamma et les électrons accelerés. Il est fait mention a) des produits alimentaires autorisés par le service de contrôle des produits alimentaires et pharmaceutiques des Etats-Unis, b) des demandes de licences acceptées et en cours d'examen et c) des objectifs particuliers des etudes sur l'irradiation par les électrons.

L'auteur examine l'influence sur la qualité du produit des conditions qui règnent pendant l'irradiation, en insistant sur les améliorations de la valeur nutritive et des caractéristiques gustatives et olfactives dues aux basses températures (cryogéniques) et aux irradiations à débit de dose élevé.

L'auteur décrit la place qu'occupe la radiopasteurisation dans le programme de l'Armée, notamment en ce qui concerne l'amélioration des produits de basse-cour que l'on peut obtenir par ces moyens.
L'auteur mentionne les travaux en cours sur les emballages et le conditionnement des produits alimentaires irradiés. Il passe en revue les études (et autorisations d'utilisation délivrées par le service de contrôle des produits alimentaires et pharmaceutiques) sur les emballages rigides et les papiers parcheminés et vernis intérieurs pour boîtes de conserves. Les progrès réalisés en ce qui concerne les emballages «flex-pack» sont très prometteurs et présentent un grand intérêt.

Une importante partie du mémoire traite des mesures prises par d'autres organismes fédéraux, tels la Commission de l'énergie atomique des États-Unis, le Département de l'Intérieur des États-Unis, le Bureau des pêcheries, et le Département de l'agriculture des États-Unis. Le mémoire donne un aperçu de la corrélation de ces mesures avec le programme de l'Armée des États-Unis.

En conclusion, l'auteur décrit brièvement les plans des activités futures. Il présente les points essentiels du nouveau programme quinquennal d'études et de réalisations. L'usine pilote d'irradiation industrielle des produits alimentaires, dont on étudie actuellement les plans, présente un intérêt tout particulier.

PROGRAMMA ARMINI SSHA PO OBLUCHENIU PISHCHEVYH PRODUKTOW. Десятилетняя программа армии США по облучению пищевых продуктов представляет собой продуманную, всеобъемлющую научно-техническую работу, которая привела к значительным результатам, подтверждающим ту уверенность, с которой относятся к данной программе в настоящее время.

В настоящее время имеются современные высокопроизводительные установки, которые могут ускорить выполнение всех фаз данной работы. В течение многих лет над осуществлением программы трудится высококвалифицированный научный персонал. При наличии значительных средств и большого количества талантливых специалистов активно исследуются все аспекты, представляющие интерес: источники, дозировка, радиационные эффекты и получение продуктов.

В настоящий доклад включены 1) объем и существенные данные исследований армии США относительно сохранения вкусовых и питательных качеств продуктов, 2) приемлемость методики испытаний и типичные гедонические характеристики; 3) положение в области применения гамма-лучей для облучения и облучение с помощью ускоренных электронов. Приводится ссылка на а) пищевые продукты, проведенные Инспекцией пищевой промышленности и лекарственных продуктов США, б) принятые и еще не принятые ходатайства и в) специальные цели исследований в области электронного облучения.

Обсуждается влияние условий в момент облучения на качество продуктов с упором на питательность и чувствительность вследствие низких (кромозенных) температур и большой мощности дозы облучения.

Дается изложение той роли, которую радиационная пастеризация играет в программе американской армии, особенно в отношении улучшения продукции птицеводства, от которого можно получить большое количество облученных продуктов.

Дается описание работ в отношении упаковок и способов упаковки облученных пищевых продуктов, которые разрабатываются в настоящее время. Дается обзор исследований (и проверок, проведенных Инспекцией пищевой промышленности и лекарственных продуктов США) жестких контейнеров, пергаментных прокладок и смолистых обекотов для консервных банок. Большой интерес представляет положительные данные по разработке эластичных упаковок.

Значительная часть доклада посвящена деятельности других федеральных учреждений, как, например, Комиссии по атомной энергии США, Министерства внутренних дел США, бюро по делам рыболовства, и Министерства сельского хозяйства США. В докладе излагаются перспективы взаимосвязей в деятельности указанных учреждений с программой для американской армии.

В заключение дается краткое изложение планов на будущее. Приводятся основные моменты пятилетней программы научных исследований. Особый интерес представляет опытная установка по промышленному облучению пищевых продуктов, которая в настоящее время находится на стадии разработки.

PROGRAMA DE IRRADIACION DE ALIMENTOS DEL EJERCITO DE LOS ESTADOS UNIDOS. El programa decenal de irradiación de alimentos que ejecuta el Ejército de los Estados Unidos es una vasta empresa científica y técnica cuyos resultados justifican plenamente la confianza que habí deliberado. Se dispone ya de instalaciones modernas y de gran eficacia para todas las etapas del trabajo. Se ha contratado a personal muy competente y con los conocimientos adquiridos y los recursos de que se dispone se están estudiando detenidamente todos los aspectos de interés — fuentes, dosis, efectos de las radiaciones y mejoramiento de los productos.

En la memoria se examinan los siguientes puntos: 1) alcance y resultados esenciales de los estudios sobre comestibilidad efectuados por el Ejército; 2) procedimientos para los ensayos de aceptación y escala hedonística típica; 3) estado actual de la irradiación con rayos gamma y con electrones acelerados.
Se hace referencia a los productos alimenticios cuya irradiación ha sido autorizada por la Food and Drug Administration de los Estados Unidos, a las peticiones aceptadas y en curso de estudio y a los objetivos especiales de los estudios sobre irradiación con electrones.

Se examinan los efectos de las condiciones en que se efectúa la irradiación sobre la calidad de los productos, y en particular los mejoramientos nutritivos y organolépticos obtenidos por tratamiento a bajas temperaturas y con una irradiación de elevada intensidad.

Se describe el papel que desempeña la radiopasteurización en el programa del Ejército, especialmente en lo que respecta al mejoramiento de los productos de volatería.

Se expone la labor que se está efectuando en materia de embalajes y empaquetamiento de alimentos irradiados, y se informa sobre los estudios (y las autorizaciones de la Food and Drug Administration) relativos a recipientes rígidos y al empleo de pergaminos y de resinas como revestimiento interior de las latas de conserva. Son de gran interés los trabajos sobre fabricación de envases flexibles.

Una parte importante de la memoria se refiere a las actividades desarrolladas por otros órganos federales: la Comisión de Energía Atómica de los Estados Unidos, el Departamento del Interior – Bureau of Fisheries, y el Departamento de Agricultura. Se señala la relación que existe entre estas actividades y los trabajos que se efectúan dentro del marco del programa del Ejército.

Por último se describen brevemente los planes futuros y se dan algunos datos fundamentales sobre el programa quinquenal de investigación y desarrollo. De especial interés es la planta piloto de irradiación de alimentos, que está actualmente en la fase de planeamiento.

More than ten years of comprehensive investigations in the United States have laid a firm foundation for the present and future applications of ionizing irradiation to the protection of food supplies, in the country and abroad.

Among the multiplicity of difficult problems confronting the first investigators of food irradiation were those concerned with safety and wholesomeness. Could irradiated foods be eaten without ill effects? What would their ingestion do to growth, longevity, reproduction, lactation, endocrines, and progeny? Would such foods be nutritionally adequate? Would irradiation induce a degree of radioactivity in the foods, or in the packages surrounding them? The importance of this latter question was enhanced by the Delaney Amendment to the United States Pure Food and Drugs Act, which defined any radioactivity above "background level" as a carcinogenic additive, and placed a zero tolerance upon it.

IRRADIATED FOOD WHOLESA MEENESS AND SAFETY

The task of "assurance of wholesomeness" of irradiated foods became the responsibility of The Surgeon General of the United States Army.

Four species of animal (mice, rats, dogs and monkeys) were involved in scores of tests in more than 40 institutions. Studies continued for more than 10 years and involved approximately 15,000 animals. As many as four generations per species were employed. Long-term feeding studies extended over a two-year time frame, the animals receiving up to 35% of total ingested dry solids as food sterilized (4.5 to 5.6 Mrad) by the gamma emanations of cobalt-60. The effects of the feeding of 21 representative foods were evaluated in terms of "growth, reproduction, haematology, longevity, histopathology and carcinogenicity" [1]. Tissue sections from each study were reviewed by the United States Armed Forces Institute of Pathology. In these studies 273 dogs and more than 3000 rats were involved. These studies proved, beyond any doubt, the wholesomeness and safety of irradiated foods which have been sterilized by the gamma rays.
of cobalt-60. More than 40 foods were tested, in acute toxicity feeding studies, followed by the exhaustive testing of 21 foods, chosen as representative of every major class consumed in the diet under study. Seven two-week human feeding studies confirmed the human safety of cobalt-gamma-preserved foods, and laid the groundwork for succeeding efforts.

To exaggerate any physiological or morphological effects attributable to the ingestion of irradiated foods, large quantities of foods unusual in the diets of the test animals were employed in some experiments. One study involved feeding large amounts of cabbage to dogs: anomalies were bound to occur, and did.

Genetic uniformity in test animals seemed desirable to many investigators in an effort to limit the range of variables extraneous to the tests. Inbred strains of animals, mostly mice and rats, were shown to have inherent constitutional weaknesses. Some of these, unimportant in the short-term periods which characterize many traditional studies, loomed very large when entire colonies were held under surveillance over their complete life-span. Initially, anomalies were ascribed in some cases to the irradiation which the diets had received. However, years of additional study have gradually shown that the anomalies were unrelated to the ionizing irradiation treatment.

Vitamin losses were encountered, but these were not very different from losses which occur in the more traditional food preservation processes [2].

Theoretical studies, followed by extensive assays, confirmed that foods irradiated with cobalt-60, and found to be wholesome, would also be wholesome if exposed to the gamma rays of caesium-137 in a similar manner, or if treated by accelerated electrons up to 10 MeV.

There is the possibility that, at sufficiently high energies, electrons may induce a degree of radioactivity in treated foods. The thresholds of activation lie within the range 10 to 16 MeV.

Recent investigations [3,4] indicate that a person might receive an added level of total-body irradiation amounting to approximately 0.26 mR/yr if the entire diet were irradiated with electrons at an energy level of 24 MeV, and if the food were ingested immediately following irradiation. This compares to the average 150 mR/yr dose which people receive from naturally-occurring radioisotopes always present in foods.

Studies must be continued to determine the maximum permissible energies to be used, as the thickness of the product to be preserved has a bearing upon the energy of the electrons impinging on and penetrating the product. This, in turn, determines the size and kind of product amenable to electron processing.

At an early date concern was felt regarding the effect of sterilizing doses of irradiation on can enamels containing different types of food, and on the selection of containers suitable for research and pilot-plant studies. Accordingly, beginning 10 years ago, extensive studies were carried out, mainly under contract arrangements with industrial groups. Representative of these is a three-year study conducted by the American Can Company [5], which included the manufacture of special lots of electrolytically-plated and "hot-dip" tin cans. Some 3000 cans were required altogether. Assays were made of the cans, of the end-lining compounds and of the coating enamels.
Eight kinds of food products were prepared for processing, either by traditional heat processes or by gamma irradiation from spent fuel rods, which included cherries, representative of acid fruit products, chili-con-carne, as a sulphur-bearing meat-vegetable mixture, beef as a meat of low fat content, pork as a meat of high fat content, and codfish as a marine product difficult to can.

The can enamels included oleoresinous types with, and without zinc oxide paste added; epoxy-phenolic types with, and without zinc paste added; polybutadiene types with, and without zinc paste added; heat-reactive phenolic, and a phenolic epon ester with aluminium added.

Radiation-sterilized products received radiation doses of 6 Mrad, and counterpart heat-processed commodities were processed in boiling water for 8 min at 212°F. All samples were stored at 98°F for periodic examination. Eighteen product and container characteristics were evaluated every 90 days for one year.

A number of processing variables was shown by this extensive experiment, and it was important to discover the existence of can enamels which were suitable for the irradiation processing of canned foods of several contrasting classes.

This, and other early studies, proved the wholesomeness and safety of enamel-lined tin-plated cans, and of aluminium cans. The approval of the Federal Department of Administration (FDA) was granted for these, together with approval of the processing of irradiated bacon, on 8 February 1963.

ACCEPTANCE OF IRRADIATED FOODS

Irradiated foods, like all new foods developed at the Natick Laboratories, undergo extensive consumer testing. In the development laboratory, three groups of observers evaluate the qualities of the foods. These are technical panels, consumer panels, and luncheon guests.

The technical panel is composed of a minimum of eight professional staff members drawn from the Food Division. Each member has had at least two years' experience in taste-testing, including irradiated foods. Evaluations are made individually and follow accepted standards. The facilities of the taste-testing kitchens and specially-constructed testing cubicles are used.

A consumer panel is composed of 35 to 40 individuals who are drawn at random, by IBM procedures, from 800 volunteers, employees of the Natick Laboratories. Consumer panels follow practices similar to those used by the trained technical panels, but discrimination is frequently less keen than in trained personnel. Scoring is by means of the Peryam-Pilgrim hedonic scale [6] rather than by other systems.

Luncheon appraisals are by 12 to 15 individuals, who sample the experimental foods as components of complete meals. They may be trained or untrained. Here again scoring is by means of the Peryam-Pilgrim scale.

The acceptability of all experimental foods is ultimately determined by testing these as components of complete military meals in a military environment. Beginning in 1958, irradiated foods were evaluated by volunteers at Fort Lee, Virginia. More than 10,000 meals have been
served to date and 60,000 more are scheduled for consumption before 1971. These panels comprise at least 100 men, who eat either the experimental food as a component of a meal of normal issue, or who are served a proper control food in lieu of the one irradiated. The controls may be fresh or frozen, or may be preserved by other traditional means. The experimental dishes are served in otherwise standard military meals and the recipients are uninformed regarding the experimental or control food. The Peryam-Pilgrim hedonic scale is used in these evaluations, as in others already described.

### TABLE I. THE PERYAM-PILGRIM NINE POINT HEDONIC SCALE FOR MEASURING FOOD PREFERENCES

<table>
<thead>
<tr>
<th>Rating</th>
<th>Points</th>
</tr>
</thead>
<tbody>
<tr>
<td>Like extremely</td>
<td>9</td>
</tr>
<tr>
<td>Like very much</td>
<td>8</td>
</tr>
<tr>
<td>Like moderately</td>
<td>7</td>
</tr>
<tr>
<td>Like slightly</td>
<td>6</td>
</tr>
<tr>
<td>Neither like nor dislike</td>
<td>5</td>
</tr>
<tr>
<td>Dislike slightly</td>
<td>4</td>
</tr>
<tr>
<td>Dislike moderately</td>
<td>3</td>
</tr>
<tr>
<td>Dislike very much</td>
<td>2</td>
</tr>
<tr>
<td>Dislike extremely</td>
<td>1</td>
</tr>
</tbody>
</table>

The hedonic scale of Peryam and Pilgrim, shown in Table I, provides a means for the subjective semi-quantifying of various degrees of acceptability of products by testers. The scale has 9 points; the value 9 is assigned to "perfection of product" (difficult to attain) related to the description "like extremely". Value 1 signifies odious, "dislike extremely". The fulcrum value (neither like nor dislike) is 5.

In Table II are shown the ratings given to various commonly eaten foods during an 'Attitude Survey', conducted in Army Camps and Stations throughout the United States during 1963 [7]. Soldiers were given lists of foods by interviewers, but the foods were not presented nor eaten. Recollection of preferences of more than 260 kinds of foods were scored, using the 9-point hedonic scale.

Ice cream, roast beef and apple pie all scored above 7.7 on the scale, indicating that they were "liked very much". These scores were at the apex of acceptance of all the foods listed. Long experience with many kinds of foods under a variety of conditions indicates that the hedonic mean value of 7.5 is rarely exceeded, even for foods most preferred. Tables III, V and VI summarize acceptance data which stem from Fort Lee Volunteer tests [8]. In Table III is given information on items of pork. Each item was irradiated to a dose of 4.5 to 5.6 Mrad at ambient temperatures in metal cans using a cobalt-60 source. In the mean hedonic ratings (columns 6 and 7, Table III) the frequency of values approaching 7.0 can be seen. Such values are indicative of relatively high levels of acceptance; they
**TABLE II. FOOD PREFERENCES a)**

<table>
<thead>
<tr>
<th>Item</th>
<th>Number of respondents</th>
<th>Mean rating</th>
</tr>
</thead>
<tbody>
<tr>
<td>Instant coffee</td>
<td>2825</td>
<td>4.79</td>
</tr>
<tr>
<td>Succotash</td>
<td>2825</td>
<td>5.82</td>
</tr>
<tr>
<td>Chicken rice soup</td>
<td>2673</td>
<td>6.27</td>
</tr>
<tr>
<td>Chili-con-carne</td>
<td>2825</td>
<td>6.79</td>
</tr>
<tr>
<td>Peaches, canned</td>
<td>2825</td>
<td>7.55</td>
</tr>
<tr>
<td>Ice-cream</td>
<td>2750</td>
<td>7.70</td>
</tr>
<tr>
<td>Roast beef</td>
<td>2825</td>
<td>7.79</td>
</tr>
<tr>
<td>Apple-pie</td>
<td>2750</td>
<td>7.85</td>
</tr>
</tbody>
</table>

*a) Survey taken February to March 1963.*

---

**TABLE III. ACCEPTANCE OF PORK-DERIVED FOODS IN MEALS a)**

<table>
<thead>
<tr>
<th>ITF-4</th>
<th>STORAGE b)</th>
<th>CONTROL</th>
<th>NUMBER OF JUDGES</th>
<th>MEAN RATINGS d)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>(months)</td>
<td></td>
<td>Irradiated</td>
<td>Irradiated</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Contr.1</td>
<td>Control</td>
</tr>
<tr>
<td>PORK</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Barbecued</td>
<td>10</td>
<td>Fresh</td>
<td>60</td>
<td>60</td>
</tr>
<tr>
<td>Roast</td>
<td>10</td>
<td>Fresh</td>
<td>60</td>
<td>60</td>
</tr>
<tr>
<td>Chops</td>
<td>5</td>
<td>Fresh</td>
<td>560</td>
<td>670</td>
</tr>
<tr>
<td>Roast</td>
<td>3</td>
<td>Frozen</td>
<td>391</td>
<td>458</td>
</tr>
<tr>
<td>SAUSAGE</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Patties</td>
<td>3</td>
<td>Frozen</td>
<td>489</td>
<td>567</td>
</tr>
<tr>
<td>Links</td>
<td>3</td>
<td>Frozen</td>
<td>303</td>
<td>272</td>
</tr>
<tr>
<td>HAM</td>
<td>9</td>
<td>Frozen</td>
<td>553</td>
<td>790</td>
</tr>
<tr>
<td>BACON</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Oven-fried</td>
<td>12</td>
<td>Fresh</td>
<td>60</td>
<td>60</td>
</tr>
<tr>
<td>Oven-fried</td>
<td>3</td>
<td>Fresh</td>
<td>391</td>
<td>482</td>
</tr>
<tr>
<td>Oven-fried</td>
<td>3</td>
<td>Fresh</td>
<td>286</td>
<td>5.57</td>
</tr>
<tr>
<td>Oven-fried</td>
<td>9</td>
<td>Fresh</td>
<td>775</td>
<td>5.59</td>
</tr>
</tbody>
</table>

*a) All items irradiated at ambient temperatures by 60Co gamma rays to 4.5 to 5.6 Mrad.*

*b) Storage at ambient temperatures 70 to 100°F.*

*c) Difference between mean ratings is significant at 0.5 probability level.*

*d) Data after Heiligman and Phillips [8].
leave some margin for product improvements, anticipated to result from continuing study. Values marked show that the attributes of the un-irradiated control are preferred to those of the comparable irradiated products, and that these differences are statistically significant at the 0.5 probability level.

Barbecued pork and pork roasts stored at room temperature (70-100°F) following irradiation were generally accorded high levels of acceptance in military meals. In these tests pork sausage was below the level of acceptance desired. Additional study has recently improved irradiated sausage significantly, as shown in Table IV.

TABLE IV. IRRADIATION-STERILIZED PORK SAUSAGE.
QUALITY OF CONTRASTING LOTS

<table>
<thead>
<tr>
<th>PRODUCT TYPE</th>
<th>DOSE (Mrad)</th>
<th>STORAGE (weeks at 70°F)</th>
<th>FRYING METHOD</th>
<th>PREFERENCE b</th>
<th>MEAN</th>
<th>S.D.</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0</td>
<td>11</td>
<td>Oven</td>
<td>6.1</td>
<td>1.67</td>
<td></td>
</tr>
<tr>
<td>50% Fat</td>
<td>2.5</td>
<td>1</td>
<td>Oven</td>
<td>6.3</td>
<td>1.45</td>
<td></td>
</tr>
<tr>
<td></td>
<td>4.5</td>
<td>1</td>
<td>Oven</td>
<td>4.8</td>
<td>1.76</td>
<td></td>
</tr>
<tr>
<td>Govt.</td>
<td>4.5</td>
<td>4</td>
<td>Oven</td>
<td>7.2</td>
<td>1.32</td>
<td></td>
</tr>
<tr>
<td>Spec.</td>
<td>4.5</td>
<td>5</td>
<td>Oven</td>
<td>7.2</td>
<td>1.53</td>
<td></td>
</tr>
<tr>
<td>40% Fat</td>
<td>4.5</td>
<td>4</td>
<td>Pan</td>
<td>7.1</td>
<td>1.83</td>
<td></td>
</tr>
<tr>
<td></td>
<td>4.5</td>
<td>5</td>
<td>Pan</td>
<td>7.4</td>
<td>1.32</td>
<td></td>
</tr>
</tbody>
</table>

a) Irradiated.
b) 20 Panelists, Natick Laboratories (NLABS) Experiments 33/85 and 63/140.

The baked ham was more than adequate gustatorily, but it was not the excellent quality the author considers it possible to achieve. These data, while encouraging, leave room for improvement.

In Table V is shown the acceptance of irradiated chicken. Chicken lends itself well to radiation processing, and this is borne out by the relatively high hedonic scores accorded to many of the items tested. Not all lots of chicken were equally excellent. Study is continuing to discover means for producing fine poultry products of uniformly high quality. Irradiation of all the lots was at ambient temperatures; this may be an important factor bearing on product quality.

Items of beef have proved to be the most intractable of all the flesh foods worked with to date. From the beginning, the irradiation of beef has been synonymous with acrylic, harsh, unappetizing, and undesirable odours and flavours. In terms of cost beef is one of the most important foods consumed in military subsistence. To be successful an irradiation programme must therefore be one consistently capable of producing beef products of excellent quality. Initially, progress towards this was painfully slow. Recently, consistent success has attended efforts. Evidence of this dramatic change can be seen in contrasting Tables VI and VII.

Table VI shows the acceptance of irradiated items of beef tested at Fort Lee. All were irradiated at ambient temperatures in the cobalt-60
TABLE V. ACCEPTANCE OF IRRADIATED CHICKEN a)

<table>
<thead>
<tr>
<th>ITEM</th>
<th>STORAGE (months)</th>
<th>CONTROL</th>
<th>NUMBER OF JUDGES</th>
<th>MEAN RATINGS</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Control</td>
<td>Irradiated</td>
<td>Control</td>
</tr>
<tr>
<td>Fried</td>
<td>3</td>
<td>Fresh</td>
<td>107</td>
<td>104</td>
</tr>
<tr>
<td>Fried</td>
<td>3</td>
<td>Fresh</td>
<td>101</td>
<td>103</td>
</tr>
<tr>
<td>Fried</td>
<td>3</td>
<td>Fresh</td>
<td>481</td>
<td>552</td>
</tr>
<tr>
<td>Fried</td>
<td>3</td>
<td>Frozen</td>
<td>312</td>
<td>324</td>
</tr>
<tr>
<td>Fried</td>
<td>3</td>
<td>Frozen</td>
<td>280</td>
<td>279</td>
</tr>
<tr>
<td>&quot;A la King&quot;</td>
<td>3</td>
<td>Canned</td>
<td>313</td>
<td>372</td>
</tr>
</tbody>
</table>

a) After Heiligman and Phillips [8] irradiated to 4.5 - 5.6 Mrad with $^{60}$Co.
b) Difference between mean ratings is significant at the 0.5 probability level.

TABLE VI. ACCEPTANCE OF IRRADIATED ITEMS OF BEEF a)

<table>
<thead>
<tr>
<th>ITEM</th>
<th>STORAGE (months)</th>
<th>CONTROL TYPE</th>
<th>NUMBER OF JUDGES</th>
<th>MEAN RATINGS</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Control</td>
<td>Irradiated</td>
<td>Control</td>
</tr>
<tr>
<td>Barbecued</td>
<td>3</td>
<td>Fresh</td>
<td>515</td>
<td>660</td>
</tr>
<tr>
<td>Steak</td>
<td>3</td>
<td>Frozen</td>
<td>378</td>
<td>478</td>
</tr>
<tr>
<td>Sandwich</td>
<td>3</td>
<td>Frozen</td>
<td>366</td>
<td>464</td>
</tr>
</tbody>
</table>

a) After Heiligman and Phillips [8]. Irradiated to 4.5 - 5.6 Mrad with $^{60}$Co.
b) Difference between mean ratings of treatment and control is significant at the 0.5 probability level.

facility of Natick Laboratories. The dose level was 4.5 to 5.6 Mrad. The hedonic ratings of such commodities ranged around the value of 6.0 ("like slightly"). Unirradiated controls were generally preferred to the irradiated foods, whether steaks, sandwiches or barbecued preparations.

However, early efforts to ameliorate the off-flavour and related degrading changes in beef by employing cryogenic temperatures during irradiation were highly rewarding. An example of such favourable experiences was the irradiated beef loin, tested on 2 March 1961. The loin had been irradiated some 6 weeks before in the gamma source of the Cook Electric Company of Morton Grove, Ill. to a sterilizing dose of 4.5 Mrad at temperatures at or near those of liquid nitrogen. When evaluated by a panel of 13 trained technologists, all with long experience in irradiated foods, this irradiated beef received an acceptance score of 7.76. Few foods processed by any means ever receive scores higher than this (Table II).

Comparison of hedonic ratings reported in Table VII with those shown in Table VI clearly indicate the superior quality of beef irradiated at low temperatures. Such high ratings have been obtained with reassuring consistency, and have had a strong psychological effect upon the morale of the research and development staff. The highly successful irradiation sterili-
TABLE VII. PANEL SCORES ACCORDED TO BEEF LOIN IRRADIATED (Cobalt-60) TO 4.5 Mrad AT -196°C

<table>
<thead>
<tr>
<th>STORAGE PERIOD (WEEKS)</th>
<th>PANEL TYPE</th>
<th>MEAN SCORE (points)</th>
</tr>
</thead>
<tbody>
<tr>
<td>4</td>
<td>Technical</td>
<td>7.4</td>
</tr>
<tr>
<td></td>
<td>Consumer</td>
<td>7.8</td>
</tr>
<tr>
<td>8</td>
<td>Technical</td>
<td>7.0</td>
</tr>
<tr>
<td></td>
<td>Consumer</td>
<td>6.7</td>
</tr>
<tr>
<td>10</td>
<td>Technical</td>
<td>7.1</td>
</tr>
<tr>
<td></td>
<td>Luncheon</td>
<td>7.8</td>
</tr>
<tr>
<td>20</td>
<td>Luncheon</td>
<td>7.3</td>
</tr>
</tbody>
</table>

a) Summary of the mean hedonic scores accorded to various samples of beef loin during the early months of 1965.
b) Stored at 70°F following irradiation.
c) Consumer panel 36-40 persons; technical panel 6-8 persons having two years' experience; luncheon appraisals 12-15 persons consuming food as a component of a complete meal.
d) Hedonic 9-point scale: 9 = Like extremely; 1 = Dislike extremely.

zation of such an "intractable food" as beef appears to ensure the technological success of the programme.

Flesh foods other than beef were irradiated during the past few months at temperatures far below these. Preliminary information only is available from such tests, but this appears to indicate general product improvement correlated strongly with low-temperature irradiation. Information drawn from early observations by C.K. Wadsworth and G.W. Shults [9] is summarized in Table VIII.

FOOD IRRADIATION FACILITY, UNITED STATES ARMY NATICK LABORATORIES

The Natick Food Irradiation Laboratory built in 1962 covers an area of 21,000 ft². One wing, shown in Fig. 1, contains facilities for raw-product storage, food preparation and quality control. The offices, conference room and taste-testing facilities adjoin.

The health physics and nuclear dosimetry laboratories are in the contiguous "controlled" area, some 9500 ft² in size. Here also are the cobalt-60 gamma source and the Varian electron linear accelerator, with its controls, conveyors and related apparatus, all appropriately shielded. The cobalt source and the linear accelerator are at present being extensively modified to improve operational performance.

The general configuration of the cobalt gamma cell is shown in Fig. 2. The cobalt source (Fig. 2, item 1), is retained in the inner pool of deionized water, except when in use; it is then elevated, as shown. The product to be irradiated is loaded into carriers, shown at point 5, and described in detail below. These are conveyed into an appropriate position between the two rows of cobalt "slugs" arranged in the equal and opposing plaques.
### TABLE VIII. EFFECT OF IRRADIATION TEMPERATURE ON FOOD PREFERENCE RATINGS ACCORDED TO PRODUCTS OF PORK AND CHICKEN a)

<table>
<thead>
<tr>
<th>TYPE</th>
<th>TEMPERATURE</th>
<th>PORK</th>
<th>CHICKEN</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>PART I</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Non-irradiated control</td>
<td>8.4</td>
<td>7.8</td>
<td></td>
</tr>
<tr>
<td>-50°F</td>
<td>7.1</td>
<td>6.5</td>
<td></td>
</tr>
<tr>
<td>4°F</td>
<td>6.1</td>
<td>5.8</td>
<td></td>
</tr>
<tr>
<td><strong>PART II</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Non-irradiated control</td>
<td>7.8 c)</td>
<td>7.4 c)</td>
<td></td>
</tr>
<tr>
<td>-196°F</td>
<td>6.8</td>
<td>6.4</td>
<td></td>
</tr>
<tr>
<td>-140°F</td>
<td>6.8</td>
<td>6.5</td>
<td></td>
</tr>
<tr>
<td>-80°F</td>
<td>6.6</td>
<td>6.5</td>
<td></td>
</tr>
<tr>
<td>-50°F</td>
<td>6.2 d)</td>
<td>6.0</td>
<td></td>
</tr>
</tbody>
</table>

a) Data after Wadsworth and Shults [9].
b) Temperature during irradiation to 4.5 Mrad in NLABS cobalt-60 source.
c) Significantly different from irradiated sample at 5% level.
d) Significantly different from other irradiated samples at 5% level.

Shown in Fig. 3. Each plaque measures 52 in. X 80 in. and contains 196 "slugs" 12 in. long by 1 in. diam.

Present "slugs" are being replaced by 400 new cobalt strips, designed by Brookhaven National Laboratory. The strips, to be arranged into modules 1 strip high and 11 strips wide are each 13 in. high, 0.8 in. wide and 0.15 in. thick. The specific activity of these will be about 60 Ci/g. The present source configuration will remain essentially unchanged. An advantage of the new strips will be to reduce self-absorption from the present level of approximately 30% to the order of 5%; the heating of both plaques and products will be significantly reduced. The total activity of the refurbished cobalt source will be of the magnitude of 1.4 million Ci.

Attention is directed to the details of the food product carrier shown in Fig. 4. Notable is the pressurized quick coupling device for supplying liquid nitrogen, and the Dewar type, stainless-steel compartments in which the product to be irradiated is stowed. These open at the ends opposite the flow-regulating valves shown.

The dwell time of the product in the gamma source is about 75 min, with an approximate dose-rate of 1000 rad/s.

The electron accelerator and its appurtenances are located within the "controlled" area of the radiation laboratory complex, as illustrated in Fig. 1. Some details of the 18-kW, 24-MeV machine, the overhead conveyor, and a product carrier can be seen in Fig. 5.

The linear accelerator at Natick Laboratories is a four-section, S-Band (2856 Mc) electron accelerator with an energy range of 6 to 32 MeV, and a maximum power capability of 18 kW at 24 MeV. Electrons are produced in pulses of five microseconds' length at a maximum repetition rate of 360 pulses per second. They are accelerated through the four sections
FIG. 1. Food irradiation facilities (United States Army Food Radiation Laboratory, Natick, Mass.)

FIG. 2. Gammacell: 1 cobalt source (elev.); 2 Inner pool; 3 Cask pool; 4 Transfer tubes; 5 Overhead conveyor; 6 Trays; 7 Man trap. (United States Army Food Radiation Laboratory, Natick, Mass.)
in a travelling wave structure through interaction with the radio frequency energy obtained from four 5-MW RF klystron amplifiers. The dose-rate is of the order of $10^8 \text{ rad/s}$.

After leaving the accelerator, the accelerated electrons pass into a scanner which bends the electron beam through a $90^\circ$ angle and across the food past the scanner output at a constant rate, thereby achieving a uniform dose on a 16-in.-wide package. Important parameters of the electron beam are summarized in Table IX.

Several improvements to enhance machine operation and beam control are being installed at present. These include:

1. A newly-designed gun bombarder current supply to increase beam stability;
2. The addition of steering coils to each of the four accelerator sections, and quadripoles to each of the output drift tubes, to restrict beam loss on the accelerating tubes and thus to increase beam current;
3. The enhancement of reliability of the vacuum system through the addition of liquid nitrogen traps;
4. Increased beam triggering reliability through the use of a newly-designed trigger-generator;
5. Replacement of the linac high-voltage control circuitry by a newly-designed "package" to better stabilize pulse-to-pulse and long-term beam performance;
(6) A new electron gun to reduce arcing and to operate at lower temperatures;
(7) Replacement of the fixed coils in the pulse-forming network by adjustable slug tuning coils, to facilitate tuning of the energy spectrum for minimum peak width at half-maximum;
(8) A new beam-handling system added to the output elements to narrow the energy spectrum and to focus the beam more exactly. The new system includes a 45° bend magnet leading from the main beam line. It directs the beam into a set of adjustable slits having horizontal focus. Through these, the beam passes into a 45° left bending magnet and emerges through a set of quadripoles and a non-intercept beam current monitor.

An important aspect of the mission of the United States Army Food Irradiation Laboratory is to compare the uses of isotopes and machines in effecting the radiation preservation of foods. The advantages and disadvantages, costs, and product quality, etc., are to be studied.

A number of authors, among them Brasch and Huber [10, 11] have emphasized the importance of high dose-rates in upgrading product quality. This is believed to be accomplished through the prevention of undesirable side reactions - between substrates and free radicals, or between species of free radicals. Taking advantage of such concepts, arrangements are being made to irradiate flesh foods under cryogenic conditions and under
ambient conditions to ascertain the relative merits of these two approaches to improved product quality and costs.

The Varian Linear Accelerator will be used in such studies, utilizing the present scanned beam linear conveyor method in the processing of flexibly packaged food products. For the irradiation of canned products, however, a can rotating device will also be used, to ensure an even dose distribution throughout the mass, or at least to minimize dose differences.

In addition to an improvement in the sensory characteristics of meat items irradiated at low temperatures, certain nutritive qualities seem to be protected also. As an example, Wilson [12] has shown protection of thiamine in the frozen state. At -79°C, he reports essentially no destruction of it at 1.0 Mrad irradiation.

MICROBIOLOGICAL CONSIDERATIONS

Low temperatures appear to protect not only the gustatory attributes of meats undergoing irradiation, and to afford some protection to vitamins, as noted, but low temperatures also appear to afford protection to the spores of microorganisms of public health importance with which such foods are experimentally inoculated. Examples of this effect are drawn from in-house studies, first reported approximately one year ago [13, 14].
TABLE IX. BEAM PARAMETERS OF NATICK LABORATORIES LINAC

<table>
<thead>
<tr>
<th>ITEM</th>
<th>DATUM S-Band</th>
</tr>
</thead>
<tbody>
<tr>
<td>Microwave frequency (MHz)</td>
<td>2856</td>
</tr>
<tr>
<td>Number of accelerator waveguides</td>
<td>4</td>
</tr>
<tr>
<td>Klystrons (1 per waveguide):</td>
<td></td>
</tr>
<tr>
<td>Maximum peak r.f. power (MW)</td>
<td>5</td>
</tr>
<tr>
<td>Maximum average r.f. power (kW)</td>
<td>10</td>
</tr>
<tr>
<td>Energy range (MeV)</td>
<td>3 to 32</td>
</tr>
<tr>
<td>Beam energy at maximum efficiency (MeV)</td>
<td>24</td>
</tr>
<tr>
<td>Peak beam current at maximum efficiency (mA)</td>
<td>375</td>
</tr>
<tr>
<td>Rated average power (kW)</td>
<td></td>
</tr>
<tr>
<td>At 2 MeV</td>
<td>.68</td>
</tr>
<tr>
<td>At 6 MeV</td>
<td>1.38</td>
</tr>
<tr>
<td>At 12 MeV</td>
<td>6.48</td>
</tr>
<tr>
<td>At 18 MeV</td>
<td>12.6</td>
</tr>
<tr>
<td>At 24 MeV</td>
<td>19.2</td>
</tr>
<tr>
<td>Maximum peak beam power (kW)</td>
<td>18</td>
</tr>
<tr>
<td>Maximum peak beam current (mA)</td>
<td>375</td>
</tr>
<tr>
<td>Normal operation duty factor</td>
<td>556</td>
</tr>
<tr>
<td>Beam pulse lengths (μsec)</td>
<td>0.5 to 5</td>
</tr>
<tr>
<td>Pulse repetition rates per second:</td>
<td></td>
</tr>
<tr>
<td>At 0.5 to 8 μsec pulse-length</td>
<td>7.5, 15, 30</td>
</tr>
<tr>
<td></td>
<td>60, 120, 180, 360</td>
</tr>
<tr>
<td>Energy spectrum</td>
<td>2.5% at half-current points for 20 MeV</td>
</tr>
<tr>
<td>Spot size</td>
<td>½ cm diam.</td>
</tr>
</tbody>
</table>

In the first set of studies, large populations of spores of the radiation-resistant C. botulinum strain 33A were grown following the methods of Anellis and Koch, to be irradiated after inoculation into ground beef or Sorensen's phosphate buffer (pH 7).

Irradiation was carried out in the gamma source of the Cook Electric Company at Morton Grove, Ill. Samples were irradiated in tin cans or in pyrex tubes at temperatures ranging from 0°C ± 1.5°C down to -194°C ± 2.0°C. A majority of the tests compared lots irradiated at 0°C, -18°C, and -196°C. Rapid freezing of spores at -196°C was in itself detrimental to viability, but at 0°C, or -18°C, such concurrent effects were not noted. A total of 320 cans of inoculated ground beef (5 × 10⁴ spores/can) were used, 10 at each temperature and at each irradiation level.

The authors reported that approximately 0.9 Mrad more irradiation dose was required to inactivate the spores of this strain at -196°C than
Cans irradiated at the lower temperature showed partial spoilage at 3.6 Mrad, but none at 3.9 Mrad. At 0°C the corresponding spoilage/no spoilage values were 2.7 and 3.0 Mrad respectively. D10 values were lower in phosphate buffer than in ground beef.

Grecz, in a separate report [14], indicated that, to achieve a comparable degree of destruction of C. botulinum, 33A at -196°C and at 0°C, it would be necessary to add 0.9 Mrad to the dose required at the higher temperature. He said, "The method of straight addition of dose difference appears to be the most reasonable one". Accordingly, if a dose of 4.5 Mrad is required at 0°C, then the equivalent kill at -196°C would require 5.4 - 5.5 Mrad. There is substantial reason for differing with this point of view; data supporting an opposing conclusion will be published.

The behaviour of strains in contrasting menstrua is highly variable. Accordingly, at the present state of knowledge, there is no substitute for tedious pragmatic approaches to an understanding of such variable behaviour.

To generate information requisite to the filing of FDA petitions, and to provide basic processing information essential to the early designing of an industry-government pilot plant for processing radiation-sterilized meats, sizeable inoculated pack studies are being undertaken, beginning immediately.

Five foods of military importance are involved in these undertakings: beef, chicken, ham, pork and shrimp. Ten strains of C. botulinum A and B types, chosen from 102 strains, have been screened at three low temperatures and over a range of irradiation doses, to identify the two which appear to be most resistant to destruction in each of these foods.

An estimated 10,000 to 20,000 cans of food products will be involved in these studies: Five foods x 2 strains of C. botulinum x 2 temperatures x 5 radiation dose levels x 200 cans per condition = 20,000 cans. If one temperature only is used, then there will be 10,000 cans. Information to be acquired from each will include spoilage data (swells), subculturing and toxin testing from all "suspicious" cans.

FOOD ITEMS CLEARED, CLEARING, AND TO BE SUBMITTED TO THE FDA

A significant measure of progress in the United States National Food Irradiation programme is the number and array of items which have received approval from the appropriate regulatory agencies for manufacture, distribution and consumption.

Josephson, of Natick Laboratories, in testimony given to Congress on June 9 and 10, 1965 [15], summarized the status of clearances by the Food and Drug Administration of food items submitted by sundry petitioners. Tables X and XI are succinct summaries, and are reproductions of Tables appearing in reference [15], appendices 2a and 2b, respectively.

Table XII summarizes the target dates for filing additional petitions with FDA by the United States Army Natick Laboratories.

For the years of 1968, 1969 and 1970, the following tentative objectives have been identified: for 1968, petitions will be submitted optimistically for the "clearance" of corned beef, pork sausage, codfish cakes and radiation-pasteurized chicken. During 1969, current objectives call
<table>
<thead>
<tr>
<th>Product and purpose of irradiation</th>
<th>Radiation source</th>
<th>Dose (permissible range) (Mrad)</th>
<th>Petitioner</th>
<th>Date of FDA approval</th>
<th>FAP No.</th>
<th>21 CFR reference</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Bacon: Purpose, sterilization</strong></td>
<td>Cobalt-60</td>
<td>4.5 to 5.6</td>
<td>Army</td>
<td>8 Feb. 1963</td>
<td>890</td>
<td>121.3002</td>
</tr>
<tr>
<td></td>
<td>Electron beam (5 MeV)</td>
<td>4.5 to 5.6</td>
<td>General Electric Co.</td>
<td>23 Aug. 1963</td>
<td>1139</td>
<td>121.3004</td>
</tr>
<tr>
<td></td>
<td>Caesium-137</td>
<td>4.5 to 5.6</td>
<td>AEC c)</td>
<td>30 Jan. 1964</td>
<td>1226</td>
<td>121.3002</td>
</tr>
<tr>
<td></td>
<td>X-rays from electron beam (5 MeV)</td>
<td>4.5 to 5.6</td>
<td>Radiation Dynamics, Inc. c)</td>
<td>15 Dec. 1964</td>
<td>4M 1433</td>
<td>121.3005</td>
</tr>
<tr>
<td><strong>Wheat and wheat products:</strong></td>
<td>Electron beam (10 MeV)</td>
<td>4.5 to 5.6</td>
<td>Army</td>
<td>15 Apr. 1965</td>
<td>1205</td>
<td>121.3004</td>
</tr>
<tr>
<td>Purpose, insect disinfestation.</td>
<td>Cobalt-60</td>
<td>0.02 to 0.05</td>
<td>Private citizens c, d)</td>
<td>21 Aug. 1963</td>
<td>941</td>
<td>121.3003</td>
</tr>
<tr>
<td></td>
<td>Caesium-137</td>
<td>0.02 to 0.05</td>
<td>AEC c)</td>
<td>2 Oct. 1964</td>
<td>1305</td>
<td>121.3003</td>
</tr>
<tr>
<td><strong>White potatoes:</strong></td>
<td>Cobalt-60</td>
<td>0.005 to 0.010</td>
<td>Army</td>
<td>30 June 1964</td>
<td>1302</td>
<td>121.3003</td>
</tr>
<tr>
<td>Purpose, sprout inhibition</td>
<td>Caesium-137</td>
<td>0.005 to 0.010</td>
<td>AEC c)</td>
<td>2 Oct. 1964</td>
<td>1302</td>
<td>121.3003</td>
</tr>
<tr>
<td><strong>Packaging materials:</strong></td>
<td>Gamma emitters</td>
<td>1.0 maximum</td>
<td>AEC</td>
<td>10 Aug. 1964</td>
<td>1297</td>
<td>121.2543</td>
</tr>
<tr>
<td>Purpose, food contactants for use in radiation preservation of prepackaged foods</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Vegetable parchment paper:</td>
<td>Cobalt-60</td>
<td>6.0 maximum</td>
<td>Army</td>
<td>8 Mar. 1985</td>
<td>SM 1622</td>
<td>121.2543</td>
</tr>
<tr>
<td>Purpose, food contactant for use in radiation preservation of prepackaged foods</td>
<td>Caesium-137</td>
<td>do</td>
<td>do</td>
<td>8 Mar. 1965</td>
<td>SM 1622</td>
<td>121.3002</td>
</tr>
<tr>
<td></td>
<td>X-rays from electron beam (5 MeV)</td>
<td>do</td>
<td>do</td>
<td>8 Mar. 1965</td>
<td>SM 1622</td>
<td>121.3005</td>
</tr>
</tbody>
</table>

a) As of April 1965  
c) The Army contributed the major proportion of the data submitted by the petitioner.  
d) Dr. L.E. Brownell, University of Michigan; Mr. T. Horne, Curtiss-Wright Co.; Mr. W.J. Kretlow, University of Michigan.  
e) 9 classes of materials: nitrocellulose-coated cellophanes; glassine papers; wax-covered paperboards; polypropylene films; ethylene-alkene-1 copolymer films; polyethylene films; polystyrene films; rubber hydrochloride films; vinlylidene chloride-vinyl chloride copolymer films.  

Note.- MeV: Million electron volts; FAP No.: FDA food additive petition number; CFR: Code of Federal Regulations.
TABLE XI. PETITIONS PENDING BEFORE THE UNITED STATES FOOD AND DRUG ADMINISTRATION a, b)

<table>
<thead>
<tr>
<th>Product and purpose of irradiation</th>
<th>Radiation source</th>
<th>Dose (recommended range) (Mrad)</th>
<th>Petitioner</th>
<th>Date of notice of FDA filing</th>
<th>FAP No.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Oranges: Purpose, inhibition of surface and subsurface microorganisms</td>
<td>Cobalt-60</td>
<td>0.075 to 0.200</td>
<td>Joint Army/AEC</td>
<td>11 Dec. 1963</td>
<td>1233</td>
</tr>
<tr>
<td></td>
<td>Caesium-137</td>
<td>0.075 to 0.200</td>
<td>ditto</td>
<td>ditto</td>
<td>1233</td>
</tr>
<tr>
<td>Wheat and wheat products: Purpose, insect disinfection</td>
<td>Electron beam (5 MeV)</td>
<td>0.02 to 0.05</td>
<td>High Voltage Engineering Corp. c</td>
<td>12 Dec. 1963</td>
<td>1276</td>
</tr>
<tr>
<td>White potatoes: Purpose, sprout inhibition</td>
<td>Cobalt-60</td>
<td>0.005 to 0.015</td>
<td>Army</td>
<td>25 Jan. 1965</td>
<td>SM 1644</td>
</tr>
<tr>
<td></td>
<td>Caesium-137</td>
<td>0.005 to 0.015</td>
<td>ditto</td>
<td>ditto</td>
<td>SM 1644</td>
</tr>
<tr>
<td>Packaging materials d: Purpose, food contactants for use in radiation preservation of pre-packaged foods</td>
<td>Cobalt-60</td>
<td>6.0 maximum</td>
<td>ditto</td>
<td>8 Dec. 1964 e</td>
<td>5B 1645</td>
</tr>
<tr>
<td></td>
<td>Caesium-137</td>
<td>6.0 maximum</td>
<td>ditto</td>
<td>ditto e</td>
<td>5B 1645</td>
</tr>
</tbody>
</table>

a) As of April 1965
c) The Army contributed the major proportion of the data submitted by the petitioner.
d) 6 classes of plastic materials: polyolefins; polyvinylidene chloride copolymers; polyvinyl chlorides; polystyrenes; polyesters; polyamides.
e) The date of petition submission.

Note.—MeV: Million electron volts; FAP No.: FDA food additive petition number.
TABLE XII. TARGET DATES FOR FILING PETITIONS WITH FDA

<table>
<thead>
<tr>
<th>FOOD</th>
<th>DESCRIPTION</th>
<th>IRRADIATION CONDITIONS</th>
<th>TARGET DATE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chicken</td>
<td>Chilled and frozen (ready to cook)</td>
<td>-40 to -80 °C</td>
<td>1967</td>
</tr>
<tr>
<td>Ham</td>
<td>Cooked, chilled or frozen, cured, smoked</td>
<td>Ambient or -40 to -80 °C</td>
<td>1966 or 1967</td>
</tr>
<tr>
<td>Pork</td>
<td>Fresh, chilled or frozen</td>
<td>Ambient or -40 to -80 °C</td>
<td>1966 or 1967</td>
</tr>
<tr>
<td>Shrimp</td>
<td>Raw and cooked Chilled and frozen</td>
<td>-80 °C</td>
<td>1967</td>
</tr>
<tr>
<td>Beef</td>
<td>Fresh, chilled or frozen</td>
<td>-80 to -185 °C</td>
<td>1967</td>
</tr>
</tbody>
</table>

a) Pertaining to additional meat, poultry and sea foods. Information supplied by E. Wierbicki, Food Division, Natick Laboratories.

TABLE XIII. SUMMARY OF PLANNED ARMY FOOD IRRADIATION STERILIZATION RESEARCH (Fiscal years 1967 through 1971)

<table>
<thead>
<tr>
<th>TASK</th>
</tr>
</thead>
<tbody>
<tr>
<td>Technical feasibility of meats, poultry, and marine products a)</td>
</tr>
<tr>
<td>Flexible packaging</td>
</tr>
<tr>
<td>Adaptation to military needs</td>
</tr>
<tr>
<td>Basic food irradiation research</td>
</tr>
<tr>
<td>Radiation services</td>
</tr>
<tr>
<td>Cobalt replenishment</td>
</tr>
</tbody>
</table>

a) To the point of satisfactory petition submission to the FDA.

for submitting petitions for turkey, frankfurters, barbecued beef, chicken and pork. In the year 1970, as now visualized, petitions to "clear" luncheon meats, lamb, salmon cakes, baked fish, duck and veal will be submitted.

All items listed above will be processed, using gamma irradiation of cobalt-60. Irradiation, with rare exception, will be at temperatures below 0°C. It is hoped that concurrent investigations will clear the way for "machine-irradiated" products of categories generally the same as those listed above.

The use of the linac at Natick Laboratories has been quite limited to date; priority has been given to the gamma sterilization of meat commodities. However, work with the accelerator will increase in future. It is anticipated that accelerator time will be divided as follows: induced acti-
vity 10%, pulsed radiolysis 20%, food irradiation 70%, with time divided between improved dosimetric studies and high dose-rate investigations of the effects on microbiological and food samples.

PROGRAMMES AND LEVEL OF EFFORT FOR THE PERIOD 1967 TO 1971

The direction of exploration and development to be pursued during the next 5-yr period is summarized in Table XIII. (See also reference [15] Appendix 7).

Two of the tasks listed in Table XIII provide essential services and materials, viz., radiation services and cobalt replenishment. This leaves four primary areas for development:

1. Technical feasibility of meats, poultry, and marine products

Petitions to the FDA and to the Meat and Poultry Inspection Divisions of the United States Department of Agriculture must be supported by a large amount of information, which is to document the safety and wholesomeness of processes and products. Efforts to gain this information are to be carried out under this task.

2. Flexible packaging

Light-weight packaging has obvious advantages. New compositions of matter, new combinations of film, new package configurations, new convenience characteristics, and more durability are objects to be realized in efforts to be executed under this task.

3. Adaptation to military needs

Civilian requirements and military requirements of foods are frequently substantially different. Products to withstand the duress of military conditions and to fit into military feeding systems will emerge from this category.

4. Basic food irradiation research

To be included are: areas of radiation physics and dosimetry; exploration of pathways and products leading to exceptionally excellent commodities; development of the most economic and practical means to sterilize selected items; the means to enhance positive quality attributes; basic microbiology; the biochemistry of enzymes and pigments; flavour entities, reactions and pathways; textural changes and textural ameliorating treatments. Enhancement of the quality and improvement in the economics of irradiated food products will be obviously in proportion to the gain in basic information in the areas noted.

This total effort will culminate in the early construction of one or more product pilot plants, and in time will ensure the commercialization of food-irradiation processes. The time has been reached, therefore, to form a lasting working relationship between industry and government to
aid in exploitation of the obvious and important potentials of these new processes.

Accordingly, formal efforts to this end were initiated during September 1965 in Washington, D.C., on the recommendation of high-ranking officials of the United States Army and the Atomic Energy Commission. A meeting of more than 40 companies and trade associations, representing a cross-section of the meat, poultry and radiation equipment industries, was convened to consider the best means of developing industry-government cooperation in establishing a pilot-plant meat irradiator. The annual throughput of the plant is to be not less than one million pounds of product.

More than 65 organizations expressed interest in this effort; a majority of these have been visited by an "Interagency Task Force" which includes Commerce, Army and AEC representatives.

Obvious benefits to be derived from such an operation will include:
a) an orderly introduction of selected irradiated meats into military subsistence systems; b) an opportunity to derive realistic performance and fiscal data for use in subsequent commercial projections; and c) the initiation of modest consumer-market testing and development.

The Atomic Energy Commission will issue formal requests for industry proposals within the next few weeks. There is evidence of a high level of lively response by industry. The Army and United States National Food Irradiation programme can be seen to be showing substantial and reassuring progress.

REFERENCES


1 Convened by Assistant Secretary of Commerce, Alexander B. Trowbridge.
M. INGRAM: The very encouraging acceptability data you have shown were obtained, I believe, with doses of 4.5 Mrad applied at -196°C. The work reported by Dr. Grecz suggests, however, that 4.5 Mrad would not, if applied at this temperature, constitute a "sterilizing dose" in the sense usually understood. May I ask what dose you propose to use in the large-scale industrial plant now envisaged for irradiating food in the frozen state?

F. MEHRLICH: As I pointed out, we are engaged in a very extensive inoculated pack study and it is this work that will enable us to determine the appropriate dose levels. It will take several months, however, before we can accumulate enough information to answer your question satisfactorily. We expect that dose-rate studies with our improved accelerator will also make an important contribution to establishing the parameters that will eventually be used in this work.

E. JOSEPHSON: You may recall the comments I made earlier on Dr. Grecz's paper (SM-73/67, these Proceedings) in connection with the radiation dose required to produce shelf-stable meat, poultry and fish when irradiation is carried out at low temperatures. We have found, in fact, that for all the products tested, except beef, our acceptance data are in the same range regardless of whether the irradiation is carried out at -30°C or at -196°C.

R. S. KAHAN: Were the stored meat products merely irradiated or were they also subjected to heat treatment to stop enzyme activity?

F. MEHRLICH: They were also treated for enzyme activity.
SOURCES D'IRRADIATION INSTALLÉES EN FRANCE POUR L'IRRADIATION DES ALIMENTS

P. LEVEQUE
CENTRE D’ÉTUDES NUCLEAIRES DE SACLAY, FRANCE

Abstract — Résumé — Аннотация — Resumen

IRRADIATION INSTALLATIONS IN FRANCE FOR FOOD IRRADIATION. The Centre d'études nucléaires de Saclay has a source whose present activity is 6000 Ci. This can be used either for homogeneous irradiation in a cylindrical space of variable dimensions or for panoramic irradiation in a casemate.

At the Centre d'études nucléaires de Cadarache two sources of 2000 Ci and 12 000 Ci are in operation. One specific use of the latter is to irradiate large quantities of grain with homogeneous doses at high rates (10⁶ rad/h).

At Dagneux (near Lyons) the Centre Lyonnais d'Applications Atomiques has an industrial-type plant which can contain up to 2 million curies of cobalt. The source at present has a strength of 80 000 Ci. This installation is of the swimming-pool type, with a conveyor permitting continuous processing of the commodities for treatment. The sources are of variable geometry, so that irradiation can be carried out on a smaller scale.

Provisionally based at Saclay, IRMA, owned by the Société Conservatome Industrie, is a mobile irradiation source containing 175 000 Ci of ¹³⁷Cs. It will allow irradiation of commodities on the production site.

Sources d’irradiation installées en France pour l’irradiation des aliments. Au Centre d'études nucléaires de Saclay, il existe une source dont l'activité actuelle est de 6000 Ci. Elle permet d'effectuer, soit des irradiations homogènes dans un volume cylindrique de dimensions variables, soit des irradiations panoramiques en casemate.

Au Centre d'études nucléaires de Cadarache, deux sources de 2000 et 12 000 Ci sont en service. Cette dernière permet, en particulier, d'irradier à des doses homogènes et avec des intensités élevées (10⁶ rad/h) de grandes quantités de grains.

A Dagneux (près de Lyon), le Centre lyonnais d'applications atomiques dispose d'une installation à caractère industriel pouvant contenir jusqu'à 2 millions de curies de cobalt. Actuellement, la source est de 80 000 Ci. C'est une installation du type piscine. Un convoyeur permet de traiter des produits en continu. Les sources sont à géométrie variable, ce qui permet d'effectuer des irradiations à plus petite échelle.

Provisoirement basé à Saclay, IRMA, appartenant à la Société Conservatome Industrie, est un irradiateur mobile contenant 175 000 Ci de ¹³⁷Cs. Il permettra d'effectuer des irradiations de produits sur leur lieu de production.

УСТАНОВКИ ДЛЯ ОБЛУЧЕНИЯ ПИЩЕВЫХ ПРОДУКТОВ ВО ФРАНЦИИ. В Научно-исследовательском ядерном центре Сакле имеется источник активностью 6000 кюри. Он позволяет осуществлять как однородные облучения в цилиндрическом объеме различных размеров или объемные облучения в специальном помещении.

В Научно-исследовательском ядерном центре Кадараш используются два источника 2000 и 12 000 кюри. Второй источник позволяет, в частности, облучать однородными дозами и с высокой интенсивностью (10⁶ рад/час) большое количество зерна.

В Данже (около Лиона) Лионский атомный центр располагает установкой промышленного типа, которая может работать с кобальтовым источником до 2 млн. кюри. В настоящее время активность источника составляет 80 000 кюри. Эта установка бассейнового типа. Транспортер позволяет вести постоянную обработку продуктов. Источники имеют различную геометрию, что позволяет облучать небольшие по размеру образцы.

Временно расположенная в Сакле ИРМА (IRMA), принадлежащая акционерному обществу "Консерватом индустри", является транспортабельным облучательным устройством, имею-
FUENTES DE IRRADIACION INSTALADAS EN FRANCIA PARA EL TRATAMIENTO DE ALIMENTOS. El Centre d’Études Nucléaires de Saclay posee una fuente cuya actividad actual es de 6000 Ci. Permite efectuar irradiaciones homogéneas en un volumen cilíndrico de dimensiones variables o irradiaciones panorámicas en casamata.

En el Centre d’Études Nucléaires de Cadarache hay dos fuentes de 2000 y 12 000 Ci en servicio. Esta última permite, en particular, irradiar grandes cantidades de grano con dosis homogéneas e intensidades elevadas (10⁶ rad/h).

En Dagneux (cerca de Lyon), el Centre Lyonnais d’Applications Atomiques dispone de una instalación de tipo industrial que puede contener hasta 2 millones de Ci de cobalto. Actualmente, la actividad de la fuente es de 80 000 Ci. Se trata de una instalación tipo piscina. Una cinta transportadora permite tratar los productos en régimen continuo. Las fuentes son de geometría variable, lo que permite efectuar irradiaciones en escala reducida.

El dispositivo IRMA, instalado provisionalmente en Saclay y perteneciente a la Sociedad Conservatome Industrie, es un irradiador móvil que contiene 175 000 Ci de 131Cs. Permitirá irradiar artículos alimenticios en el lugar de producción.

Il n'y a pas à proprement parler, en France, d'installations d'irradiation qui soient employées à plein temps pour l'irradiation des aliments. Les installations qui seront décrites ont été employées ou sont encore employées à temps partiel pour cette activité.

1. SOURCES DE LABORATOIRE [1]

Ce fut le premier équipement réalisé. Sa conception est assez semblable à celle de la Gammacell du Canada, mais la manipulation du piston est manuelle. Elles sont généralement chargées avec 1000 Ci de 60Co. Réalisées à plusieurs exemplaires elles permettent, avec un investissement modeste, des expériences à l'échelle du laboratoire.

2. CENTRE LYONNAIS D'APPLICATIONS ATOMIQUES

Celui-ci a déjà été décrit [1, 2] en détail. D'une capacité de 10⁶ Ci, il est équipé actuellement de 80 000 Ci et passera très prochainement à 110 000 Ci. Il est maintenant équipé d'un convoyeur à vitesses différentes pour le labyrinthe et la cellule d'irradiation ce qui permet de réduire au minimum l'immobilisation des matériaux à irradier. On peut faire varier facilement, par manipulation sous eau, la géométrie des sources, ce qui confère à cette installation de type semi-industriel une grande souplesse d'utilisation.

3. IRRADIATEUR MOBILE IRMA [3]

C'est la première installation importante équipé d'une source de césium. L'emploi de ce radioélément permet l'utilisation d'une source de 450 000 Ci pour un poids total de 35 t. Actuellement l'appareil est chargé de 175 000 Ci. La source a son propre conteneur. Au moment de
l'utilisation, celui-ci vient se fixer au-dessous de la chambre d'irradiation. Un système de vis vient se fixer sur le cadre porte-source, et celle-ci est montée dans la chambre d'irradiation. Le convoyeur est du type mécanique entraînant, par des cliquets, des conteneurs en aluminium (section 30×30 cm, hauteur 60 cm). Une des originalités de l'installation est le sas d'entrée et de sortie. C'est un barillet de plomb tournant à axe vertical, possédant quatre alvéoles. Par un demi-tour, on introduit un conteneur dans la chambre, et l'on en extrait un autre. La protection biologique est excellente pour un poids minimal. La vitesse du convoyeur détermine la dose reçue.

Il faut noter que ces deux dernières installations ont été financées par l'industrie privée. La Société Conservatome Industrie en assure l'exploitation.

4. INSTALLATION DU CENTRE D'ETUDES NUCLEAIRES DE CADARACHE - DEPARTEMENT DE BIOLOGIE

Le Service de radioagronomie dispose d'installations variées qui correspondent à ses besoins en matière de laboratoires, dispositifs d'irradiation et moyens de culture (serres, ferme).

La première tranche actuellement édifiée comporte un bâtiment laboratoire de 760 m² répartis sur deux plans, un hall de 400 m² destiné aux expérimentations à plus grande échelle, et, relié à ce hall, un ensemble d'irradiation gamma équipé en ⁶⁰Co (période 5,3 ans).

Cet ensemble comporte deux salles et deux cellules autonomes:

- Salle de 2000 Ci (diamètre 10 m, hauteur 3 m). Prévue pour irradier des plantes entières en cours de développement (radiogénétique), elle est éclairée et climatisée: l'éclairement est de 10 000 lx, la température est réglée à ± 1 degC entre 8 et 35°C, et l'humidité stabilisée à 60%. Le cobalt, contenu dans une boule, est véhiculé par air comprimé; le débit de dose va de 150 à 15 000 rad/h.

- Salle de 12 000 Ci (diamètre 1,20 m; hauteur 1,70 m) destinée aux études de radiopasteurisation. Les boules de cobalt, au nombre de six, y sont introduites selon une géométrie variable; le débit de dose s'échelonne entre 1000 et 3·10⁶ rad/h.

- Cellule de 2000 Ci où 40 bâtonnets de cobalt, disposés en couronne, permettent de traiter un volume de 1 litre avec un débit de dose de 70 000 rad/h, la dispersion étant inférieure à 7%.

- Cellule de 2 Ci, pour le traitement de petits échantillons (graines, boutures) sous faible débit de dose (350 rad/h).

5. SOURCE DE COBALT DU CENTRE D'ETUDES NUCLEAIRES DE SACLAY-DEPARTEMENT DE PHYSICO-CHIMIE

Cette source est composée de 10 bâtonnets de 1000 Ci, disposés sur une circonférence à diamètre variable (Ø = 4,9 et 15 cm). L'écartement des sources est commandé par téléphone depuis la salle de commande. Au repos, les sources sont escamotées dans un château de plomb de 12 t. La translation verticale des sources se fait par un vérin à commande hydraulique. L'ensemble est à l'intérieur d'une casemate de béton (épaisseur
1,50 m) de 5 × 5 × 2,5 m. L'accès de la casemate se fait par l'intermédiaire d'une porte en béton. Les irradiations peuvent être effectuées, soit à l'intérieur des sources, soit à l'extérieur. Ceci permet de disposer de flux allant de 1000 rad/h à 3 × 10^6 rad/h.

6. ACCELERATEUR CIRCE

La SRTI (Société de recherche et technique industrielle) met actuellement en service un accélérateur CIRCE à Corbeville près de Saclay.

La source de rayonnement β est un accélérateur linéaire dont la section est placée verticalement dans un blockhaus. Les essais sous rayonnement se font à l'intérieur de ce blockhaus, qui communique avec le hall où se trouve la salle de commande par une chicane. L'accélérateur linéaire d'électrons CIRCE 10, construit par la CSF (Compagnie générale de télégraphie sans fil) a les caractéristiques suivantes:

- Puissance: 10 kW
- Energie: de 4 à 9 MeV
- Durée des impulsions: 2,5 μs
- Fréquence de répétition des impulsions: réglable de 50 à 550 Hz
- Diamètre du faisceau: 30 mm
- Largeur de balayage du faisceau: réglable de 300 à 500 mm
- Fréquence de balayage: réglable entre 0,7 Hz et 6 Hz.

Les matériaux à irradier sont amenés du hall sous l'accélérateur par un convoyeur horizontal dont la vitesse peut varier de façon continue de 0,12 à 12 m/min. Les dimensions maximales des colis qui peuvent être traités sont 500 × 500 × 400 mm.

La France dispose ainsi de moyens très variés d'irradiation, qui lui ont permis de réaliser un programme important d'irradiation alimentaire.

REFERENCES

INTERNATIONAL PROJECT ON THE IRRADIATION OF FRUIT AND FRUIT JUICES

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Abstract — Résumé — Аннотация — Resumen

INTERNATIONAL PROJECT ON THE IRRADIATION OF FRUIT AND FRUIT JUICES. To extend the application of irradiation to food preservation in a more general way, and to obtain the best conditions for this new technique, more fundamental research is needed.

The main problem is to reduce the dose as much as possible. Reducing to the minimum the degradation due to radiation of the constituents of food assures organoleptic quality and wholesomeness and renders the product economic.

Fruit juice was selected as a model substance for fundamental studies for the following reasons: (a) The components are representative for most foods; (b) The components can be easily separated; (c) The microorganism spoiling the fruit juice is mainly yeast, on which extended research work has been done; and (d) The item has economic value.

The programme includes the following lines of research:

Fundamental research. This has dealt mainly with the radiosensitization of microorganisms, that is, yeast in the case of fruit juice and, to a certain extent, mould.

Technological studies. Based on the results of the basic research, studies on technological feasibility have been undertaken, including organoleptic and microbiological analysis of volatile and non-volatile substances. The results on apple juice are promising.

Wholesomeness tests. Animal feeding studies on rats, mice and pigs started with tests of the amount of apples and apple juice which can be tolerated by the animals. Tissue cultures have been cultivated for the biological screening of degradation products.

Irradiation facility. An irradiation plant of a new design for about 30 to 40 000 Ci and 10 000 Ci ⁶⁰Co is under construction.

PROJET INTERNATIONAL D’IRRADIATION DES FRUITS ET DES JUS DE FRUITS. Pour généraliser l’application des rayonnements à la conservation des produits alimentaires et utiliser cette nouvelle méthode dans les meilleures conditions, il est nécessaire de pousser davantage les recherches fondamentales.

Le problème principal consiste à réduire la dose le plus possible. La réduction au minimum de la radiodétérioration des composants des produits alimentaires assure la qualité organoleptique et la comestibilité et rend le traitement économique.

Les jus de fruits ont été choisis comme sujets des études fondamentales pour les raisons suivantes: a) leurs composants sont représentatifs de la plupart des produits alimentaires; b) leurs composants peuvent être facilement séparés; c) les micro-organismes qui détériorent les jus de fruits sont principalement les levures, lesquelles ont fait l’objet d’études très poussées; d) le produit a une valeur économique.

Le programme comporte des recherches dans les domaines suivants:

Recherches fondamentales. Ces recherches ont porté principalement sur la radiosensibilisation des micro-organismes, c’est-à-dire, dans le cas des jus de fruits, sur les levures et, dans une certaine mesure, les moisissures.

Etudes technologiques. Ces études s’appuient sur les résultats des recherches fondamentales; elles concernent les possibilités de réalisation technique et comprennent également des études organoleptiques et microbiologiques, et l’analyse des substances volatiles et non volatiles. Les résultats obtenus avec le jus de pommes sont prometteurs.

Essais de comestibilité. Les études d’alimentation sur des rats, des souris et des porcs ont commencé par des essais effectués avec les quantités de pommes et de jus de pommes que ces animaux peuvent absorber. L’auteur a procédé à des cultures de tissus en vue d’une séparation biologique des produits de la détérioration.

Installations d’irradiation. Deux installations d’irradiation au ⁶⁰Co d’un type nouveau, l’une de 30 à 40 000 Ci et l’autre de 10 000 Ci, sont en cours de construction.
МЕЖДУНАРОДНЫЙ СИМПОЗИУМ ПО ВОПРОСАМ ОБЛУЧЕНИЯ ПИЩЕВЫХ ПРОДУКТОВ. В целях расширения применения облучения для предохранения от порчи пищевых продуктов более обычным способом и для создания благоприятных условий этим новым методам необходимо проведение фундаментальных исследований.

Главной проблемой является сокращение дозы настолько, насколько это возможно. Сокращение потерь составляющих элементами пищевых продуктов своих свойств в результате облучения означает органолептическое качество, сохранение вкусовых и питательных качеств и экономическую технологию.

Фруктовый сок был выбран в качестве модели вещества для фундаментальных исследований в связи со следующим: а) его составные элементы представлены в большинстве пищевых продуктов; б) его составные элементы могут быть легко отделены; в) микроорганизмы, вызывающие порчу фруктовых соков, являются дрожжами, которые были подвергнуты обширным исследованиям; г) этот вопрос представляет ценность с экономической точки зрения. Программа должна включать три аспекта исследований:

Основные исследования. Они посвящены в основном вопросам чувствительности микроорганизмов к радиоактивным лучам; в случае с фруктовыми соками имеются в виду дрожжи и определенный вид распространенной плесени.

Исследования вопросов технологии. На основе результатов теоретических исследований были проведены исследования относительно практической осуществимости с точки зрения технологии, включая вопросы органолептики и микробиологии, анализа летучих и нелетучих веществ. Результаты, касающиеся яблочного сока, являются многообещающими.

Испытания, касающиеся вкусовых и питательных качеств. Исследования вопросов кормления животных проводились на крысах, мышах и свиньях; они были начаты с определения количества яблок и яблочного сока, которые могут съесть животные.

Были культивированы культуры тканей для биологической защиты продуктов деградации. Оборудование для облучения. Установка по облучению новой конструкции мощностью около 30 000 — 40 000 кюри и установка мощностью 10 000 кюри с использованием кобальта-60 находятся в стадии строительства.

PROYECTO INTERNACIONAL DE IRRADIACION DE FRUTAS Y ZUMOS DE FRUTA. Para poder generalizar el empleo de las radiaciones en lo que se refiere a la conservación de los alimentos y para poder aplicar esta nueva técnica en condiciones óptimas es preciso llevar a cabo un mayor número de investigaciones fundamentales.

El problema principal consiste en reducir la dosis en la medida de lo posible. Si la radiodegradación de los componentes de los alimentos es mínima, éstos conservan sus buenas propiedades organolépticas y su comestibilidad, y el procedimiento resulta más económico.

Se decidió emplear zumos de fruta como sustancia tipo para los estudios fundamentales por las siguientes razones: a) sus componentes constituyen una muestra representativa de la mayor parte de los productos alimenticios; b) dichos componentes son fácilmente separables; c) los microorganismos que estropean los zumos de fruta son principalmente levaduras, sobre las que se han efectuado importantes trabajos de investigación; d) son productos que poseen valor económico.

El programa comprende tres clases de investigaciones:

Investigaciones fundamentales. Se refieren, en particular, a la radiointoxicación de microorganismos, es decir, en el caso de los zumos de fruta, de levaduras, y, hasta cierto punto, de molos.

Estudios tecnológicos. Sobre la base de los resultados de las investigaciones fundamentales se han emprendido estudios de viabilidad tecnológica relativos a los aspectos organolépticos y microbiológicos, así como análisis de sustancias volátiles y no volátiles. Los resultados obtenidos con el zumo de manzana son prometedores.

Pruebas de comestibilidad. Se están estudiando los efectos de esos productos en ratas, ratones y cerdos; se ha comenzado por determinar las cantidades de manzanas y zumo de manzana que estos animales pueden tolerar. Se han preparado cultivos de tejidos para separar por métodos biológicos los productos de degradación.

Instalación de irradiación. Se está construyendo una instalación de irradiación de nuevo tipo a base de cobalto-60, con capacidades aproximadas de 10 000 Ci y de 30 000 a 40 000 Ci.

INTRODUCTION

In 1960 a study group was set up by the European Nuclear Energy Organisation (ENEA) of the Organisation for European Co-operation and Development (OECD) to examine the technical and scientific problems
involved in food irradiation. These studies indicated that the widespread application of the radiation preservation of food can only be considered in the future when more is known about the fundamental phenomena of radiobiology and radiobiochemistry. The main hindrance to the general application of this new technique is the radioresistance of the microorganisms responsible for deterioration in food. The dose necessary to inhibit their multiplication and metabolic activity normally changes the chemical constitution of the foodstuff in such a way that undesired organoleptic qualities occur. Furthermore, the wholesomeness of the food could be influenced by these changes. Finally, the economic aspects related to the dose applied must be considered. The main problem in food irradiation is therefore research into possibilities of the radiosensitization of microorganisms.

Research work should be done on a model foodstuff which offers the following qualities:
(a) It should be easily divisible into its single components;
(b) These components should be representative for most foodstuffs;
(c) The microorganisms responsible for the deterioration should be of a well-known type;
(d) The model substance should have some economic value per se.

With these points in mind, the Austrian Delegate in this study group recommended fruit juice as a "model substance" and offered the facilities and equipment of the Institute of Biology and Agriculture at the Reactor Centre in Seibersdorf, Austria, for joint work. The components of this food cover the aspects of the first point and partly the second one; yeast is a well known microorganism. As to the last point, the consumption of fruit juice in the United States of America is valued at more than one billion dollars per annum.

In collaboration with the experts of the study group, and of the ENEA, scientists of the Austrian Institute formulated the general outlines of an international programme under the following headings:
1. Radiosensitivity of microorganisms;
2. Technological feasibility studies;
3. Wholesomeness studies.

The Member States and associated Member States of the OECD showed interest in this programme as also did the International Atomic Energy Agency (IAEA) in Vienna. On 16 September 1964 an agreement was signed by the ENEA, representing the OECD, the IAEA and the Österreichische Studiengesellschaft für Atomenergie responsible for the Reactor Centre in Seibersdorf, for the carrying out of an international project on the irradiation of fruit and fruit juices within the framework of the proposed programme. On 1 January 1965 work began on the project in Seibersdorf.

To date, the following countries have stated their willingness to participate in the project and many of them have already seconded scientists, namely, Canada, Denmark, the Federal Republic of Germany, France, Italy, Japan, Spain, Switzerland and the United States of America. In addition, Spain and Switzerland are carrying out special research work for the project in their own laboratories and Italy intends to do so. The Federal Republic of Germany is also giving additional financial support.
STATUS OF RESEARCH WORK

1. Radiosensitivity of microorganisms

The metabolism and structure of the cytoplasm, as well as genetic material, are responsible for the radiosensitivity of a cell; therefore, interfering with the protein and nucleic acid metabolism may show the possibility of radiosensitization. In principle, two different ways are open to such interactions: by variation of the kind and application of the irradiation or by combining physical or chemical treatments with irradiation, the effect of the irradiation may be increased in a synergistic manner. The other way is to obtain a deeper insight into the radiobiological and radiobiochemical processes of the cell, thus showing a possibility for direct and causal interference into the metabolism of the cell. Of course, both ways have many connecting paths.

This kind of research must be carried out on the most radioresistant strains of yeast present in fruit juice. For this purpose yeast strains were selected from grape juice (Griiner Veltliner) [1].

1.1. Effect of gamma-irradiation (\(^{60}\)Co)

To determine the radioresistance of the strain, the relationship between the fermentation ability [2, 3] or the colony-forming process [4] to the dose of irradiation can be investigated. The first relation, measured in Warburg apparatus, shows (Fig. 1) that fermentation activity will not be reduced immediately after irradiation, but after some generations.

The survival curves of yeast strains - the yeast cells are counted 24 h after irradiation - show the expected logarithmic shape at room temperature; the most resistant strain, Saccharomyces cerevisiae Hansen, has been determined [4]. This needs a dose of 1.8 Mrad to stop its colony-forming process over a period of 20 d.

Some attempt has been made to induce and select more resistant mutants than the one mentioned [5], but with no success till now; therefore the strain mentioned will be used as a tracer in the experiments.

The effect of irradiation depends to a certain extent, of course on the phase of the cell cycle during which the irradiation is applied [6], but for practical purposes synchronization of the yeast cells in a sufficiently high amount should be possible. This problem is not yet solved. Therefore, the relationship of phase cycle and radioresistance will be studied on a model of synchronized Chlorella cultures [7]. A semi-automatic apparatus has been constructed which produces 15 - 16 litres of synchronized Chlorella suspension in 28 hours of light and dark period.

1.2. Combined treatment

The combination of low-dose irradiation with mild physical and/or chemical treatments may lead to a radical change in the metabolism of the cell resulting in inhibition of fermentation and/or multiplication activity.

From preliminary investigations [3] it seems promising to carry out extensive studies on the combined effect of irradiation and heat on the most resistant yeast strains mentioned above. These studies are
FIG. 1. Inactivation of yeast by $^{60}$Co gamma irradiation (krad)

described in the paper of G. Stehlik and the author in these Proceedings. The results show a clear synergistic effect by heating to 50°C and simultaneous irradiation. Heating alone reduces the survival of yeast by the factor $3 \times 10^2$ and $^{60}$Co irradiation of 150 krad alone, at room temperature, by a factor of 2-3. The combination reduces by a factor of $5 \times 10^4 - 10^5$. Based on these results, technological studies were carried out which are described later in this paper.

Investigations on the combined effect of irradiation and chemicals are in a preliminary state. Besides some studies on vitamin K$_5$ [2], which have not been very promising, such compounds which block the SH groups, or interact with some structures of the genetic material, are being investigated.

To know more about the blocking mechanisms, Saccharomyces cerevisiae was incubated with different concentrations of p-hydroxymercuribenzoate (HMB) and the non-toxic one was determined with 0.5 mM (Fig. 2) [8]. The amount of mercury in the cells was measured by neutron activation analysis, which was developed in the Institute for the determination of metal ions [9, 10]. The survival curves of Saccharomyces cerevisiae treated with HMB concentrations up to 0.5 mM and irradiated with different doses, show the influence of the blocked SH groups (Fig. 3). Combining a concentration of 0.5 mM HMB and irradiation of 100 krad, the number of survivals of Saccharomyces cerevisiae decreases two to three times compared with the control. Another strain, however, Schizosaccharomyces bombei, does not show this effect because HMB does not cross the cell wall. Other investigations on the combined effect of irradiation and chemicals used in food preservation (sorbic acid) as well as ultrasonic treatment are continuing. Special emphasis is given in the research to the influence on radioresistance of the content of trace elements in the cell. This is discussed later in the paper. Similar investigations have been started with mould.

1.3. Biochemical research

Investigations which may lead to the radiosensitization of microorganisms by interference with the metabolism of the cell should include the cell as a whole and its individual components and compounds.
1.3.1. Intact yeast cells

Investigations dealing with the $O_2$-uptake of intact yeast cells in relation to their irradiation show that no significant difference in the ability of $O_2$-uptake of the yeast systems irradiated up to 100 krad can be observed, but less respiratory activity is apparent at dose levels of 200 krad (about 10% reduction) and 500 krad (about 20% reduction) [11]. It is to be expected that the permeability of the cell wall will be influenced by irradiation. The uptake of $^{14}C$-labelled glucose and glycine, as well as the release of $^{14}C$-labelled substrates from the cell, could serve as measures in the permeability study.

The release of $^{14}C$ to the ambient solution of yeast cells labelled by the uptake of $^{14}C$-glucose or glycine, and irradiated, is significantly greater at 100 krad and above compared to the control, or smaller doses of irradiation [12]. The analyses of the compounds given up by the yeast cell treated with 500 and 1000 krad showed the presence of large amounts of sugar phosphates, but not of fructose -1, 5-diphosphate which is usually present in higher amounts. Smaller quantities of amino acids and nucleotides could be detected [13]. Also, the total uptake of the $^{14}C$-glucose of glycine by the yeast cells depends on the irradiation dose. At 500 and 1000 krad a notable decrease in $^{14}C$-uptake could be observed; 1 Mrad reduces the uptake of glucose to $\frac{1}{3}$ and of glycine to $\frac{1}{4}$ of the control [14].

In general, the uptake of glucose by cells which are irradiated or not is significantly higher (2-4 times) than that of glycine.
This change in permeability could be the result of the cells killed in the culture by irradiation, that means the increasing overall permeability of a culture results from the increasing amount of dead cells which have highly permeable walls. The effect of irradiation on the colony production of the irradiated yeast cells (survival curves) shows significant decrease in survivals with a dose of 100 krad and above [15]. This correlates with the relation between 14C-release and irradiation, but not exactly with the other permeability tests. Investigations are going on to discover how far the observed permeability change is masked by the dead cells.

1.3.2. Yeast cell components

These investigations firstly involved studies on cell rupture; a mechanical technique was developed, using a homogenizer, and a biochemical technique was developed using a certain snail enzyme to dissolve the cell wall [16]. These techniques made it possible to fractionate the cell into various particulates and a final supernatant by differential ultracentrifuging.

The influence of gamma irradiation on the distribution of 14C in various particulates obtained from yeast cells incubated with 14C-labelled glucose and glycine has been investigated [12]. The results show, in relation to the total 14C-activity taken up by the cell, that the distribution of 14C among the various particulates is reasonably independent of the irradiation treatment. In the supernatant, about 20 soluble proteins have been isolated by the technique of disc electrophoresis [12]. The relative amounts of nine major protein bands appearing on the polyacrylamide gel,

![FIG. 4. Disc electrophoresis. Protein bands of the supernatant from unirradiated and irradiated yeasts](image-url)
after staining with amino schwartz, were measured by using densitometric curves of the individual gels (Fig. 4). In this way, the influence of gamma irradiation on this relative amount could be determined. An example is shown in Table I.

**TABLE I. RELATIVE AMOUNT OF 9 MAJOR PROTEIN BONDS APPEARING ON THE POLYACRYLAMIDE GEL IN RELATION TO IRRADIATION**

<table>
<thead>
<tr>
<th>Treatment (krad)</th>
<th>Higher molecular weight</th>
<th>Lower molecular weight</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Disc number</td>
<td></td>
</tr>
<tr>
<td></td>
<td>1</td>
<td>2</td>
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<tr>
<td>0</td>
<td>100</td>
<td>100</td>
</tr>
<tr>
<td>10</td>
<td>81</td>
<td>77</td>
</tr>
<tr>
<td>100</td>
<td>74</td>
<td>72</td>
</tr>
<tr>
<td>500</td>
<td>57</td>
<td>38</td>
</tr>
<tr>
<td>1000</td>
<td>95</td>
<td>102</td>
</tr>
<tr>
<td>1800</td>
<td>89</td>
<td>103</td>
</tr>
</tbody>
</table>

1.3.3. Yeast cell compounds

Main emphasis has been given to the studies on nucleic acids, especially in relation to their trace-element content [17-22], as well as to the pool of free nucleotides [23, 24]. It could be shown that the radioresistance of the nucleic acids depends significantly on the trace-element content (Figs. 5, 6). Further investigations will show how far a change in the trace-element content of DNA and RNA influences the radioresistance of the whole cell.

2. Studies on technological feasibility

The possibility of preserving fruit juice by irradiation has been outlined by some authors (e.g. 25-28). The basic fact that a combined treatment of irradiation and slight heating shows a synergistic inhibitory effect on the multiplication of yeast cells has been used for technological investigation in the preservation of apple and grape juice.

Storage tests have been carried out and are going on for different storage temperatures (4°C, 10°C, 28°C). The following parameters are studied during the storage time:

(a) Fermentation;
(b) Microbiological status;
(c) Organoleptic behaviour;
(d) Volatile components;
(e) Non-volatile components.
The results to date show that apple juice pressed from low-quality mixed varieties, as used in the fruit juice industry, can be stored without fermentation for over more than one year at room temperature and lower, even in an unfiltered state, when heated to 50°C and irradiated with 0.3 Mrad. For grape juice, a higher dose, even in the filtered state, of about 1 Mrad, is needed.

Microbiological investigations during storage are now in progress and the organoleptic tests show that the irradiation dose of apple juice produces a product which is slightly different from the control of deep frozen juice, but is better in quality than the heat-pasteurized juice. These
results are in agreement with the tests of Farkas et al. [25]. The change in taste during storage is under investigation. The change in colour is insignificant compared with heat-pasteurized juice [25, 29].

The gas chromatographic analyses of the aroma substances in apple and grape juice, unirradiated and irradiated, are described in the paper by P. Dubois et al. in these Proceedings. Gas chromatographic preparation of the different degradation products of aroma substances is the subject of special research work in Spain [30] within the framework of the International Fruit-Juice Project1. These degradation products will be needed for wholesomeness tests (described in section 3 of this paper).

On volatile substances, extensive work has been done on glucose in aqueous solution [31, 32]. By thin-layer chromatography 21 degradation products appear in the presence of oxygen at an irradiation dose of 0.55 Mrad, of which 12 could be identified to date (see Table II): On an average, apple juice contains about 80 g sugar per litre and the degradation of glucose in fruit juice medium will now be followed by the use of 14C-labelled glucose. Preliminary results show that the radiodegradation of glucose is significantly reduced in fruit juice solution [33].

This has also been studied with malic acid in aqueous solution and five degradation products could be detected by the thin-layer technique, which could be identified (see Table III). In a fruit juice medium the radiodegradation is much more ineffective [34].

Investigations into the protein component (enzymatic systems) and on the amino acids are in progress and show the aggregation and degradation of the compounds by irradiation.

3. Wholesomeness

The wholesomeness of irradiated products should be tested by animal feeding as well as by cell cultures. An effort should be made to standardize these tests in such a way that the health authorities could accept them as criteria for the clearance of irradiated foodstuffs.

Irradiated fruit and fruit juice will be tested on mice, rats and pigs. These studies can be carried out when the irradiation facility is ready at Seibersdorf. A detailed description of this plant is given in the paper by N. Weidinger and the author in these Proceedings.

Preliminary investigations determined the amount of fruit and fruit juice which can be mixed in the basic diet of the test animals without any harmful effects [35]. The results show that for mice and rats apple juice can be taken instead of water and 20% of dehydrated apples can be mixed into the basic diet without any significant change in the following parameters: the blood picture, weight, growth, and the histopathology. The spontaneous tumour-rate and illness were equally distributed throughout each animal test group.

In the case of pigs, the feeding tests showed that up to 40% of the basic diet could be substituted by apples. Similar investigations with apple juice are being carried out.

However, it is also of interest not only to test the whole foodstuff, but also single components, unirradiated and irradiated, and their degradation products. It is not possible to examine all these products

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1 Mr. de la Cruz of Spain is working on the project at Seibersdorf.
TABLE II. RADIODEGRADATION PRODUCTS OF GLUCOSE IN AQUEOUS SOLUTION IN THE PRESENCE OF OXYGEN (0.55 Mrad) BY THIN LAYER CHROMATOGRAPHY

<table>
<thead>
<tr>
<th>Glycol aldehyde</th>
<th>Glucuronic acid</th>
</tr>
</thead>
<tbody>
<tr>
<td>Glyceraldehyde</td>
<td>Tartaric acid</td>
</tr>
<tr>
<td>Xylose</td>
<td>Glyoxylic acid</td>
</tr>
<tr>
<td>2-Ketogluconic acid</td>
<td>Oxalic acid</td>
</tr>
<tr>
<td>5-Ketogluconic acid</td>
<td>Arabinose</td>
</tr>
<tr>
<td>Gluconic acid</td>
<td>Glucuronic acid-γ-lactone</td>
</tr>
</tbody>
</table>

TABLE III. RADIODEGRADATION PRODUCTS OF MALIC ACID IN AQUEOUS SOLUTION IN THE PRESENCE OF OXYGEN (0.5 Mrad) BY THIN LAYER CHROMATOGRAPHY

<table>
<thead>
<tr>
<th>Oxalacetic acid</th>
</tr>
</thead>
<tbody>
<tr>
<td>1,2,3,4,(1,2,3,4 tetra-hydroxy) cyclobutane-tetracarboxylic acid</td>
</tr>
<tr>
<td>1,2,3,4,(1,2,3 tri-hydroxy) cyclobutane-tetra-carboxylic acid</td>
</tr>
<tr>
<td>Dihydroxy malic acid → glycolaldehyde</td>
</tr>
<tr>
<td>Unknown compound (diketopolycarboxylic acid ?)</td>
</tr>
</tbody>
</table>

by feeding tests; tissue cultures will therefore be used as a biological screening system. This kind of pre-selection takes place on human fibroblast cultures [36] and on plant tissue cultures [37]. Only those compounds which show significant effects in reasonable concentrations will be tested by animal feeding.

As mentioned above, for this purpose the degradation products of the volatile and non-volatile substances of the fruit juice have to be identified or prepared. Preliminary tests on glucose and the degradation products arabinose and xylose have been carried out [36] and show no remarkable effect on the cell growth. The influence of the degradation products on the DNA synthesis in fibroblasts will be studied.

ACKNOWLEDGEMENTS

The author is grateful for the financial support of the Austrian Government and the assistance of officials of the Federal Chancellor's Office and some ministries, for the administrative support of the three signatories of the project, and for their help in seconding experts to the project. Special thanks are due to the participating countries for sending
scientists to the project and to the Project Committee and all colleagues
both abroad and in Austria who have helped in the research work.

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DISCUSSION

D. A. A. MOSSEL: Perhaps you could tell us something of the motives
behind this most interesting research on radurization of fruit juices, in
particular whether it has been prompted by dissatisfaction with current
industrial methods of HTST fruit-juice pasteurization.

K. KAINDL: No, the research was not prompted by dissatisfaction
with current methods, nor was fruit juice chosen as a product requiring
new techniques more urgently than others. It was taken simply as a model
substance in which the radiosensitivity of microorganisms, the behaviour of protein components, and a possible standardization of wholesomeness tests could conveniently be investigated. On the other hand, any new technological developments in fruit-juice irradiation emerging from this research may be regarded as a useful by-product of it. We have in fact seen that the taste of irradiated apple juice is better than that of heat-treated apple juice.

J.K. MIETTINEN: You have shown by electrophoresis that irradiation removes some of the proteins from the fruit juice. What happens to these proteins? Do they remain at the starting line or are they precipitated? And what is the significance of this finding?

K. KAINDL: The experiments were performed with proteins isolated from grape juice. On irradiation the proteins were denatured and aggregates formed. These aggregates were partially or completely retained at the start line on the disc electrophoresis sheet, depending on the radiation dose employed. No evidence was obtained that these aggregates are precipitated from the solution during or after irradiation within the dose range studied (0.5 - 5 Mrad).

J. PAHISSA CAMPA: Do you replace all the water in the rats' feed by irradiated juice?

K. KAINDL: Most of the fruit juice is dried and then mixed with the normal diet. Only a few animals in each group are given fruit juice instead of water, the remainder receiving as much water as they wish.

J. PAHISSA CAMPA: Is the diet containing irradiated juice a balanced one?

K. KAINDL: Yes, it is isocaloric and nutritionally well balanced in that it contains equal amounts of total protein and other food components.

J. PAHISSA CAMPA: What is the overall percentage of irradiated juice?

K. KAINDL: This depends on the kind of animals and the strains used. In mice and rat feeding tests 30% of the dry substance may be fruit juice, in the case of pigs 40%. In the multi-generation feeding tests adverse clinical effects are observed if more than 25% dry substance is added.
CANADIAN FOOD IRRADIATION FACILITIES

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Abstract — Résumé — Аннотация — Resumen

CANADIAN FOOD IRRADIATION FACILITIES. Atomic Energy of Canada Limited (AECL) began work on the irradiation of potatoes in 1956, using spent fuel rods as the radiation source. In 1958 the first Gammacell 220, a self-contained irradiator, was designed and manufactured by AECL, and cobalt-60 was then used exclusively in the food irradiation programme. In 1960 the first food and drug clearance was obtained for potatoes. The next stage was to demonstrate to the potato industry that cobalt-60 was a safe, simple and reliable tool, and that irradiation would inhibit sprouting under field conditions.

A mobile irradiator was designed and produced by AECL in 1961 to carry out this pilot-plant programme. The irradiator was mounted on a fully-equipped road trailer and spent the 1961/1962 season irradiating one million pounds of potatoes at various points in Eastern Canada.

In 1965 the first commercial food irradiator was designed and built by AECL for Newfield Products, Ltd. Whilst the potato programme was under way, AECL initiated co-operative programmes with Canadian food research laboratories, using additional Gammacells.

In 1960, AECL constructed an irradiation facility in a shielded room at its own plant in Ottawa for the irradiation of larger objects, such as sides of pork and stems of bananas.

During 1963 the mobile irradiator, already a most useful tool, was made more versatile when its source strength was increased and it was equipped with a product cooling system and van air conditioning. Following these modifications, the unit was employed in California for the irradiation of a wide spectrum of fruits at the United States Department of Agriculture Station in Fresno.

The Gammacell, mobile irradiator, shielded-room facility, the commercial food irradiator and some of the main food programmes are described in detail.

There is an increasing amount of interest in irradiation by the food industry, and prospects are encouraging for future installations.

INSTALLATIONS CANADIENNES D'IRRADIATION DES ALIMENTS. L'Atomic Energy of Canada Limited (AECL) a entrepris en 1956 des travaux sur l'irradiation des pommes de terre en utilisant comme source des barreaux de combustible épuisé. En 1958, l'AECL a conçu et fabriqué le premier appareil Gammacell 220, qui est un irradiateur complet, et l'on n'a plus utilisé que du cobalt-60 pour l'exécution du programme d'irradiation des aliments. En 1960, la première autorisation du service de contrôle des produits alimentaires et pharmaceutiques a été obtenue pour les pommes de terre. La phase suivante consistait à montrer aux producteurs et distributeurs de pommes de terre que le cobalt-60 est un instrument sans danger, simple et sûr, et que l'irradiation entraîne la germination.

En 1961, l'AECL a conçu et fabriqué un irradiateur mobile afin d'exécuter le programme de démonstration. L'irradiateur a été monté sur une remorque routière entièrement équipée et, au cours de la saison 1961/1962, 500 tonnes de pommes de terre ont été irradiées en divers endroits du Canada oriental.

En 1965, l'AECL a conçu et construit le premier irradiateur commercial de denrées alimentaires pour la compagnie Newfield Products Ltd. Pendant l'exécution du programme d'irradiation des pommes de terre, l'AECL a lancé des programmes communs avec des laboratoires canadiens de recherche sur les produits alimentaires, en utilisant d'autres appareils Gammacell.

En 1960, l'AECL a construit une installation d'irradiation en casemate dans son établissement d'Ottawa pour l'irradiation d'articles plus volumineux tels que des quartiers de porcs et des régimes de bananes.

Au cours de l'année 1963, l'irradiateur mobile, qui avait déjà montré son utilité, a été modifié en vue d'élargir ses applications: l'intensité de la source a été augmentée et il a été équipé d'un dispositif de refroidissement des produits; en outre, la remorque a été climatisée. Ainsi transformé, il a été utilisé en Californie pour l'irradiation d'une grande variété de fruits à la station du Département de l'agriculture des États-Unis, à Fresno.
Le mémoire décrit en détail l'appareil Gammacell, l'irradiateur mobile, la casemate, l'irradiateur commercial et quelques-uns des principaux programmes d'irradiation.

L'industrie alimentaire s'intéresse de plus en plus à l'irradiation et les perspectives sont encourageantes pour les installations futures.

КАНАДСКИЕ УСТАНОВКИ ДЛЯ ОБЛУЧЕНИЯ ПИЩЕВЫХ ПРОДУКТОВ. В 1956 году Канадское акционерное общество по атомной энергии (КАОЭ) начало облучать картофель, применяя отработаные топливные стержни в качестве источника излучений. В 1958 году КАОЭ сконструировало и изготовило первую гамма-камеру 220 — автономный облучатель, и кобальт-60 затем использовался исключительно в рамках программы исследований по облучению пищевых продуктов. В 1960 году Управление пищевых продуктов и лекарственных веществ впервые разрешило облучать картофель. Следующая стадия заключалась в том, чтобы доказать производителям картофеля, что кобальт-60 является безопасным, простым и надежным средством и что облучение задержит прорастание в полевых условиях.

Затем КАОЭ сконструировало и изготовило передвижной облучатель в целях осуществления программы создания опытной установки. Облучатель был установлен на полностью оборудованном автомобильном прицепе и использовался во время сезона 1961 - 1962 г. Он было обработано 450 т картофеля в различных местах Восточной Канады.

В 1965 году КАОЭ сконструировало и изготовило первый промышленный облучатель пищевых продуктов для компании "Ньюфилд Продактс Лимитед".

В ходе осуществления программы по картофелю, КАОЭ приступило вместе с канадскими исследовательскими лабораториями пищевых продуктов к совместным программам исследований с применением дополнительных камер для гамма-облучения.

В 1960 году КАОЭ сконструировало установку для облучения в экранированном помещении на своем собственном заводе в Оттаве, чтобы облучать более крупные предметы, например свиные окороки и грозды бананов.

В 1965 году передвижной облучатель, который и до этого был наиболее полезным средством, стал более универсальным за счет увеличения мощности источника и оснащения системой охлаждения продуктов и установкой для кондиционирования воздуха в аэрофургоне. После этих модификаций установка использовалась в Калифорнии для облучения разнообразных фруктов на опытной станции министерства сельского хозяйства США в Фресно.

Дается подробное описание камеры для гамма-облучения, передвижного облучателя, установки в экранированном помещении, промышленного облучателя пищевых продуктов, а также некоторых основных программ исследований пищевых продуктов.

В настоящее время предприятия пищевой промышленности проявляют все больший интерес к облучению продуктов, и перспективы использования будущих установок являются благоприятными.

INSTALACIONES DE IRRADIACION DE ALIMENTOS EN EL CANADA. En 1956 la Comisión de Energía Atómica del Canadá (AECL) comenzó sus trabajos sobre irradiación de patatas utilizando barras de combustible agotado como fuente de radiación. En 1958 proyectó y construyó su primera fuente tipo Gammacell 220, que es un dispositivo de irradiación autónomo; entonces, para el programa de irradiación de alimentos sólo se utilizaba cobalto-60. El Servicio de productos alimenticios y farmacéuticos concedió en 1960 su primera autorización para la irradiación de patatas. La etapa siguiente consistió en demostrar a los sectores dedicados a la explotación de ese tubérculo que la fuente de cobalto-60 es un instrumento sencillo y seguro, y que la irradiación impide la germinación en las condiciones usuales de almacenamiento.

En 1961 la AECL diseñó y construyó un dispositivo móvil de irradiación para ejecutar este programa experimental. El irradiador se montó en un autotrailer completamente equipado que durante la temporada de 1961-1962 irradió 1 000 000 de libras de patatas en varios puntos del Canadá oriental.

En 1963 la AECL diseñó y construyó para la Newfield Products Ltd el primer dispositivo de irradiación comercial de alimentos.

Mientras se ejecutaba el programa de irradiación de patatas la AECL inició algunos programas de cooperación con laboratorios canadienses de investigaciones sobre productos alimenticios, para los que se utilizaron también fuentes tipo Gammacell.

En 1980 la AECL construyó en su centro de Ottawa una instalación de irradiación con cámara blindada para irradiar objetos voluminosos tales como piezas de carne de cerdo y macizos de plátanos.

En 1963, se dieron nuevas posibilidades de empleo al dispositivo móvil de irradiación, ya de por sí sumamente útil; se aumentó la potencia de su fuente y se le dotó de un sistema de refrigeración de productos y de acondicionamiento de aire. Una vez modificado el dispositivo se utilizó en California para irradiar una gran variedad de frutas en la estación que el Departamento de Agricultura de los Estados Unidos tiene en Fresno.
En la memoria se describen en detalle la fuente tipo Gammacell, el dispositivo móvil de irradiación, la instalación con cámara blindada, el dispositivo de irradiación comercial de alimentos y algunos de los principales programas.

El interés de la industria por la irradiación de alimentos aumenta constantemente y las perspectivas en lo que respecta a nuevas instalaciones de irradiación son muy alentadoras.

INTRODUCTION

Atomic Energy of Canada Limited (AECL) began work on the irradiation of food in 1956, using spent fuel rods at the Chalk River Nuclear Laboratories as the source of radiation. The irradiations were carried out under water in sealed containers in the rod storage bay.

To accelerate the programme, AECL turned to cobalt-60, manufactured in its own reactors, as the source of radiation, and began to design and produce irradiators, the first of which was in use in 1958. Thus AECL started to build up its technical experience to provide a complete isotope service from the scientific research stage through pilot-plant work to industrial utilization.

The results of Canada's efforts obtained the first Food and Drug clearance in the western world for the irradiation of potatoes to inhibit sprouting, and the construction in Canada, for a private company, of the world's first commercial food irradiator [1].

This paper describes the Canadian food-irradiation facilities and the work carried out by them.

GAMMACELL 220

The Gammacell 220 (Fig.1) is a cobalt-60 irradiation facility designed for use in an unshielded room. The unit consists of an annular-shaped source, a lead shield around the source, and a long cylindrical drawer free to move vertically through the centre of the source. An opening, or sample chamber, in the drawer will accept objects 6 in. diam. and 8 in. high. When the drawer is in the top position, the sample chamber is accessible for loading, and when the drawer is fully down, the sample chamber is located within the annular source. A swing-open shielding collar on top of the lead shield provides adequate shielding whilst the drawer is in motion.

The source is made up of 48 sealed stainless-steel tubes which contain seven cobalt-60 source rods each 1 in. diam. and 1 in. long, and covered by a 1/8 in.-thick layer of aluminium. The source is loaded into the Gammacell 220 in a hot cell.

With a source strength of 24,000 Ci cobalt-60 the dose-rate at the centre of the sample chamber is $2 \times 10^6$ R/h. The maximum dose variation within the sample chamber is ± 20%. The advantage of the high dose-rate, which is many times higher than that obtained in larger pilot or production irradiators, is that it becomes feasible to prepare many samples quickly at different dose levels for storage and feeding trials. The dose delivered is controlled by an electric timer which automatically sends the drawer up when the pre-set radiation time is reached.
FIG. 1. Gammacell 220

The Gammacell 220 weighs 8250 lb and requires only electric power for its operation.

GAMMACELL 220 IN THE FOOD PROGRAMME

The first Gammacell 220 was manufactured in 1958 and is still in use at the AECL plant. This unit was used to irradiate potatoes to provide some of the data provided for Food and Drug clearance. It has been utilized for many experimental studies, which have been followed up by the Mobile Cobalt-60 Irradiator. Foods irradiated include potatoes,
onions, dehydrated vegetables, strawberries, chicken, egg products, cheese, fish, mushrooms, apples, pears, grain and insects.

In 1960 a unit was placed at the Ontario Agricultural College of the University of Guelph, Ont., where wholesomeness studies on irradiated onions were carried out. Work has been carried out also on bacon, wieners, Salmonella in frozen eggs, carrots, turnips, soil sterilization and seeds for plant-breeding studies. The Fisheries Research Board in Halifax, Nova Scotia, were supplied with a Gammasell 220 in 1962 to study the effects of pasteurizing doses of irradiation on the shelf life of various marine products. Present indications are that a dose of 75 000 rad will double the shelf life of halibut, scallop and lobster meat. This is an important result when it is considered that large markets in Canada are a very great distance from the sea.

A unit was supplied to MacDonald College, of McGill University, Montreal, P.Q., in 1965 and is being used to study the effects of pasteurizing doses of irradiation in the shelf life of poultry. This year it is expected that three more Gammasell 220's will go to food research institutes in Canada.

MOBILE COBALT-60 IRRADIATOR

The Mobile Cobalt-60 Irradiator (Fig. 2) was built in 1961 and is an enclosed trailer-mounted facility set up for the continuous automatic irradiation of produce in aluminium buckets 8 1/2 in. X 8 1/2 in. X 15 in. long. The

MOBILE COBALT-60 IRRADIATOR

The Mobile Cobalt-60 Irradiator (Fig. 2) was built in 1961 and is an enclosed trailer-mounted facility set up for the continuous automatic irradiation of produce in aluminium buckets 8 1/2 in. X 8 1/2 in. X 15 in. long. The
irradiator can best be described by looking at the main components which are: the main irradiator shield, inlet and outlet mazes, cobalt-60 source and source storage container, conveying system and the trailer.

The main irradiator shield is a horizontal cylinder with a cavity 35 in. diam. and 32\(\frac{1}{4}\) in. long, surrounded by steel-encased lead walls 10\(\frac{1}{2}\) in. thick.

The inlet and outlet mazes are lead-walled square tubes which line up with openings in the end walls of the main irradiator shield. Each maze has three right-angle bends, which limit the radiation fields at the outside entrance and exit to an acceptable tolerance.

The cobalt-60 source is in the form of pellets 1 mm diam. and 1 mm long, doubly encapsulated in stainless-steel tubes \(\frac{1}{2}\) in. diam. and 15 in. long. In the irradiated position the source is on the axis and in the centre of the main irradiator shield. The source can be withdrawn by hand into a separate 6500-lb shipping container. This feature allows complete maintenance access to the irradiator and also permits easy source-loading in a hot cell.

The conveying system (Fig. 3) transports the aluminium buckets from the end of the trailer through the inlet maze, around the source and out through the exit maze to the end of the trailer. Live roller and belt conveyors are used within the trailer and they may be connected to systems which transport buckets to and from a warehouse. Buckets are
pushed through the mazes by electrically driven ball screws, and gear-driven limit switches outside the radiation field control the bucket travel. The conveying mechanism within the main irradiation shield consists of four square tubes, each long enough to hold two buckets. These square tubes are equally spaced about the axis of the source and are held in a frame which is free to rotate. This frame is driven by a four-position Geneva mechanism in such a manner that when the frame is stationary one of the square tubes is in line with the conveyor in the mazes. The square tubes are driven by a secondary gear system in such a way that the tubes always remain upright when the frame is rotated. When the frame is stationary, the inlet maze conveyor pushes a new bucket into the bottom tube and this process ejects one bucket from the tube onto the outlet maze conveyor. At the completion of this operation the frame rotates through 90°. Each time the frame stops, a bucket is pushed into the bottom tube, and in this way each bucket passes around the source twice in a total of eight positions before receiving the full radiation dose. The dose delivered is controlled by the interval at which buckets are pushed into the irradiator. The frequency of handling buckets can be quickly varied from a maximum of 140/h with no limit on the minimum.

The trailer is insulated and equipped for winter use with a 20 000 BTU/h heater. For summer use there is a 35 000 BTU/h air conditioner and a system for blowing refrigerated air through the main irradiator shield to remove 7500 BTU/h.

With a maximum source of 42 000 Ci cobalt-60 the dose delivered is 5200 rad/min, with a uniformity of ±13%.

MOBILE COBALT-60 IRRADIATOR IN THE FOOD PROGRAMME

The Mobile Cobalt-60 Irradiator was built after Food and Drug clearance for irradiated potatoes had been obtained. The main purpose of the first season of demonstrations was to bridge the gap between laboratory experiment and full-scale commercial operation.

The Mobile Cobalt-60 Irradiator has been a most useful tool for the food irradiation programme. First and foremost, it has been able to take cobalt-60 irradiation right into the world of the future users, and has demonstrated that radiation is a safe, reliable source of energy which is simple to use. The Mobile Irradiator has travelled 16 700 miles since September, 1961, and made 36 stops at points from the east to the west coast. The longest stop was at the United States Department of Agriculture Station in Fresno, Calif., where it was used for almost one year for irradiating a wide variety of fruits. Altogether 127 000 buckets (75 000 ft³) of produce have been irradiated, and in 1965 alone 37 different food items were irradiated.

SHIELDED-ROOM FACILITY

The AECL built an irradiation facility within a shielded room at its own plant in Ottawa in 1960. The purpose of this facility (Fig. 4) is to irradiate objects which are large and awkward. The source of this de-
FIG. 4. Shielded room facility

FIG. 5. Commercial potato irradiator
vice is unusual in that it is blown from its safe storage position into the irradiate position by compressed air. There are two cobalt-60 sources, each made up of 18 capsules, to form a line 30 in. long and containing 8000 and 35000 Ci, respectively. In the safe position each source is stored in a helical tube within a lead flask fixed into the wall of the shielded room. Source position tubes which are normally straight, to give line sources, are fastened to the tubes in the flask. An air supply is connected to the other end of the helical tube and the source is blown into the irradiate position, provided that the cell door is closed and all the interlocks are set. Objects to be irradiated are suspended from a rotating drive mechanism which can be positioned at varying distances from the source tube. This facility has been used to irradiate such different objects as stems of bananas and sides of pork.

![Diagram of commercial potato irradiator](image)

**COMMERCIAL POTATO IRRADIATOR**

The food industry became seriously interested in the irradiation of potatoes after the 1961/62 field demonstration by the Mobile Cobalt-60 Irradiator.

However, there were still some technical problems to be solved. The results of the Mobile Irradiator programme confirmed that potatoes must be carefully handled during and after irradiation; thus the designer of a commercial irradiator would have to consider keeping the handling of potatoes to a minimum. In Canada it is common practice, particularly in the most modern stores, to store potatoes in pallet boxes, which range
FIG. 7. Commercial potato irradiator - source pass mechanism

in size up to 48 in. × 48 in. × 48 in. If potatoes could be irradiated in these boxes it would certainly reduce handling damage and handling costs.

The maximum radiation dose permitted by the Food and Drug Directorate of the Department of Health and Welfare was 10 000 rad, which meant that some potatoes within a pallet box would not receive a sufficient dose of radiation to inhibit sprouting. Therefore, in 1963, a petition was made to the Food and Drug Directorate to increase the maximum dose of radiation to 15 000 rad; this made the irradiation of potatoes in pallet boxes a practical proposition.

Following this, the first Commercial Food Irradiator was designed and constructed by AECL for Newfield Products Ltd., a private company at Mont St. Hilaire near Montreal, P.Q., and began operation in September 1965. The plant is illustrated in Fig. 5 and a plan view of the irradiator, showing the method of product entry into the irradiation room, is shown in Fig. 6. An enlarged view of the source pass mechanism, which conveys the pallet boxes around the source, is shown in Fig. 7.

Pallet boxes, 42 in. × 48 in. × 40 in. high, containing 1350 lb of potatoes, are transported in and out of the irradiation room on powered roller conveyors. The source pass mechanism (Fig. 7) conveys the pallet boxes around the radiation source, which is in the form of an annular ring. The mechanism consists of four horizontal conveyors disposed one to each side, one above and one below the source; each conveyor holds three pallet boxes. At each end of the source mechanism there are transfer elevators, a single transfer elevator at the front end and a double transfer elevator at the rear. Movement of the pallet boxes is by pneumatic cylinders within the irradiation room. At the
start of an indexing cycle there are three pallet boxes in each row and one pallet box on the single transfer elevator in the top position. When a box arrives in the roller conveyor in line with the bottom conveyor, the top and bottom rows of pallets are pushed through one box length. Two boxes are displaced onto the double transfer device, which rotates through 90° into line with the side rows. These rows are then pushed, one box being pushed onto the single transfer device, where it is elevated to the top row to await the next cycle, and the other is displaced onto the outlet conveyor and taken to storage. The radiation dose is governed by the time interval at which pallet boxes are injected into the irradiator. The conveying system can handle a maximum of 40 pallet boxes per hour (54 000 lb/h), and to deliver a minimum dose of 6000 rad to each box, a source of 185 000 Ci would be required. The overdosing ratio through a pallet box containing potatoes is about 2.25 to 1.

When the source is not in the irradiate position it is safely stored at the bottom of a water-filled pool. This is the safest and simplest method of storing large sources. A pool is relatively straightforward to construct, and, apart from occasional regeneration of the demineralizer, it is practically maintenance-free. The source is always available for inspection, including direct-contact wipe tests. In fact, AECL does offer a comprehensive ten-year warranty on its source pencils when they are used in irradiators which have wet source storage.

The building which houses the irradiator is constructed from normal-grade concrete and the plant is fully equipped with radiation detectors and safety interlocks to prevent hazards to personnel.

It is expected that 15 million pounds of potatoes will be irradiated during the first season's operation.

CONCLUSIONS

This paper has dealt mainly with the past, the last ten years having been particularly successful for food irradiation in Canada. The prospects for more commercial food irradiators in the near future are very good.

Although the technology of designing and constructing cobalt-60 irradiation plants is well advanced, AECL is carrying out a great deal of engineering development, so that suitable machines will be available as Food and Drug clearance is obtained for new items.

Emphasis is being placed on industrial participation, to expedite early commercial application, and basic research on radiation effects to improve existing knowledge.

REFERENCE

R. SCHÖNBERG: What is the efficiency of radiation application in the commercial potato irradiation facility?

H. F. M. WARLAND: Because there are so many different ways of expressing efficiency, the best reply I can give, perhaps, is to state that 40 pallet boxes of potatoes would be processed per hour by a source of 185,000 Ci (content). Each pallet box, containing 1350 lb of potatoes, would receive a minimum dose of 6000 rad.

H. RINDORF: Are irradiated potatoes marked as such when sold to consumers in Canada?

H. F. M. WARLAND: Yes; irradiated potatoes are in fact being sold to Canadian consumers now, and the packages are marked "SPROUT INHIBITED BY GAMMA ENERGY".
PILOT PLANT FOR FOOD IRRADIATION IN THE NETHERLANDS

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Abstract — Résumé — Аннотация — Resumen

PILOT PLANT FOR FOOD IRRADIATION IN THE NETHERLANDS. The main problem raised by pilot-plant investigations is to devise a method for bridging the gap between developmental work in the laboratory and the practical applications of this work. How can the knowledge acquired in the laboratory be passed on to manufacturers or processors? The following questions are pertinent: (a) Is the pilot plant regarded as an immediate precursor of commercial plants? (b) How is a 100-fold increase in product handling realized? (c) How is commercial interest increased? (d) Who carries the final responsibilities for the programme of the pilot plant? (e) What technical facilities are needed, and (f) How the pilot plant should be organized to keep a constant flow of information between interested parties.

All these aspects are discussed on the basis of a planned pilot plant for food irradiation in the Netherlands.
INTRODUCTION

Possibilities of the radiation preservation of food have been investigated all over the world. A number of university laboratories, governmental agencies, non-profit organizations and private industries have subjected more than one hundred food items to research in the areas of microbiology, chemistry, physics, radiation dosimetry, acceptability, packaging, economics, wholesomeness, nutrition and source design. Scientific knowledge has thus accumulated, from which it can be tentatively concluded that

(1) Ionizing radiation enables many food items for human and animal consumption to be stabilized in the fresh, or semi-preserved stage;
(2) This treatment, under pre-defined conditions, causes no, or such little change in the food item that it can be considered a nutritionally good and safe process.

Considering, furthermore, that the commercialization of this process leads, inter alia, to savings resulting from reductions in spoilage, to a reduced incidence of food-borne diseases and parasites, to a considerable market and international trade expansion and to market stabilization, it can be asked why this process has not yet been more widely applied.

To ascribe this solely to the general concern of public health authorities with respect to radiation is, at least, an over-simplification. Much of this can be explained by the fact that food irradiation, once applied and commercialized, will affect not only agriculture, fisheries and food-processing industries, but also packaging and packaging materials, refrigeration and refrigeration equipment, storage facilities, transportation, chemicals and last, but not least, marketing facilities and operations. This means that the potential impact of this process is great, and this is alarming to many, especially when it is realized that this requires large capital investment.

Furthermore, although benefits to the consumer are obvious — the improvement and extension of quality, reduction in food-borne hazards to health, the development of new, and more convenient foods — pressure from the consumer has always been and is still very small. What is offered is accepted, unfortunately, or perhaps fortunately, and a better quality and safer food is very seldom required.

Moreover, the number of people hitherto involved in the radiation preservation of food has been relatively small. Especially is this true in the smaller countries.

Finally, responsibility for the application of this new method has been, and unfortunately still is, mainly in the hands of very few organizations, most of which are non-food organizations. This process has remained too long in the hands of atomic-energy organizations without industry taking over. It is obvious, of course, that the former started the ball rolling, but it seems that they have 'fallen in love' so deeply with this new process that the two can hardly be separated. However, industry should realize that the food irradiation process is like a very attractive girl, whose beauty should not be hidden within the walls of a 'dull' atomic-energy laboratory, and that food technological institutes and food organizations should take over the responsibility for the commercialization of this process more and more.

It seems logical, therefore, that a pilot plant should be designed so that
this first, and perhaps last, step in commercialization will overcome the above-mentioned barriers in the best possible way. With this in view, the programme and organization of the pilot plant should aim at the following:

(a) The food industry and marketing organizations to be given the opportunity to test the commercial values of the food irradiation process, namely, these organizations should carry the first responsibility for the pilot plant.

(b) Investigation of the impact of this process on the whole chain of events which are at present involved in the production, transformation, and distribution of food, including international trade. Particular emphasis should be placed on necessary changes in the existing food chain, so as to be able to profit fully from the prospects of food irradiation.

(c) As acceptance of the food is one of the most important goals, the consumer should be asked to contribute in the pilot plant programme. Through this contribution an evaluation could also be made of possible psychological barriers with respect to acceptance of the irradiated food by the public. This contribution could, for instance, be effected via consumer and housewife organizations in the form of consumer panels and the controlled distribution of irradiated food.

(d) As the scientific potential in smaller countries is not adequate for full appreciation of this new method, a pilot plant in these countries should make ample use of results obtained elsewhere, and should not be tempted to become an extension of a local or national scientific organization. Food scientists of high international standing should therefore be asked for advice in the pilot plant programme.

(e) To be able to judge irradiation techniques, working methods and reliability of the irradiation process, especially under continuous operation, the pilot plant could serve as an example. Therefore engineers should be asked not only to design and construct the plant, but also to carry part of the responsibility.

(f) As the pilot plant is to irradiate large quantities of food, responsibility should be undertaken for clearance of marketing, controlled or free, of these food items. Public health specialists should thus participate in the programme and be made co-responsible for the running of the plant.

ORGANIZATION

The aims described led to the setting up and organization of the pilot plant in the Netherlands. The 'Proefbedrijf Voedselbestraling' is an autonomous foundation and is independent of food technological or atomic-energy organizations. The board of governors consists of the chairmen of the six Netherlands, so-called, commodity boards. These commodity boards are vertical public organizations in which representatives of the production, the processing and storage, and the marketing of a particular group of products are the members. The six commodities are: fruit and vegetables, fish, meat and meat products, poultry and eggs, dairy products, and agricultural products. All commodity boards participate, not because it is expected that each commodity would have equal commercialization possibilities for the time being, but based on the principle that, because of the properties of ionizing energy, in the case that commercialization for a limited number of products
can be realized, in the long run, this would also have a great impact on the handling of other food items.

These chairmen are assisted within their commodity boards by working groups, which supply the chairmen with information on the characteristics of the commodity, economics, the desired length of storage, attractiveness to the consumer, etc.

To each board are added four advisory members, two from the Ministry of Agriculture and Fisheries and two from the Institute for the Application of Atomic Energy in Agriculture, whose role is to achieve continuity during the transition period from the laboratory to practical application, and to acquire a physics and engineering team.

An advisory board, which advises the board of governors on the pilot plant's programme and helps to evaluate the results of the pilot-plant experiments, consists of specialists in the fields of food technology, nutrition, packaging, consumer's acceptance and public health.

In this way it is hoped that the pilot plant will not only become a facility in which food can be irradiated in larger quantities than in a laboratory, but through which optimal co-operation between people and organizations, directly or indirectly concerned in the commercialization procedure, can be obtained under the primary responsibility of the commodity boards. In other words, a pilot plant should not only aim at a hundred-fold increase in product handling, but also aim at a hundred-fold increase in the number of people involved in the food irradiation process.

A director, with a limited staff, is responsible for the execution of the programme and for stimulating private and governmental organizations to participate, both financially and technically, in the pilot-plant programme.

TECHNICAL FACILITIES

Pilot-plant operations are well-known procedures in food technology. However, general rules describing the requirements do not exist. There are several ways of approaching the problems connected with pilot-plant research. The only feature that pilot plants have in common is the enlargement of laboratory-scale experiments to such an extent that the results obtained are valuable for commercial application. This type of work should include the technological procedure as well as the economics.

A further specification of the type of plant under consideration has already been mentioned in the preceding paragraphs, by its semi-industrial nature. This makes high demands on the throughput of the plant. In addition, the fact that it is impossible, with the funds available, to set up a plant for each food item, or for a group of related products, as is done in the United States, meant that the one pilot plant must meet all requirements as efficiently as possible. Consequently, the design puts emphasis on the flexibility in throughput due to the necessity to irradiate a large variety of products. For instance, the study of sprout inhibition of potatoes, a product of low economic value, requires the handling of tons of potatoes, whilst experiments with products of high economic value, such as mushrooms, will not make high demands on the capacity.

The treatment of several products in one facility decreases the interest in the question: must the plant be mobile or fixed? Mobile plants are use-
ful if designed for one commodity, or for a group of products of the same nature. The mobility becomes even more effective when food items are harvested in different periods of the year.

Another point to consider is that the scientific and technical knowledge in agriculture and atomic energy in the Netherlands are concentrated in one particular place, Wageningen. Taking into account also the fact that the largest distance in the Netherlands for shipping is less than 120 km, there appear to be reasons in favour of a fixed plant.

It has therefore been decided that the Netherlands pilot plant for food irradiation will be a fixed one, and the site Wageningen.

Gamma rays, bremsstrahlung and electrons are considered for food irradiation. Without doubt, with a broad programme in mind, both penetrating and shallow irradiations are required. From the point of view of flexibility—energy and output—machine sources are very useful. The high output of electrons and the relatively good efficiency of the conversion of electrons into penetrating irradiation are advantages which should not be easily overlooked when making the choice of the radiation source. The operation of a pilot plant with the characteristics described requires high reliability. It is known that the utilization factor of machine sources is not as high as with isotope sources. On the other hand, it should be realized that a pilot plant is also the site for evaluating the real potentialities of machine sources. In combination with the prospects of electron irradiation for many food items, the final decision has led to the concept of a twin source.

The pilot plant will be equipped, therefore, with a cobalt-60 source having a strength of 85,000 Ci, which can be increased to 250,000 Ci if and when necessary, and with a 3-MeV Van de Graaff accelerator of standard K type, solely for the production of electrons.

The housing of both sources is designed in such a way that simultaneous use is possible.

With the initial load of cobalt-60, a throughput of 500 kg of product per hour at an absorbed dose of 250 krad can be achieved. It has been anticipated that a capacity of 500 kg per hour is a reasonable quantity as far as evaluation of the process for high-ranking commodities is concerned; this figure will appear to be too low for the processing of bulk materials of low economic value. This drawback is partially overcome by the fact that sprout inhibition and disinfestation doses are a factor of 25 and 10, respectively, lower in magnitude.

The required throughput for products of low and high economic value can be easily attained with the 3-MeV electron machine. The problems here are two-fold and interrelated, those of dosimetry and the passage of the product through the radiation field.

Finally, during the developmental period of this pilot plant it has been clearly demonstrated that the source designers have not kept pace completely with the needs, which exist nowadays, in food technology. Food preservation by irradiation is in no way comparable to the sterilization of medical apparatus or radiation polymerization processes. Food, in general, is subject to rapid decay. Hence, the stabilization of food quality by means of irradiation must be attained in a relatively short period of time. It is the author's opinion, therefore, that source designers must pay more attention to this specific aspect of food irradiation.
One of the major problems in food irradiation is the organoleptic deterioration of protein and/or fat-rich items. The application of low temperature, in combination with ionizing energy, is a promising procedure for the elimination of off-flavour and off-odours. This development in food irradiation research has been considered in the design of the pilot plant. Therefore, the temperature inside the gamma-irradiation room is adjustable between ambient temperature and -20°C. In this way, quality decay resulting from defrosting can be avoided during the long irradiation.

A separate temperature-controlled area for the pre-treatment of odious commodities, like fish and fishmeal, has been planned at one end of the main hall. A small number of low-temperature storage rooms will be built also. A laboratory for routine dosimetry and some administrative offices complete this facility.

Construction of the plant will start in July of this year, and operation is expected to commence 16 months later.

In conclusion, the importance of good organization in the creation of a pilot plant has been emphasized because only in such a plant can the practical importance of the food irradiation process be determined. Also, once it has been decided that commercialization of the food irradiation process should be given a fair chance, it should be done as well as possible. Therefore, five years of operation will be allowed before conclusions are drawn, either positive or negative. It is realized that these conclusions may prove to be negative, but this cannot be discovered without construction of a pilot plant and a fair trial. It may be asked why it has been decided to construct a pilot plant at this time when so many problems still remain to be solved. It would appear, however, that all the problems may never be solved; also, today the world is facing a tremendous food problem. Is not too much attention being paid to small details, in an understandable drive for perfection, while the big problems remain untouched? It is hoped, with the Netherlands pilot-plant programme, to contribute a share to the solution of the world food problem.

DISCUSSION

R. SCHÖNBERG: Can you explain why a 3-MeV electron source was selected rather than one of higher energy?

D. de ZEEUW: Simply for financial reasons; a larger source would have been too expensive.

K. KAINDL: May I ask how the financing of the plant has been arranged, and who is to bear the running costs?

D. de ZEEUW: The capital costs are being shared equally between industry and the Government. It is hoped that the pilot plant itself will be able to take care of the running costs; in other words, that they will be paid by the industries that have shown an interest in the plant. I think the Government realizes, however, that not all the running costs will be covered in this way at the outset, and that it will have to make up the difference.
Abstract — Résumé — Аннотация — Resumen

THE 60Co RESEARCH FACILITY AT SEIBERSDORF. The irradiation facility which is now under construction at Seibersdorf was designed especially for research on the International Fruit Juice Programme. The plant consists of two irradiation chambers, with a capacity of 30 kCi and 10 kCi, respectively. The first is proposed to irradiate quantities of fruit juice for feeding tests and for investigations in source technology. The other was especially designed for research purposes in microbiology and chemistry and has an optimal versatility in source configuration and position according to the experiment conditions.

The biological shield, ordinary concrete with a density of about 2.4 ton/m³, gives an outside dose-rate of 0.2 mR/h maximum. The rest position of both sources is a lead cylinder let into the shielding concrete. Twelve stainless-steel tubes (six tubes for the small chamber), in which the cobalt rods are fitted, pass in a spherical ganway into the irradiation chamber. The 60Co rods of the 30 kCi facility, each with an outside length of 300 mm, consist of two linked parts. They may be arranged individually or in any combination within five seconds by an air pressure system. Different tubes with the respective curvature allow practically every arrangement of source geometry. The chamber, measuring 3 x 3 x 3 m inside, may be closed by a concrete door: a binocular periscope enables the scientist to observe the experiment during irradiation.

The other facility, measuring 3.5 x 3 x 3 m inside, can be entered through a labyrinth and has a source activity of 10 kCi. Six rods, with an outside length of 250 mm, may be moved individually by Teleflex cable. They can be stopped in any position desired, measured from the entrance into the chamber.

For observing experiments, a monocular periscope system is installed. The room is controlled at a temperature of between -18°C and +35°C, with an accuracy of ±1°C.

Several tubes, up to a diameter of 300 mm, pass the concrete shield to enable the installation of cables and tubes for experiments. The irradiation time can be set by means of a separate timer, so that the sources may be taken back into the rest position after irradiation, or they may be taken into the irradiation position after expiration of the time, as desired.

The entire plant is automatically controlled and supervised by an interlock system. A system of radiation detectors and mechanical locks secures optimal safety of the plant against accidents. All important aggregates are supplied by a buffered battery so that, even in the case of a voltage breakdown, undisturbed operation is possible.

In the case of defects in important parts of the plant, or wanton damage, an alarm system is triggered off. In acute danger this system immediately takes the sources back into their rest position or, if there is no acute danger, brings them up to the scientist to decide whether or not to continue irradiation.
géométrie. La casemate a intérieurement 3x3x3 m; elle peut être fermée au moyen d'une porte en béton; un télescope binoculaire permet à l'opérateur d'observer l'expérience pendant l'irradiation.

Tout l'installation est réglée automatiquement et contrôlée par un dispositif de verrouillage asservi. Un ensemble de détecteurs de rayonnement et de verrous mécaniques assure à l'installation un maximum de sécurité contre les accidents. Tous les ensembles importants sont pourvus d'une alimentation de secours par batterie, de sorte que, même en cas de brusque coupure de courant, le fonctionnement reste intarouché. En cas de défaillance d'un organe important de l'installation ou de dommages imprévus, un système d'alarme se déclenche. En cas de danger grave, ce dispositif ramène immédiatement les sources à leur position de repos; s'il n'y a pas de danger grave, il les laisse à la disposition du spécialiste qui décide s'il y a lieu de poursuivre ou non l'irradiation.
Para el logro del proyecto internacional de irradiación de frutas y zumos de fruta, se proyecta un sistema de irradiación con una capacidad de 30 kCi y de 10 kCi, respectivamente. La primera cámara ha sido diseñada para efectuar ensayos para determinar el valor alimenticio de los zumos de fruta e investigar la tecnología de la fuente. La segunda cámara ha sido diseñada para realizar investigaciones sobre tecnologías específicas, y ofrece condiciones óptimas para modificar la posición y configuración de la fuente según las condiciones del experimento.

El blindaje biológico es de hormigón ordinario, con una densidad de 2,4 t/m³ aproximadamente, y la intensidad de dosis en su exterior es de 0,2 mR/h como máximo. En su posición de reposo, esto es, cuando no se utiliza, las dos fuentes se encuentran en un cilindro de plomo inserto en el blindaje de hormigón. Una serie de tubos de acero inoxidable -12 en una cámara y 6 en la otra- que se ajustan las barras de cobalto, penetran en la cámara de irradiación a través de un paso de sección circular. Las barras de ⁶⁰Co de la cámara de irradiación de 30 kCi, cada una de las cuales tiene una longitud de 300 mm medida en su exterior, están constituidas por dos piezas unidas. Una instalación neumática permite colocarlas en posición en unos 5 s, bien individualmente o combinándolas de cualquier forma. Los distintos tubos, con su curvatura respectiva, permiten obtener prácticamente cualquier geometría de la fuente. La cámara de irradiación, que mide internamente 3 x 3 x 3 m, puede cerrarse mediante una puerta de hormigón; durante el proceso de irradiación los científicos pueden observar el desarrollo del experimento con un periscopio binocular.

La segunda cámara de irradiación, cuyo interior mide 3,5 x 3 x 3 m, tiene una entrada del tipo de laberinto y la actividad de su fuente es de 10 kCi. Sus seis barras, de una longitud de 250 mm medida en su exterior, pueden desplazarse independientemente unas de otras mediante una instalación de cable Teleflex. Este desplazamiento puede interrumpirse a voluntad cuando la barra ha alcanzado la posición deseada, medida a partir de la entrada en la cámara. Esta segunda cámara dispone de un periscopio monocional para observar el desarrollo del experimento. Su interior se mantiene a una temperatura comprendida entre -18°C y +35°C que puede regularse con una aproximación de ± 1°C.

El blindaje de hormigón queda atravesado por varios tubos de un diámetro de 300 mm, como máximo, que permiten el tendido de cables y tubos para la realización de los experimentos. El tiempo de irradiación puede regularse de antemano mediante un cronorregulador independiente, de modo que las fuentes se pueden retirar hasta su posición de reposo después de la irradiación o pueden colocarse en su posición de funcionamiento una vez terminado el tiempo prefijado, según se prefiera.

El funcionamiento de la planta está automáticamente controlado por un sistema de dispositivos interconectados. Un sistema de radiodetectores y cierres mecánicos proporciona a la planta condiciones óptimas de seguridad. Todos los conjuntos principales están alimentados con una batería compensadora, de modo que incluso en el caso de un corte de corriente, la planta puede seguir funcionando.

Si se deteriora algún elemento importante de la planta, entra en acción un dispositivo de alarma. En caso de grave peligro ese dispositivo hace que las fuentes vuelvan inmediatamente a su posición de reposo; si el peligro no es grave, las pone al alcance del científico para que éste decida si debe o no continuar la irradiación.

1. CONCEPTUAL DESIGN OF THE FACILITY

For the accomplishment of the International Fruit Juice Project a large irradiation facility is under construction, which will be useful not only for biochemical and microbiological investigations, but also for source technology. All requirements, especially optimal versatility for radiation-chemical experiments under special conditions – for example, various temperatures, inert-gas atmosphere, pressuré, etc. – can be satisfied only by a dry-irradiation facility consisting of two chambers. These chambers are to conform to the dimensions of a small laboratory, be supplied with all connections and ought not to need specialists to operate them. Figure 1 shows the floor plan of the building.

The irradiation chamber, with a capacity of 30 kCi (equivalent to 444 W), is useful for technological investigations and permits conclusions to be made in respect of industrial facilities. The through output of
about 24 Mrad kg/h (efficiency = 15%) is sufficient to produce irradiated feed for wholesomeness tests without disturbing continuous experiments. The irradiation chamber with the smaller capacity (maximum 10 kCi), has been equipped as a pure research facility. In this facility the irradiation temperature can be chosen and the configuration of the source can be adapted within one hour to the conditions of the experiment concerned. Furthermore, the irradiation position of the source can be adjusted as desired, independent of the tube end.

2. SHIELDING

The biological shield consists of normal concrete with a density of 2.4 ton/m³ (150 lb/ft³). The dose-rate in the adjoining rooms amounts to a maximum of 0.2 mR/h.

Both irradiation chambers have an inside dimension of 3×3×3 m. The large facility can be entered through a door of concrete; the small one has a labyrinth entrance. For observation of the chamber during an experiment there are periscope systems in both facilities, each with an adjustable viewing angle up to 60°. The observation system for the large facility is binocular, and photographs can be taken during irradiation. In the small facility space has been left for a glass window, which can be installed later. In addition, there are plans to complete both facilities by a Master-Slave Manipulator, for which two tubes have already been installed in each chamber. There are also numerous tubes of diameter 105 mm (about 4 in. each) for the later installation of cables.
and pipes. They have two bends, and lead into the operation room or into
the engine room above the facility. There are also three straight tubes
of diameter about 300 mm (12 in.) in each chamber to permit installation
of the conveyor belt.

The large facility has a ventilator system only; the smaller one is air-
conditioned and the temperature in the entire chamber can be stabilized
between -18°C and +35°C, with a tolerance of ±1°C. A resistance thermo-
meter, which is connected with a multi-channel point printer, measures
the temperature in both chambers.

3. SOURCE OPERATION

The cobalt rods of both facilities have an active length of about 250 mm
and they are tightly welded into stainless-steel tubes. Figure 2 shows the
moving system for the large and small facilities. The conduction of the
active material is effected in steel tubes which lead from the irradiation
chamber through a bent spheric gangway to the rest position. The latter
consists of a cylinder of lead, which is mounted in the shield. The canal
in which the tubes are situated is lined with sheet steel and filled with
barytes sand (Fig. 2).

The large facility contains twelve of these tubes, which can be drawn
down to the proper length from the ceiling of the irradiation facility. At
an admissible minimum radius of 1000 mm (40 in.) any desired source
configurations (plates, cylinders) can be obtained. As shown in Fig. 3.
this source consists of two parts which are connected by a ball joint. The rabbit, which is also connected by a joint, is sealed off by bronze rings. The end position is carried out over a length of 400 mm as a smooth tube and guarantees precision of the axial source position of better than 0.5 mm.

![Fig. 3. Cobalt-60 source - end position](image)

This degree of precision guarantees safe use of high dose-rates near the tube. The twelve sources can be set to the irradiation position singly, or in optional combinations, within 5 sec. To control the source near the end position the progress of pressure in the pneumatic system is used, whereby any end contact is avoided.

The small facility contains six rods, each of which consists of one piece and can be moved by a Teleflex cable. The drive is effected by a 24-V DC motor of 0.12 HP, which is connected to a pulse transducer. This makes it possible to stop the source in any desired position, measured from the entrance into the chamber; thus, source configuration and the position can be adapted to the conditions of the experiment. The minimum radius of the conductor tubes is 800 mm.

About one hour is required to change an existing configuration. The end position of this facility guarantees an axial accuracy of source position of better than 0.1 mm.

4. INTERLOCK SYSTEM

The whole facility is automatically regulated and controlled. All the important aggregates are supplied by a buffered battery of 24 V. Even in the case of a voltage breakdown, undisturbed operation is possible for more than a week.

The supply of compressed air is provided by a compressor and an air chamber containing 300 l. All regulating functions are controllable, not only mechanically, but also with a radiation detector to guarantee safe operation. The pneumatic system is tested by compressed air before the irradiation sources are introduced. In the case of defects, or wanton damage to important parts of the plant, an alarm system is triggered off. A major alarm means acute danger to the operator. In this case the sources are withdrawn immediately and, at the same time, an acoustic and optical warning system goes into action as follows:

(a) An alarm is set off when a temperature of 105°C is exceeded. In each irradiation chamber there are four fire detectors which react to temperatures of 60°C and 105°C, respectively. If inadmissible temperatures occur during an experiment, and if all fire detectors
respond, then a major alarm is set off. If the sources are in the emerged position, then they will be withdrawn to their rest position at once and, at the same time, a CO₂ fire-extinguisher will go into operation;

(b) When all sources are in the rest position, and an inadmissible dose-rate is still indicated in the irradiation chamber, a major alarm is automatically set off. Control of the irradiation is effected by two G-M counters, which cover a range of 1mR to 10kR/h. The indication is effected in the range from 1mR/h to 1R/h by a logarithmic rate-meter and in the range above 1R/h by an optical indicator. At an adjustable level between 100 and 200 mR/h a major alarm operates when all the sources are indicated at rest position at the same time. A fixed level, at about 2 mR/h, is maintained by a small caesium-137 source, thus making continuous function control possible;

(c) When the level of irradiation lies above the adjusted rate and when a door contact is opened, a major alarm results;

(d) A major alarm can be induced at once by a scram button in each irradiation chamber. This button is especially marked and is under glass.

In all cases in which a defect in the installation cannot give rise to direct danger to persons, a preliminary alarm is induced, which is marked by an optical indicator and a bell. This warning service can be re-set, and thus leaves the decision as to whether to continue the experiment or not to the scientist. A preliminary alarm is induced in the following cases:

(i) When the lower temperature limit (60°C) is exceeded;
(ii) When the current supply for the DC motors, which operate the 10 kCi source, fails;
(iii) When the lower limit of the radiation detectors is exceeded (damage to cables);
(iv) When the current supply (220 V AC) fails;
(v) In the case of a breakdown in the air-pressure system; and
(vi) When the battery charger fails to operate.

For special purposes, i.e. installation of the source, cleaning the conductor tubes, or in the case of accident or fire, the interlock system, or parts of it, can be blocked. In addition, the sources can be withdrawn from the rest position when the system of motion is blocked (e.g. damage to cables).

5. TECHNICAL DATA OF THE PLANT

All the control instruments and service elements of the plant are in the operation room, from which all functions can be controlled. Introduction of the sources takes place automatically after adjustment of the irradiation time, and according to selection of the desired elements. Numerous control elements prevent faulty operation, and thus possible accidents during operation.

It is also possible to achieve discontinuous irradiation of substances by pushing the selected cobalt-60 bars forward step by step. Depending upon the planned charge of the plant, the following characteristic data are to be expected:
(a) Large facility

Activity: 30 kCi cobalt-60

Shape of sources: bipartite cylinders with an outside length of 320 mm and minimum diameter of 32 mm

Number of sources: 12, which can be moved by compressed air, independently of one another

Conductor tubes: stainless-steel, inside diameter — 34 mm, thickness — 2 mm, minimum radius — 1000 mm

Presumed inhomogeneity in the longitudinal axis: +5%, -15%

Effect of dose in formation of a cylinder of diameter 20 cm: about 2.58 MR/h

Theoretical through output of (n = 100%): 160 Mrad kg/h

Precision of the end position: radical < 0.5 mm, axial < 3.0 mm

Time needed for the source to run between rest position and irradiation chamber: less than 5 sec

Time of manipulation for changing source configuration: about 8 h

Dimension of the irradiation chamber: 3 x 3 x 3 m

Entrance into the irradiation chamber: door of concrete with a weight of 19 ton, which can be moved by a motor

Time needed for closing: about 1 min

Inside diameter: 2000 x 1300 mm

(b) Small facility

Activity: 10 kCi cobalt-60 (148 W)

Shape of the sources: single cylinders with an outside length of 277 mm and an active length of 251 mm

Maximum diameter: 17 mm

Number of sources: 6, which can be moved over a Teleflex cable by a driving motor, independently of one another

Conductor tubes: stainless-steel, inside diameter — 27 mm, thickness — 1.5 mm

Effect of dose in formation of a cylinder, diameter 20 cm: about 0.86 MR/h

Precision of the end position: radial ~ 0.1 mm, axial < 1.0 mm
Precision of the statement of position given by the pulse transmitted before reaching the end position: \( \pm 3 \) mm

Radial divergence outside of the end position: \( \pm 5 \) mm

Time needed for the source to run to the end position: maximum 50 sec

Time of manipulation for changing configuration of the source: about 1 h

Dimensions of the irradiation chamber: \( 3 \times 3 \times 3 \) m

Inside length of the labyrinth entrance: 1400x2000 mm

REFERENCES


DISCUSSION

H. A. MUGLIAROLI: I should like to ask Dr. Weidinger whether the labyrinth of the irradiation chamber was designed from experimental data or whether its shape was determined by some more elaborate method.

N. WEIDINGER: We calculated attenuation and scattering at the labyrinth entrance, although an exact solution is impossible for scattering. In the main we used experimental data supplied by Brookhaven National Laboratory, and I might say that we are grateful to Mr. Kuhl for his helpful suggestions. At the moment we are measuring energy and dose-rate at the labyrinth entrance, and we hope to find a more exact method.
THE ISRAEL FOOD IRRADIATION PROGRAMME AND PROGRESS DURING 1964 - 1966

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Abstract — Résumé — Аннотация — Resumen

THE ISRAEL FOOD IRRADIATION PROGRAMME AND PROGRESS DURING 1964-1966. The Israel programme on the irradiation of agricultural produce is being co-ordinated by a committee set up by the Israel National Scientific Research Council, consisting of representatives of the Israel Atomic Energy Commission (AEC), the Ministry of Agriculture, and the various growers and marketing associations. The programme is threefold: to obtain Government approval of crops already licensed elsewhere (potatoes, onions), to work on local problems (apricots, pears) and on items of export importance (citrus, bananas, avocados).

A 30 000 Ci source was installed in a versatile irradiator of novel design. Objects ranging from a few grams to 50 kg are treated with 20 to \(5 \times 10^6\) rad doses at dose-rates of 1.5 to 800 krad/h.

For citrus, the effects of growing conditions, maturity, irradiation conditions and storage temperature were investigated. Seven million irradiated Mediterranean fruit flies were released per week in a test programme. The lethal doses for immature stages of fruit fly were determined.

Summer- and winter-crop potatoes of the "Up-to-date" variety were stored up to 12 months at different temperatures, after irradiation at different doses and dose-rates, in 40-kg batches.

Tests are being made on the effectiveness of irradiation in delaying sprouting in onions. Delay of maturation in bananas from three climatic regions and in avocados of three varieties is being tested.

Preliminary experiments were conducted on sugar beets to prevent loss of sucrose between harvesting and extraction, on dehydrated vegetables to reduce cooking time, on filled chocolate confectionery for insect disinfestation, and canned juice from irradiated oranges.

LE PROGRAMME ISRAELIEN D'IRRADIATION DE DENREES ALIMENTAIRES ET SON EVOLUTION ENTRE 1964 et 1966. Le programme israélien d'irradiation des produits agricoles est actuellement coordonné par un comité créé par le Conseil national de la recherche scientifique d'Israël, qui se compose de représentants de la Commission israélienne de l'énergie atomique, du Ministère de l'agriculture et des diverses associations de producteurs et de distributeurs. Ce programme a un triple objectif: obtenir l'approbation du Gouvernement pour les produits déjà autorisés ailleurs (pommes de terre, oignons), étudier les problèmes locaux (abricots, poires) et les problèmes d'exportation (agrumes, bananes, avocats).

Une source de 30 000 Ci a été montée dans un irradiateur à usage multiple de type nouveau. Cet appareil traite des articles d'un poids variant de quelques grammes à 50 kg à des doses de 20 à \(5 \times 10^6\) rad selon un débit de dose de 1.5 à 800 krad/h.

Pour les agrumes, les auteurs ont fait des recherches sur les effets des conditions de croissance, de la maturité, des conditions d'irradiation et de la température de stockage. Dans le cadre d'une campagne d'essai, on a lâché par semaine 7 millions de mouches méditerranéennes des fruits irradiées. Les auteurs ont déterminé les doses mortelles pour les stades non adultes de la mouche des fruits.

Les auteurs ont stocké, pendant des périodes allant jusqu'à 12 mois et à des températures différentes, des pommes de terre d'été et d'hiver de la variété "Up-to-date", après irradiation par lots de 40 kg à des doses et débits de dose différents.

Ils procèdent actuellement à des essais en vue de déterminer dans quelle mesure l'irradiation retarde la germination des oignons. Ils poursuivent également des essais sur le retardement de la maturation de bananes provenant de trois régions climatiques, et de trois variétés d'avocats.

Des expériences préliminaires sont actuellement effectuées sur les betteraves à sucre pour empêcher la perte de sucre pendant la période qui s'écoule entre la récolte et l'extraction, sur les légumes déshydratés pour réduire le temps de cuisson, sur les bonbons en chocolat fourrés pour la désinfection, et sur les jus d'orange en boîte provenant d'oranges irradiées.

ИЗРАИЛЬСКАЯ ПРОГРАММА ПО ОБЛУЧЕНИЮ ПИЩЕВЫХ ПРОДУКТОВ И УСПЕХИ, ДОСТИГНУТЫЕ В ЭТОЙ ОБЛАСТИ В 1964 - 1966 ГГ. Программа по облучению сельско-
The program of food irradiation in Israel during the period 1964-1966.

Since 1960, exploratory studies on food irradiation have been made in Israel, mainly on the control of rot [1], the effects on the respiration rate [2, 3] and on the juice constituents of oranges [4], in-vitro studies of the rot-causing pathogens [5, 6, 7], and studies of preliminary design and cost estimates for a commercial-scale irradiator to be used for seasonal crops [8]. These studies followed economic-technological surveys [9, 10, 11, 12] which showed that the biggest potential commercial application for
radioisotopes and radiation in Israel was the radiopasteurization of the citrus fruit crop.

The initial experimental work used at first an adapted teletherapy unit with a maximum flux of about 10 kR/h and later a Gammacell 200, which had a flux of about 400 kR/h but could accommodate only relatively small targets.

In 1964, the Industrial Applications Department of the Soreq Nuclear Research Centre was expanded to include a Large Radiation Sources Branch which incorporated an Agricultural Applications Group.

2. PLANNING OF THE ISRAEL PROGRAMME FOR EXPLOITATION OF LARGE RADIATION SOURCES

A 1964 re-survey of the economically attractive potential uses of radiation [13] confirmed that uses in Israel industry and medicine were relatively limited, but that major industries could be developed for preserving fresh fruit and vegetables, both for the local market and for export. Citrus was again the largest single potential commodity fruit, but the long-range possibilities could not be accurately estimated. No successful irradiation technology had yet been developed and, no less important, the development and application of suitable technology in Israel would involve the installation of radiation capacity that would be used for the citrus crop during less than 30% of the year. Furthermore, all other possible agricultural and industrial uses during the off-season could not utilize more than 10% of this radiation capacity. However, in estimating the long-range potentialities of irradiated citrus, the most difficult point was the lack of international legislation for wholesomeness approval of irradiated foodstuffs.

The bulk of the local citrus crop is exported to about ten major importing countries, few of which had any legislative machinery, even for authorizing human consumption of foodstuffs irradiated in their own countries. Apart from France, where an application for the licensing of irradiated potatoes had been submitted, no approvals were anticipated in the foreseeable future. Even if the Food and Drug Administration (FDA) in the United States approves the submitted petition on citrus, and the approval for sale of irradiated citrus in Israel is obtained from the competent public health authorities, it can only be guessed how long it would take to obtain foreign clearances for the importation of Israel-irradiated citrus fruit.

A programme for introducing irradiated foodstuffs in Israel was therefore established, with the goals of obtaining fairly rapidly, health authority approval for locally consumed commodities and of simultaneously developing new processes which could be commercially exploited only somewhat later. The third main goal was the development of a satisfactory technique for irradiating citrus.

This proposed programme [14] was based on the following three premises:

(a) Government (Ministry of Health) approval of wholesomeness should be readily obtainable for foodstuffs already approved elsewhere (potatoes, onions) if it is demonstrated that the local varieties yield satisfactory results, and if the radiation technique is economically more advantageous than existing procedures;
(b) Work would be done on crops which presented serious local storage or marketing problems (e.g. apricots and pears). For both these fruits, the literature was conflicting. Furthermore, there were still no wholesomeness approvals abroad, although the feeding tests results were sufficiently advanced and promising to anticipate FDA approval within two to three years in the United States. There were chances of developing a successful technology if sufficient effort was made on the most favourable varieties.

(c) Crops with large or potentially expandable export markets would be investigated. The three crops selected were citrus fruit, banana and avocado.

Israel citrus, oranges in particular, is pre-eminent in the world for its quality. However, the long sea voyage, of about three weeks, to export markets necessitates either expensive refrigerated shipping or the use of the unpopular, diphenyl-impregnated wrapping paper to prevent the development of storage mould rots, with consequent lowered market prices and, more important, damage to the reputation for quality won by Israel fruit in the consumer market. Bananas can be shipped by sea without refrigeration to markets as far as Italy. An exception, however, is fruit grown under unfavourable climatic conditions which ripen more quickly with greater spoilage losses. A process which would prolong the maturation process by two to four weeks could guarantee delivery in good condition to existing markets without resource to refrigeration, and could also make possible export to more distant markets. Avocado pears are a relatively new Israel export which have won an important market because of their superior quality. However, since fruit normally matures 8-15 days after picking, it is flown to Europe to ensure prime quality when retailed. Air shipment costs $70 - 80/ton, and a process which would retard maturation could save most of this.

The results of experiments on citrus in several countries, including Israel, indicated that a successful technology could probably be developed. Proper exploitation of an irradiation technology for citrus would require tens of irradiators, each containing at least one megacurie of cobalt-60. Both the large potential market for radiation sources and the importance of citrus as the pre-eminent Israel agricultural export justified devoting the major portion of the food programme to various aspects of citrus irradiation.

Recent experimental evidence on irradiating bananas with 10 - 40 krad doses indicates that maturation could be delayed in some varieties for 10 to 20 days [15, 16]. The United States Atomic Energy Commission was preparing a wholesomeness petition and expected FDA approval by 1969 [16]. Therefore, an effort on the local dwarf Cavendish variety, for which no literature references were found, was justified. A successful technology could extend the marketing period for the local market to one month during the hot season when natural ripening is most rapid. Thus irradiation would be useful even before approval of irradiated fruit could be obtained in the importing countries.

Avocados resemble bananas in that both are picked in a hard, inedible condition and soften and become edible when ripe. With most avocado varieties, however, the ripening process is usually more rapid. No literature references were found on irradiation of avocado. The authors' exploratory tests on Fuerte avocados during 1964/65 showed that a wide
range of doses delayed maturation, but also caused deleterious changes in the peel and edible portion [17]. Several varieties are exported, each with markedly different physiological properties. Israel avocados are infected by a latent, indigenous pathogen which "hibernates" after falling onto the growing, unripe fruit and develops only after the fruit has softened and become edible, forming unsightly dark stains in the peel and the pulp. This rot development is similar to one recently described in bananas [18].

3. EXECUTION OF THE ISRAEL FOOD IRRADIATION PROGRAMME

Proposed research and development (R and D) programmes were drawn up for the crops mentioned in the previous section. A number of others (for various dried foods and freshly slaughtered poultry) were prepared after consultation with various agricultural specialists at the Ministry of Agriculture, at one of the Agricultural Research Institutes, or with the producers or marketing organizations. An interdepartmental governmental committee was set up to co-ordinate the various parts of the proposed programme, to decide on the order of priority, to finance and to supervise the progress of the programme. The Israel National Science Research Council had decided to support the proposed programme and offered to match dollar for dollar R and D funds provided by other bodies. Because the general public's natural fear of the word "radiation", due to its association with nuclear arms and devastation, a public education and enlightenment programme would be required to ensure consumer acceptance of irradiated food. It was clearly advantageous that the Food Irradiation Programme should be under the direction of the independent and unbiased National Science Research Council, since the Atomic Energy Commission and the Ministry of Agriculture might be considered biased in their evaluation.

The chairman of the committee is a representative of the National Science Research Council, with other members representing the Ministry of Agriculture, the Atomic Energy Commission and an independent leading agronomist, a specialist in citrus. Two sub-committees, for citrus fruit and for other fruits and vegetables, also include representatives of the research institute where the research is being done, and of the relevant producing and marketing organizations; specialists on the specific topics, and the senior scientists responsible for execution of the programmes, attend as observers.

The subcommittee recommends programmes, suggests new topics for investigation, and is responsible through its chairman for supervision of the execution of the approved programme.

The committee added to the programme investigation of the radiation-pasteurization of green bell peppers and strawberries. It was decided to postpone the investigations of grain, other dried foodstuffs, meat and fish products.

4. IRRADIATION FACILITY AND DOSIMETRY

The irradiation facility and dosimetry are described in another presentation at this Symposium [19].
Suitable containers for grapefruit, oranges, potatoes, onions, bananas, avocados, strawberries, fruit-fly pupae, chocolate, and dehydrated vegetable flakes have been prepared. Some of these containers are insulated, making possible irradiation in gases other than air, and some variation of temperature.

These containers were calibrated for dose distribution. A dose uniformity of better than ±10% for most of the containers is usually attained by turning the container back to front at half-dose. Dosimetry is routinely checked by attaching a pair of either glass or Fricke dosimeters to the centre of each container irradiated. For doses above the range of these dosimeters, the check dosimeter is irradiated for only a portion of the total irradiation time. For doses below the minimum dosimeter sensitivity, the irradiation time is calculated; this has been found satisfactory for doses as small as 20 rad.

5. EXPERIMENTAL RESULTS

None of the harvesting seasons had ended when this paper was written, and the final results for each item investigated will be reported elsewhere. The results presented here are therefore in the form of progress reports and subject to review.

5.1. Citrus

Shamouti oranges and grapefruits were irradiated with doses of 10-200 krad at dose-rates of 10-190 krad/h. The surrounding atmosphere was either air or nitrogen. For the latter, the fruits were usually stored overnight before irradiation in a closed nitrogen environment, and a slow stream of nitrogen gas was passed through the container during the irradiation. Irradiations in air were made either in the normal atmosphere of the "cave" or in a closed container through which was passed a stream of air to remove the ozone formed among the fruit during the irradiation. Fruit was usually irradiated three to five days after picking, though a few experiments were made after longer intervals. Fruit was obtained both from selected trees in experimental groves and from central packing houses. The commercially picked fruit was irradiated both after preliminary culling at the packing house and after the various washing and waxing procedures employed there. Some of the fruit was also waxed in the laboratory before irradiation. The fruit was stored at both 2° and 15°C for six weeks after irradiation, was inspected once weekly and scored for external appearance. The usual experimental unit was a Bruce box containing about 13 kg fruit.

The effects of radiation on various peel constituents and enzyme activities are being investigated in a separate series of experiments. The initial results of gamma radiation on green and ripe Shamouti fruits have been published [20]. Results obtained with Valencia oranges and grapefruits and the comparative effects of electron and gamma radiation are reported elsewhere [21].

1 With S. Ben-Yehoshua of the Volcani Institute of Agricultural Research, Rehovot.
2 With S. P. Monselise of the Faculty of Agriculture, Hebrew University, Rehovot.
Disinfestation from Mediterranean fruit fly has been investigated\(^3\) by in vitro determination of the lethal and sterilization doses for the various immature fly stages. It was found that 5.5 krad was sufficient to prevent emergence of viable adults from any of the stages in laboratory-bred stock and will probably constitute a sufficient dose for quarantine purposes.

5.2. Sprouting control in potatoes\(^4\)

Summer crop "Up-to-date" variety potatoes harvested in late June 1965 were withdrawn from cold storage after about eight weeks at 8°C. They were irradiated 3 - 10 days later, i.e. at the end of August, when the tubers were at the end of their dormancy, with 6, 10, or 14 krad at two dose-rates (19 krad/h and 76 krad/h). The experimental unit was one sack containing about 42 kg. For most of the irradiations, this quantity was divided between two boxes and several string bags holding 1.5 kg. The boxed tubers were returned to the sacks after irradiation, but those in the string bags were weighed and left in the bags for checking loss in weight during storage. The sacks of tubers were stored at 4°C, 8°C and 14°C and at ambient temperature, in a blacked-out room for seven storage periods ranging up to 12 months. The 168 sacks (7.5 tons) of potatoes needed for the experiment required about eight days of irradiation time.

After each storage period the sacks were removed, then inspected 24 hours later, and scored for per cent and degree of sprouting, per cent and type of rot, general appearance, and loss in weight. The tubers, including those showing rot, were returned to the sacks covered to exclude light, and held for four more weeks under ambient conditions in an open shed. Inspection and scoring were repeated after two and four weeks under ambient conditions. The effects of irradiation were compared with those of treatments with the chemical sprouting controllers, maleic hydrazide (MH-30) and chloro-isopropyl N-phenyl carbamate (CIPC). To date, inspections after four storage periods have been completed, the first being five weeks of storage and the most recent, in February, 24 weeks after irradiation and eight months after harvest.

At the first inspection (October 1965), 80% of the non-irradiated controls stored at room temperature had sprouts up to 15 mm long. In those stored at 4°C and 8°C, there was about 50% incipient sprouting up to 2 mm long. After two weeks under ambient conditions, the cold-store control showed almost 100% sprouting, with sprouts up to 15 mm in length. The tubers irradiated with 6 krad showed some incipient sprouts, which continued to grow up to 15 mm long after the four-week holding period. There was some incipient sprouting with the 10 and 14 krad treatments, but the length did not exceed 6 mm during the four-week holding period. These irradiated potatoes were still sound and in good condition with acceptable organoleptic and cooking properties in March 1966, that is after 24 weeks under ambient conditions.

At the fourth inspection, 24 weeks' storage after irradiation, the controls at 14°C had sprouts 150 mm long, about 75% of controls from 4°C cold store had sprouts 4 mm long; after four weeks under ambient conditions, there was 100% sprouting with sprouts 15 mm long. Ten krad

\(^3\) With D. J. Nadel and B. A. Peleg, Biological Control Unit, C.M.B., Rehovot.

\(^4\) With Mrs. N. Temkin-Gorodeiski, Volcani Institute of Agricultural Research, Rehovot.
doses reduced initial sprouting to 5% and 15% at 4° and 14°C storage, res- spectively, with almost no growth of the initial sprouts during the four weeks under ambient conditions. Rots were somewhat more prevalent than for corresponding controls under some of the experimental conditions. The lower irradiation rate usually gave slightly less sprouting control and caused a somewhat higher incidence of rots than the higher irradiation rate.

Two experiments were started on "Up-to-date" potatoes during the winter of 1965-1966, using crops harvested in early December and late January in two separate growing areas in southern Israel. The first crop was picked under difficult climatic conditions. The tubers were irradiated on three dates 15, 25 and 50 days, respectively, after cleaning, to test the effect of pre-irradiation delay, both on sprouting control and on tubers damaged during sorting. Doses of 6, 10 and 14 krad applied at about 75 krad/h were used, as for the summer crop. The potatoes were then stored at 8°, and 14°C, to be inspected during an eight-month period.

The experiments on the tubers harvested in late January were planned to test the effects of five closely-defined doses (5, 7, 9, 11 and 15 krad ± 10%) on the delay of sprouting during specific storage periods at three different storage temperatures (8° and 14°C and ambient in a darkened, ventilated room). The effect of two delays; up to 60 days, prior to irri- diation was also tested at two doses (5 and 15 krad) and at two dose-rates (19 and 76 krad/h). Since in Israel the winter crop is normally consumed during the months January to June, and the natural dormancy of the tubers in about 120 days, smaller doses may be sufficient for adequate sprouting control of this crop during relatively short storage periods.

5.3. Onions

The main onion crops in Israel are collected during the period May to September, and the better storage varieties are stored at 0°C until about December. From January, there are serious losses even in cold storage, and imported onions are often used until the new crop is harvested. A new locally-developed variety – the Beit Alpha onion, derived from a Spanish variety – matures in December to January under special culti- vation techniques, and can be stored until about March. It was being raised during 1965/66 on a pilot-plant scale in several growing regions in an attempt to supply local produce on a year-round basis.

The Israel Food Irradiation Programme called for work on sprouting control with the three important local onion varieties, but it was decided to start irradiation tests on the experimental Beit Alpha variety, which was the first onion crop to be harvested after the programme had been approved.

Beit Alpha onions, grown in the Lachish hill region near the northern Negev, were harvested late in December 1965 and irradiated 1, 20 and 35 days after cropping with 2-, 7- and 12-krad doses. In another experiment, Beit Alpha onions grown in the Jordan Valley and harvested at the end of December were irradiated 15, 28 and 40 days after cropping, also with 2-, 7- and 12-krad doses.

The onions were carefully selected before irradiation to remove those which showed signs of fresh sprouting at the time of harvesting. Some
secondary experiments were made to ascertain whether the storage of sprouted onions could be improved by irradiation.

After irradiation the onions were stored in boxes at 0°C and under ambient conditions in a wire-walled shed. Commencing two weeks after irradiation, they are being inspected every three to four weeks, and scored for appearance, external sprouting, percent and type of rots. Internal sprouting is checked on a few bulbs during the routine inspections. The results are also being compared with those obtained with MH-30.

There is little to report from the storage tests, as the controls have not yet sprouted very much. However, accelerated growth tests, using the Japanese technique of planting the bulbs in water, as reported by Hori et al. [22], showed marked differences between irradiated and non-irradiated bulbs. Within one week after planting, only the non-irradiated control had grown fresh roots. After 45 days, the control showed vigorous root and top growth. With 2 and 7 krad there was only very feeble new root growth, which stopped shortly after appearance of the root tips. A dose of 12 krad prevented growth.

Bulbs that had sprouted in the field had more root growth after 7- and 12-krad doses than the selected bulbs which had received 2 krad. The sprouting continued slowly for some time and then stopped and wilted.

5.4. Avocados

Four varieties of avocado (Ethinger, Fuerte, Nabal and Hass) were irradiated with 10–80 krad on the day of picking and after various delays ranging up to five days after picking. Delay in ripening with a given dose was most marked for irradiation soon after picking. For the early variety Ethinger, which is a local selection from Fuerte stock, ripening was delayed for some days without damage and for up to 35 days, but with serious deleterious effects. The experiments made this season with Fuerte, irradiated in an atmosphere of air, did not give satisfactory results, but a nitrogen atmosphere before and during irradiation caused some improvement. It should be mentioned that this was not a good season for Fuerte avocados in Israel; this may explain why the Fuerte, which is normally less delicate than the Ethinger, has been less radioresistant. Irradiating at lower dose-rates and temperatures did not cause marked improvement.

5.5. Bananas

Bananas, harvested the same day in mid-December 1965 in three growing regions (Western Galilean coastal plain, Jordan Valley and at Hulda, near the Jerusalem foothills) were irradiated with 10–40 krad after intervals ranging from 24 hours to 7 days after picking. Marked differences were reported by Teas et al. [23] in Puerto Rico, who presumably worked with freshly picked fruits, and by workers in Britain, Norway, Canada and the United States, who used bananas shipped from the tropics and which were green, but close to their natural de-greening.

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6 With M. Nadel-Shifman and G. Zauberman, Volcani Institute of Agricultural Research, Rehovot.
7 With Mrs. N. Temki-Gorodeiski and Y. Aharoni, Volcani Institute of Agricultural Research, Rehovot.
Wide variations were found in results, due to the different radiation response of "hands" taken from various parts of a single stem, and subjected to identical treatments.

In an experiment on bananas picked in mid-January at Huida, portions of the same "hands" were treated with 10 - 80 krad at various times after picking. Ten- and 20-krad doses sometimes caused marked delay of maturation. The delay caused by 80 krad was less than for 10 - 20 krad, while 60 krad appeared to cause some acceleration of maturation. Ferguson et al., in Canada, reported initial acceleration of maturation by 25-krad doses administered to Gros Michel bananas grown in Honduras [24].

Irradiation of whole stems may prove feasible if the stems are de-greened before final marketing since, as is well known, variations in de-greening disappear after ethylene treatment, and the fruit is of a uniform colour.

5.6. Sugar beets

In a single experiment on sugar beets in June 1965, 20-kg batches were treated on the day of harvesting with four doses in the 1-20-krad range, and with 100 krad. The sugar content was analysed 1-10 days later. Irradiation, even the smallest dose, apparently prevented the natural decrease in sugar content which occurs during post-harvest storage of beets prior to the extraction of sugar. These preliminary results require careful confirmation. A sufficient number of replicates must be used because of the natural wide range of sugar content in individual beets.

5.7. Dehydrated vegetables8

Dehydrated carrots, beets and potatoes were irradiated with doses of up to 5 Mrad and then tested for softening time in cooking and for organoleptic properties. Preliminary experiments yielded carrots of excellent quality and markedly reduced cooking time.

5.8. Chocolate confectionery9

Filled chocolates, heavily infected with the saw-toothed grain beetle (Oryzaephilus surinamensis) were treated with 20 krad. In one sample, four adult beetles were dead 12 days after irradiation, and the remaining 28 adults had all died before a second examination 40 days later. All immature stages were killed, as well as all other insects present.

5.9. Canned juice from irradiated oranges10

Juice expressed from Shamouti oranges, irradiated with doses of up to 500 krad, has been canned and is being stored prior to chemical analysis and organoleptic testing.

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8 With P. Levi, Deko Ltd., Bror Hayil, Israel.
9 With J. Donahaye, Stored Products Division, Ministry of Agriculture, Jaffa.
10 With Z. Stuhl, Z. Berk And M. Lapidot, Techion Institute of Technology, Haifa.
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Much of the agricultural and biological testing was carried out in the Volcani Institute of Agricultural Research, Rehovot. That of the Mediterranean fruit fly was done in the Biological Control Institute of the Citrus Marketing Board, and on chocolate disinfection by the Stored Products Division of the Ministry of Agriculture.

Work on sugar beets and dehydrated vegetables was in collaboration with the Sugat and Deko factories.

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A VERSATILE COBALT-60 IRRADIATION FACILITY WITHIN A SWIMMING-POOL RESEARCH REACTOR

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Abstract — Résumé — Аннотация — Resumen

A VERSATILE 60Co IRRADIATION FACILITY WITHIN A SWIMMING-POOL RESEARCH REACTOR. The IRR-1 enriched-fuel swimming-pool-type reactor incorporates a concrete-shielded gamma cell for using the radiation from spent fuel elements. A versatile 60Co irradiation facility was added at relatively low cost.

The 30 000 Ci 60Co source runs on a carriage at the bottom of the reactor pool. The source plaque completely covers the aluminium window between the pool and the irradiation cell. This geometry allows for a "source-to-target" overlap; therefore, dose-rate homogeneity within ±20% is attained inside two commercial cases (43 x 31 x 31 cm) or two commercial sacks (80 x 45 x 45 cm) and within ±10% in two flat boxes (40 x 20 x 5 cm) irradiated simultaneously.

A set of steel and aluminium screens attached to two rotating turn-tables permits irradiation of commercial cases at any desired dose-rate smaller than 100 000 R/h without the need for turning over at half-time.

Two special underwater canisters allow long-term irradiation of flat specimens at dose-rates of less than 50 000 R/h, while the source is used for normal short-term irradiations in the gamma cell.

Safety is ensured by a visible and audible indicator and alarm system and by an elaborate interlock system. A system of ionizing gauges and recorders permits measurement of dose-rates over the range 0.001 to 1 000 000 R/h. Isodose curves for the irradiation chamber have been determined.

The cell is soon to be modified to include a refrigeration plant and a timing system for automatic control of source movement.

The disadvantages of low source utilization inherent in required source-to-target overlap and of one-sided utilization of the radiation are more than compensated for by the possibility of pilot-scale irradiation of commercial cases and by the greater versatility and low cost.

This installation is therefore recommended for all similar swimming-pool reactors. It is especially valuable for countries desiring to embark on a food irradiation programme at minimum cost but with maximum experimental versatility.

INSTALLATION D'IRRADIATION AU 60Co A UTILISATIONS MULTIPLES DANS UN REACTEUR PISCINE DE RECHERCHE. Le réacteur piscine IRR-1, à combustible enrichi, comprend une cellule gamma blindée en béton pour l’utilisation des rayonnements émis par les éléments combustibles irradiés. On y a ajouté, pour un prix de revient relativement réduit, une installation d’irradiation au 60Co à usages multiples.

La source de 60Co de 30 000 Ci se déplace sur un chariot au fond de la piscine du réacteur. La plaque constituant la source couvre complètement la fenêtre d’aluminium qui sépare la cellule d’irradiation de la piscine. Cette géométrie assure un chevauchement source/cible qui permet d’obtenir une homogénéité de débit de dose dans la limite de ±20% à l’intérieur de deux caisses de format commercial (43 x 31 x 31 cm) ou de deux sacs du format commercial (80 x 45 x 45 cm), et dans une limite de ±10% dans deux boîtes plates (40 x 20 x 5 cm) irradiées simultanément.

Un jeu d’écrans d’acier et d’aluminium fixés à deux plateaux rotatifs permet l’irradiation des caisses au débit de dose voulu au-dessous de 100 000 R/h sans qu’il soit nécessaire de les retourner pour la seconde moitié du temps d’irradiation.

Deux boîtes spéciales immergées, de forme cylindrique, permettent l’irradiation de longue durée d’objets plats à des débits de dose inférieurs à 600 000 R/h, alors que la source est utilisée pour les irradiations normales de courte durée dans la cellule gamma.

La sécurité est assurée par un dispositif d’alarme visuel et auditif et par un système complexe de verrouillage automatique. Un ensemble de compteurs et d’enregistreurs d’ionisation permet de mesurer les
détectons de dose dans la gamme de 0,001 à 1 000 000 R/h. Les auteurs ont déterminé les courbes d'isodoses pour la cellule d'irradiation.

La cellule doit bientôt être dotée d'une installation de réfrigération et d'une minuterie qui assurera un contrôle automatique du mouvement de la source.

Les inconvénients que présente le faible taux d'utilisation de la source par suite du chevauchement source/cible nécessaire et de son emploi unidirectionnel sont plus que compensés par la possibilité d'irradiation à l'échelle semi-industrielle, par la grande souplesse du système et par son faible coût.

On recommande donc cette installation pour tous les réacteurs piscine similaires. Elle est particulièrement précieuse pour les pays qui désirent appliquer un programme d'irradiation de denrées alimentaires à moindres frais, mais avec un maximum de possibilités d'applications expérimentales.

MНОГОЦЕЛЕВАЯ ОБЛУЧАЮЩАЯ УСТАНОВКА НА КОБАЛЬТЕ-60 ВНУТРИ РЕАКТОРА БАССЕЙНОГО ТИПА. Внутри реактора бассейного типа на обогащенном топливе класса 1RR-1 имеется гамма-камера с бетонной защитой, предназначенная для использования излучения от отработанных топливных элементов. При сравнительно небольших затратах на ней была приспособлена облучающая установка с источником кобальта-60.

Источник кобальта-60 активностью в 30 000 кюри передвигается по дну бассейна реактора на тележке. Диск источника полностью закрывает алюминиевое окно между бассейном и камерой облучения. Такое расположение обеспечивает наложение "источника на мишень"; таким образом достигается однородность мощности доз в пределах ± 20% в пределах коммерческих ящиков (43 x 31 x 31 см) или двух коммерческих мешков (80 x 45 x 45 см) и в пределах ±10% в двух плоских ящиках (40 х 20 x 5 см) при одновременном облучении.

Набор стальных и алюминиевых экранов, соединенных с двумя поворотными платформами, позволяет облучать коммерческие ящики при любых желаемых мощностях доз меньше 100 000 рентген в час, причем отпадает необходимость переворачивать ящики в середине периода облучения.

Две специальные подводные канистры позволяют проводить длительное облучение плоских образцов при мощностях доз менее 600 000 рентген/час, причем отпадает необходимость переворачивать ящики в середине периода облучения.

Скоро камера будет модифицирована и включит охлаждающую установку и систему регулирования во время циклов автоматического контроля за движением источника.

Недостатки устройства, такие, как небольшой коэффициент использования источника, вызванный необходимостью наложения источника на мишень при одностороннем использовании излучения, более чем компенсируются возможностью проведения облучения коммерческих ящиков в экспериментальных масштабах, а также большей универсальностью и незначительными затратами.

Таким образом подобная установка может рекомендоваться для всех подобных реакторов бассейного типа. Она может быть особенно полезной для стран, которые хотели бы начать программу по облучению пищевых продуктов с минимальными затратами, но с максимальными экспериментальными возможностями.

INSTALACION DE IRRADIACION PARA USOS MULTIPLES ALIMENTADA CON 60Co Y MONTADA EN UN REACTOR DE INVESTIGACION TIPO PISCINA. El reactor tipo piscina 1RR-1, de combustible enriquecido, comprende una celda gamma con blindaje de hormigón para aprovechar las radiaciones de los elementos combustibles agotados. Se le ha provisto, con gastos relativamente reducidos, de una instalación de irradiación para usos múltiples, alimentada con 60Co.

La fuente de 60Co, de 30 000 Ck, se desplaza sobre un carro en el fondo de la piscina del reactor. Tiene forma de placa que se ajusta exactamente a las dimensiones de la ventana de aluminio existente entre la piscina y la celda de irradiación. Esta disposición geométrica permite una razón de dimensiones fuente a blanco ampliamente suficiente, con lo que se obtiene una dosis homogénea, con un margen de ±20% en dos envases de tipo comercial (48 x 31 x 31 cm), o en dos sacos de tipo comercial (60 x 45 x 45 cm) y, con un margen de ±10%, en dos cajas aplanadas (40 x 20 x 5 cm) que se irradian simultáneamente.

Un juego de pantallas de acero y de aluminio acopladas a dos plataformas rotativas permite administrar a envases comerciales la dosis que se desea, siempre que sea inferior a 100 000 R/h, sin necesidad de darles la vuelta a la mitad del tiempo de irradiación.

Dos recipientes especiales permiten inmediaciones largas de objetos aplanados en inmersión, con dosis inferiores a 600 000 R/h, mientras la fuente se utiliza para irradiaciones normales cortas en la celda gamma.

La seguridad está garantizada por un indicador y dispositivo de alarma visual y acústico y por un complejo sistema de enclavamientos. Una serie de medidores y registradores de ionización permite determinar
las dosis en el intervalo de 0,001 a 1 000 000 R/h. Se han establecido las curvas de isodosis de la cámara de irradiación.

La celda se modificará en breve para dotarla de un sistema de refrigeración y de relojería para el control automático del movimiento de la fuente.

Las desventajas del escaso grado de utilización de la fuente resultante de la relación entre las dimensiones de ésta y del blanco y del aprovechamiento de las radiaciones por un lado solamente, se hallan con creces compensadas por la posibilidad que ofrece de irradiación de envases comerciales en escala experimental y de adaptación para usos múltiples con gastos moderados.

Esta instalación es, pues, muy conveniente para todos los reactores tipo piscina de características análogas. Es particularmente útil para los países deseosos de emprender un programa de irradiación de alimentos con gastos mínimos y con el mayor número posible de aplicaciones experimentales.

The prevailing conditions in food irradiation and industrial applications of ionizing radiation in 1964 encouraged the Israel Atomic Energy Commission (ARE) to undertake an experimental survey of the processes which may be adapted to local conditions. Since a basic research programme was beyond means, it was decided to screen the most promising processes on a semi-commercial scale. Thus, it was essential to use an irradiation facility in which the various products could be irradiated in their commercial packing, and which would provide a wide, uniform irradiation field (for cases, and even sacks) as well as a wide range of dose-rates. The other prerequisite was that the cost be the lowest possible. These specifications were met in the following design.

The swimming pool of the IRR-1 reactor is built in the conventional way, the pool consisting of two parts, one small and one large (see Fig. 1). The large pool is normally used for storage of the reactor core, when it is not in operation, and for storage of spent fuel elements. Near the bottom of the farthest corner of the large pool, a one-inch-thick aluminium window (60 X 60 cm) separates the pool from a concrete-shielded (1.2 m thick) room which is inside the concrete wall of the pool. A lead-filled steel door (80 cm thick) seals the entrance to the room. This room, the "gamma chamber", was designed primarily for utilization of the radiation emitted from the spent fuel elements, eight of which could be inserted into a special cartridge below the window.

This set-up constituted an ideal basis for a versatile 60Co irradiation facility. It was also necessary to have a cobalt-60 source plaque (60 X 60 cm) that could be moved to and from the window while being controlled from the other side of the gamma chamber.

The source plaque1, which comprised 30 000 Ci 60Co on 30 March 1965, consists of 48 standard BNL2 elements (33 X 2 X 0.4 cm) in two vertical rows. The elements are contained in eight cartridges which, in turn, are placed in two cartridge holders (see Fig. 2). Each cartridge holder is introduced into its compartment within the source carriage. Special handling tools — hooks of various shapes, manipulators, etc. — were designed to permit loading and unloading of the cartridges, the cartridge holders, and the carriage, at a depth of 9 m below the surface of the water. Special fixtures were designed for retention of the cartridges and cartridge holders during loading and unloading. Although enough experience was accumu-

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1 The source plaque, carriage, and frame were designed and manufactured by Nuclear Materials and Equipment Corporation (NUMEC), Apollo, Pa., United States of America.
2 Brookhaven National Laboratory, L.I., N.Y., United States of America.
lated in the loading operation at the 9-m depth to guarantee trained operators for emergencies, a special platform was suspended from the pool top to permit routine loading and unloading of the elements at a depth of only 5 m. The tools were modified to operate at both depths. It was found convenient to handle the $^{60}$Co elements by means of a rectangular magnet suspended from two plastic strings at right-angles to each other; one is used for picking up elements from horizontal positions, the other for raising elements to an almost vertical position in order to be inserted into the cartridge slot. The cartridges and cartridge holders include hinged flaps and dowels to ensure that no element will escape accidentally near the window. In the event of an emergency, the cartridges can be rapidly transferred to a special compact holder which fits into a lead cask which is always kept near the reactor pool. The cask (6 tons) can be suspended from hoists at a depth 3 m below the water level, which is sufficient to give adequate protection to the operator handling the 30,000 Ci $^{60}$Co (see Fig. 3). The source carriage runs on a pair of tubular rails supported by a framework which is bolted to the floor of the large pool (its ceramic tiles
are interspersed at regular intervals with stainless-steel tiles bearing anchoring bolts). In order to prevent radiation damage to the pool wall tiles and cement, the carriage in its storage position is 30 cm from the wall and 3 m from the aluminium window, yet parallel to it. When in this
position, the radiation dose-rate at the inside surface of the window is less than 0.1 mR/h. When in the irradiation position, the source is only 5 mm from the aluminium window and the dose-rate on the inside surface is 400 000 R/h over two fields 45 × 20 cm.

The carriage is driven by a cable system connected at one end to a three-phase electric motor with a cable-collecting drum capable of rotating in both directions, and at the other end to a counterweight (100 kg) which provides tension to the cable. Special rod supports ensure that the counterweight will not reach the floor tiles if the cable should break. A special removable hoisting assembly permits easy extraction of the counterweight to allow modifications in the carriage, cables, and motor assembly.

The carriage motion is arrested in the storage and in the irradiation positions within ±5 mm by a system of microswitches operated by rotating cams (these will be supplemented shortly by two additional sets of microswitches, one set operated mechanically by the carriage itself, the other operated by riders on the cables above the water surface). A special device enables manual return of the carriage to its storage position in case of power failure or any other emergency (this will be supplemented shortly by an automatic gravity-operated device which will automatically return the source to the storage position in the event of power failure or of a pull on the emergency cord which runs along the walls of the gamma chamber).

The electric motor, located on top of the large pool, is operated by a control panel adjacent to the gamma chamber. It contains push-button controls for source movement to and from the window, and for arrest of this motion. Also included are indicator lights for the two extreme positions of the source carriage and for the direction of the carriage movement. These lights are duplicated above the door of the gamma chamber. The control panel also includes a system of remote area monitors (VICTOREEN) which, for safety reasons, cover the ranges of 1-1000 mR/h, 100-100 000 mR/h, 10-10 000 R/h, and 1-1000 000 R/h. These monitors are coupled to a recorder system, thus permitting checks of the irradiation log book. The ionization gauges connected to the monitors are so located inside the gamma chamber that two monitors measure the radiation inside, while two monitors are in alarm. The alarm indicators of these monitors are repeated above the door of the gamma chamber. This ensures that the operator will not enter the chamber in the remotely possible event that a reactor fuel element was inadvertently dropped near the aluminium window.

Because of the danger of exposure to a dose-rate of 4000 R/h at the door, an elaborate system of interlocks placed in series is operated by (a) a single key (in the operator's pocket) to deactivate the power system; (b) the indicator light for the source in the storage position; (c) the door pushing against the wall of the gamma chamber indicating tight closure; (d) an electromagnetically operated lock on the door; (e) a manually operated emergency cord along the chamber walls. The source carriage cannot be moved from its storage position if any of these items is not in the safe position. Checks are made periodically to ascertain that no short circuits have occurred in any of these microswitches. The electromagnetic lock itself prevents entrance into the chamber when the indicator light for the source in the storage position is not operating (that is, even when the source itself is safe but the lamp has burned out). The system
will soon be modified to incorporate, among other improvements, a timer for automatic start and return of the source carriage to its storage position after a preset period.

Reactor safety rules require that the operator be trained in health physics. Therefore, the following procedure has been adopted: upon the doors being opened by an assistant, the operator himself enters the chamber with a portable radiation monitor to ascertain the safety of the personnel. He then stays on guard until the assistant has replaced the experimental boxes and has left the chamber (an additional timer lock, to be introduced shortly, will require shutting of the door within 45 seconds after leaving the chamber in order to prevent accidental trapping of untrained personnel). To reduce the danger of radiation exposure in the event that all safety devices have failed, a second steel door (15 cm thick) was constructed inside the chamber (see Fig. 4) which reduces the dose-rate in the external part of the chamber from an average of 6000 R/h to 15 R/h (that is, from 100 R/min to 250 mR/min).

The dimensions of the gamma chamber are indicated in Fig. 4. The dose-rate is uniform — within 5% — over a flat surface 45 X 45 cm close
to the window, increasing to 90 × 90 cm at a distance 1.20 m from the window. Dosimetry was effected by means of Fricke phials and silver phosphate activated and cobalt glass chips, which were stuck to a set of 15 thin plastic screens suspended from 15 wooden frames. These frames are successively larger in cross-section to correspond to the enlarging uniform field; they are held together at fixed intervals (every 25 mm for the first 200 mm, every 50 mm thereafter) by two pairs of wooden combs at top and bottom. This arrangement is very satisfactory for quick dosimetric charting in volume and surface. A new type of dose-rate meter developed at BNL, the silicon light-sensitive cell, was recently introduced and was found to be of great advantage for confirmation of the dosimetric charting. It operates with good reproducibility in the range > 40 000 rad/h.

The dose-rate along the horizontal line, starting at the midpoint of the aluminium, decreases rapidly from 400 000 R/h at the window to 80 000 R/h at 45 cm from the window, then decreases slowly to 10 000 rad/h at a distance of 1.60 m and finally to 2000 rad/h at 3.50 m from the window (see Fig. 5). The dose-rates in the external part of the gamma chamber decrease by a factor of 400 when the steel door is closed.

Dosimetry was also performed with various products in commercial as well as in flat, laboratory-scale packages. With operation at the full source-to-target overlap of about 10 cm on all sides, a dose uniformity of ±10% over the range of 20 - 300 000 R/h was obtained in two flat boxes (40 × 20 × 5 cm) inverted inside-outside at half-dose. The products were fruit fly pupae, or other small items, packed rather uniformly. Using two commercial cases (42 × 23 × 31 cm), inverted inside-outside at half-dose, and operating at a partial source-to-target overlap (see Fig. 6) of 10 cm on top and bottom, a dose-rate uniformity is obtained better than ±20% at dose-rates of 20 - 200 000 rad/h. In a similar way, two commercial sacks (80 × 45 × 45 cm) can be irradiated at the same uniformity at dose-rates of 20 - 20 000 rad/h. In order to reduce downtime, a set of rotating turntables (driven by an explosion-proof motor inside the gamma chamber) was placed near the aluminium window (see Fig. 7). In this manner, two commercial cases (42 × 51 × 31 cm) can be irradiated at an improved dose distribution at dose-rates of 100 000 rad/h or less. The dose-rate can be varied by placing 6-mm-thick steel and aluminium screens between the window and the turntables. A pair of steel screens coupled to one aluminium screen reduced the dose-rate by a factor of 2. The three-phase electric motor driving these turntables was coupled to either of two gearboxes delivering 1 or 10 rev/min, which are satisfactory for pasteurizing or disinfection doses, respectively. A further improvement considered would allow continuous irradiation of a series of commercial cases or sacks, supported on rails, in the external part of the gamma chamber.

There are several inlets into the gamma chamber through which air, N₂, or other gases may be introduced for controlled atmosphere tests, which are of great significance for many fruit irradiations. Furthermore, it is essential to remove the ozone-laden air from the cell. This is effected by means of a centrifugal water-seal vacuum pump in order to overcome the high flow resistance encountered in the S-shaped 1-in. pipe passing through the 1.2-m-thick concrete wall of the gamma chamber. As the air cannot be purged into the reactor hall, it is expelled — after separation of the entrained water — through a pipe passing out of the reactor hall cupola. The air is removed at the rate of 1 m³/min, sufficient to
change the volume of air in the internal part of the gamma chamber 60 times per hour and in the external part 5 times per hour. The ozone concentration in the entire chamber reaches 1 ppm if the internal door is open and the air is not extracted; when the pump operates, no ozone is detected. For safety reasons, a Hampden ozonomat is used for continuous atmospheric control.

To augment the irradiation possibilities, a refrigeration plant was designed for the internal part of the chamber, and it is to be installed towards the end of this year. It should permit irradiation of pre-cooled products in two commercial cases (41 × 23 × 31 cm) at temperatures ranging from 2 to 30°C. In addition, pre-chilled air will be continuously drawn through the unit to ensure removal of ozone and uniform tempera-
ture distribution, and to prevent condensation. The cases will be pre-cooled in commercial refrigerators with fans, ensuring good temperature distribution.

The versatility of the irradiation facility is increased by the use of two canisters (60 x 20 x 1.5 cm) which are lowered into the source carriage and which can utilize the wasted irradiation from the other side of the source for long-duration irradiations (doses of several Mrad and more). The dose-rate inside these canisters is 600 000 rad/h, within ± 10%. The canisters are especially useful for controlled atmosphere testing of various materials under a high radiation field as they are connected.
It was determined experimentally that the efficiency of this irradiation facility is at best only \( \sim 3\% \). This is due to many losses: half the radiation is wasted on the other side of the source, half of the remainder is lost at the sides of the source, and again half is lost in the aluminium window through absorption; finally, only a part of that radiation which does enter the gamma chamber is utilized at a source-to-target overlap geometry. The production capacity is therefore not more than Mrad/kg h (40 kg irradiated at a dose-rate of 200 000 rad/h) under optimum conditions. Nevertheless, this facility is preferable to equivalent-cost (\( \sim \$45\,000 \)) small-scale irradiators, as the latter are greatly restricted in package size.

The facility described above permits simulation of commercial conditions because of the dimensions of the source and of the irradiation chamber. Through its high versatility, it also enables the gathering of valuable dose distribution and other critical data for the design of a final commercial irradiation facility. In fact, it is already projected to remove the present source to a final facility — if the irradiation programme will increase in volume and scope within the next year so that the utilization efficiency will be increased 6-8 fold — with relatively moderate additional expenses, mainly for the concrete shield, the building and some auxiliary equipment. Most of the other components can be easily incorporated in the final facility at small cost. Some preliminary designs have already been drawn, based on the practical experience gained with the present irradiation facility.

This type of installation is in many respects a makeshift arrangement, relatively inexpensive when one considers its performance and capabilities. It is therefore recommended for similar swimming pool research reactors. It is especially valuable in countries which are about to embark on a food irradiation study programme, and thus require a versatile irradiation facility at low cost.

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\(^3\) The Nuclear Materials and Equipment Corporation, Apollo, Pa., United States of America.
RECENT ADVANCES IN FOOD IRRADIATION RESEARCH IN JAPAN

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Abstract — Résumé — Аннотация — Resumen

RECENT ADVANCES IN FOOD IRRADIATION RESEARCH IN JAPAN. The current trend towards establishing the national programme on food irradiation appears to be maturing with great interest in fundamental and practical problems. Efforts of the Atomic Energy Commission to devise a programme on development studies, and their practical application, which will probably commence in 1967, are now being made. The collaboration of researchers in this field has resulted in the setting-up of the Japanese Research Association for Food Irradiation. This organization is expected to play an important role in promoting the national programme. At present there are in Japan about 30 kCi-scale sources of radioisotopes, and almost the same number of electron generators, including some pilot-scale irradiation facilities.

Practical studies on food irradiation in Japan are classified into three categories, in terms of their purpose. The first is radiation preservation, to which major efforts have been devoted. Sprout inhibition of potatoes, onions and sweet potatoes, disinfection of rice, wheat and their products, low-dose treatment of vacuum-sealed fish and shell-fish with doses of less than 0.5 Mrad, and of some fruits, such as strawberry and orange, are the examples which are considered to be potential subjects for radiation treatment. The first interesting observation was in rice irradiation where, at 5000 to 20 000 rad disinfection dose, quality changes detectable immediately after irradiation became insignificant after eight months' storage according to the statistical analysis of organoleptic data. The second was in connection with studies on the elimination of harmful biological and biochemical factors in foods from the viewpoint of public health. Radiation sensitivity of the toxin produced by Cl. botulinum, Type E, was investigated in studying the wholesomeness of irradiated foods. The third was concerned with the utilization of the chemical effect of radiation. For example, studies were made of the irradiation of marine algae with 0.5 to 0.7 Mrad to improve quality and the yield of extracted agar and the radiation acceleration of the ageing of alcoholic beverages, particularly distilled liquors, with doses of up to 0.5 Mrad.

Besides these practical investigations, extensive work has been conducted with the fundamental aspects, including the radiosensitization of microorganisms, enzyme inactivation by radiation, and other subjects in radiation chemistry associated with food irradiation.

RECENTS PROGRES DE L’IRRADIATION DES PRODUITS ALIMENTAIRES AU JAPON. Actuellement, l’organisation du programme national d’irradiation de produits alimentaires semble se préciser, l’intérêt se portant à la fois sur les problèmes fondamentaux et les questions pratiques. La Commission de l’énergie atomique s’occupe activement d’élaborer le programme d’études et de réalisations qui sera mis en œuvre vraisemblablement en 1967. La collaboration des chercheurs dans ce domaine a abouti à la création de l’Association japonaise de recherches sur l’irradiation des denrées alimentaires, organisme qui est appelé à jouer un rôle important dans le développement du programme national. Le Japon dispose actuellement de quelque 30 sources de radioisotopes de l’ordre du kCi et d’autant de générateurs d’électrons, y compris quelques installations expérimentales.

Les études pratiques sur l’irradiation de denrées alimentaires au Japon sont orientées dans trois directions. Premièrement, la radioconservation, qui bénéficie de l’effort principal. L’inhibition de la germation des pommes de terre, des oignons et des patates, la désinfection du riz, du blé et de leurs dérivés, et le traitement à faible dose (moins de 0,5 Mrad) en emballages sous vide du poisson et des crustacés et mollusques ainsi que de quelques fruits tels que la fraise et l’orange sont autant d’exemples des possibilités d’utilisation des rayonnements. L’irradiation du riz a permis de faire une observation intéressante, à savoir qu’à la suite d’une irradiation de désinfection à des doses comprises entre 5000 et 20 000 rad, les modifications de qualité décelables immédiatement après l’irradiation se sont révélées insignifiantes après huit mois de conservation d’après l’analyse statistique des données organoleptiques. Deuxièmement, étude de
l'élimination des agents biologiques et biochimiques nuisibles dans les produits, du point de vue de la santé publique. La sensibilité aux rayonnements de la toxine produite par Cl. botulinum E a été étudiée en rapport avec l'innocuité des produits irradiés. Troisiblement, l'utilisation des effets chimiques des rayonnements. On a étudié par exemple l'irradiation d'algues marines à des doses de 0,5 à 0,7 Mrad en vue d'améliorer la qualité et la quantité de la gélose extraite, ainsi que l'accélération, par des doses de rayonnement atteignant 0,5 Mrad, du vieillissement des boissons alcooliques, notamment des liqueurs distillées.

Outre ces études de caractère pratique, on s'est occupé activement des problèmes fondamentaux comprenant la radiosensibilisation des micro-organismes, l'inactivation des enzymes par les rayonnements et d'autres questions de radiochimie intéressant l'irradiation des denrées alimentaires.

ПОСЛЕДНИЕ ДОСТИЖЕНИЯ В ИССЛЕДОВАНИЯХ ПО ОБЛУЧЕНИЮ ПРОДУКТОВ ПИТАНИЯ В ЯПОНИИ. В настоящее время, как представляется, существует большой интерес и вырисовывается тенденция в отношении выработки национальной программы по облучению продуктов питания в области как фундаментальных, так и практических проблем. В настоящее время Комиссия по атомной энергии предпринимает усилия по разработке программы исследований методов и их практического применения, которая, вероятно, начнет осуществляться в 1967 году. Сотрудничество исследователей в этой области привело к созданию Японской исследовательской ассоциации по облучению продуктов питания, и эта организация, как ожидается, будет играть важную роль в разработке национальной программы.

В настоящем время в Японии имеется около 30 радиоизотопных источников порядка килокюри и почти такое же число генераторов электронов, включая несколько крупных облучающих установок.

Практические исследования по облучению продуктов в Японии разделяются на три категории в зависимости от их цели. Первая - это предохранение продуктов питания от порчи с помощью облучения; этим исследованиям уделяется главное внимание.

Вторая категория - это исследования по оценке вредных биологических и биохимических факторов в продуктах питания с точки зрения здравоохранения. Чувствительность к облучению, произведённого Cl. botulinum типа Е, исследовалась в связи с целостностью облученных продуктов питания. Третья категория связана с использованием химического воздействия облучения. Например, исследовалось облучение морских водорослей дозами в 0,5 — 0,7 Мрад и некоторых фруктов, таких как клубника и апельсиновые, — это примеры потенциального применения облучения. Интересное наблюдение при облучении риса состояло в том, что при обеззараживающей дозе в 5 000 — 20 000 рад качественные изменения, обнаружимые непосредственно после облучения, стали после восьмимесячного хранения незначительными при статистическом анализе органолептических данных.

Вторая категория - это исследования по оценке вредных биологических и биохимических факторов в продуктах питания с точки зрения здравоохранения. Чувствительность к облучению, произведённому Cl. botulinum типа Е, исследовалась в связи с целостностью облученных продуктов питания. Третья категория связана с использованием химического воздействия облучения. Например, исследовалось облучение морских водорослей дозами в 0,5 — 0,7 Мрад для улучшения качества и выхода экстрагированного агара и радиационное ускорение старения алкогольных напитков, особенно очищенных ликеров, дозами до 0,5 Мрад.

Кроме этих практических исследований проводилась широкая работа по фундаментальным аспектам, включая радиочувствительность микроорганизмов, инактивацию ферментов облучением и другие проблемы радиационной химии, связанной с облучением продуктов питания.

PROGRESOS RECIENTES DE LAS INVESTIGACIONES SOBRE IRRADIACION DE ALIMENTOS REALIZADAS EN EL JAPON. En la actualidad parecen perfilarse los planes para establecer en el Japón un programa nacional de irradiación de alimentos orientado hacia los problemas fundamentales y prácticos. La Comisión de Energía Atómica ha comenzado ya a preparar el programa de estudios fundamentales y sus aplicaciones, que se emprenderá probablemente en 1967. Gracias a la colaboración de especialistas se ha constituido la Sociedad japonesa de investigaciones sobre irradiación de alimentos; se espera que esta organización desempeñe una labor importante en la ejecución del programa nacional. En la actualidad, el Japón dispone de unas 30 fuentes radioisotópicas del orden del kilocurie, y casi del mismo número de generadores de electrones, incluidas varias plantas piloto de irradiación.

En el Japón los estudios prácticos sobre irradiación de alimentos se clasifican en tres categorías, según la finalidad: la primera comprende los estudios sobre conservación, a los que se dedican los mayores esfuerzos. Entre las aplicaciones interesantes de las radiaciones que cabe mencionar figura la inhibición de la germinación de patatas, cebollas y batatas, la desinfección de arroz, trigo y sus derivados, el tratamiento en dosis ligeras (inferiores a 0,5 Mrad) de pescado y mariscos envasados al vacío, así como de algunas frutas, tales como fresas y naranjas. Una observación interesante, en lo que se refiere a la irradiación del arroz en dosis de 5000 a 20 000 rad para desinfectarlo, es que los cambios de calidad apreciables inmediatamente después de la irradiación resultaron insignificantes en el análisis estadístico de datos organo-lépticos efectuado al cabo de ocho meses de almacenamiento. La segunda categoría comprende los estu-
dios sobre eliminación de agentes nocivos (biológicos y bioquímicos) de los alimentos desde el punto de vista sanitario. Se ha investigado, en relación con la comestibilidad de los alimentos irradiados, la sensibilidad a la irradiación de la toxina producida por el Cl. botulinum tipo E. La tercera categoría comprende los estudios referentes al aprovechamiento de los efectos químicos de las radiaciones. Cabe citar, como ejemplo, la irradiación de algas marinas con dosis de 0,5 a 0,7 Mrad para mejorar la calidad y rendimiento del agar extraído, y la aceleración por irradiación del envejecimiento de bebidas alcohólicas, sobre todo de licores destilados, con dosis no superiores a 0,5 Mrad.

Además de estas investigaciones prácticas se han realizado amplios estudios sobre algunos aspectos fundamentales: radiosensibilización de microorganismos, inactivación de enzimas por irradiación y otras cuestiones de radioquímica referentes a la irradiación de alimentos.

INTRODUCTION

In the recent increasing attention being given to the practical application of food irradiation, difficulties arising from the lack of a comprehensive research plan are realized in Japan, although much information on food irradiation has been accumulated in past studies during more than ten years.

Currently, the trend towards establishing a national research programme on food irradiation appears to be maturing. Efforts of the Atomic Energy Commission (AEC) to devise a programme on development studies, and their practical application (which will probably start in 1967), are now being made. The collaboration of researchers in this field has resulted in the setting-up of the Japanese Research Association for Food Irradiation; this organization is expected to play an important role in promoting the national research programme. The Japan Atomic Industrial Forum has also supported these movements in food irradiation.

Under these circumstances, food irradiation research in Japan is about to step into the new phase of development study. At present, there are about 30 kCi-scale sources of radioisotopes, and almost the same number of electron generators, including some pilot-scale irradiation facilities, such as a 240 000-Ci 60Co source in the country.

This paper is concerned with recent studies on food irradiation in Japan, mostly carried out after the International Conference on Food Irradiation held at MIT in 1959, in which Japanese work, in the early stage, was reviewed by Professor Sumiki, of the University of Tokyo [1].

PRESERVATION BY IRRADIATION

Disinfestation of grain

In Japan, loss occurring through insect damage during transportation and storage is estimated to be 5-10% in domestic rice — 12 700 000 tons a year — and 10% or more in various grains, including wheat and barley. Imported rice, 900 000 tons in 1965, and other grains, are also subject to considerable damage caused by insects and microorganisms. To protect grain against such intensive losses, studies on disinfestation have attracted increasing attention in the country, as well as in many foreign countries.

Regarding the killing of insects by radiation, the radiosensitivity of the rice weevil (Sitophilus sp.) [2, 3], the azuki bean weevil (Callosobruchus chinensis Linne) [4, 5], and the flour beetle (Tribolium confusum,
Jaquelin du Val. [6] were investigated. It was found that irradiation by 5 to 7 krad can exert its action completely as a reproduction inhibitor on all these insects, while doses required for death within 24 h are 300 krad, or more. Radiation susceptibility of the flour beetle at different developmental stages was in the order: egg > pupa > larva > adult [6]. Mortality in the rice weevil was found to increase at higher temperatures and at lower atmospheric moisture after irradiation [3].

The quality changes in rice irradiated at 5, 10 and 20 krad were examined by chemical analysis and an organoleptic test by a trained panel [7]. Changes in the physico-chemical and chemical parameters associated with the acceptance of cooked rice were not significant at all these doses. On the other hand, the panel test revealed differences in organoleptic properties between irradiated and unirradiated samples, by statistical analysis. Radiation off-flavour was detected, even at 5 krad.

However, such influences of radiation were not so severe, depending on the variety of rice and the storage period. Interesting observations on the organoleptic properties of irradiated rice were that quality changes, as mentioned above, were detectable immediately after irradiation, while they became insignificant after eight months' storage, and that changes caused by irradiation at 10 krad appeared smaller in 'Koshihikari', a variety of better quality, by ordinary cultivation, than 'Towada', a variety of early-season cultivation. Other studies did not indicate any detectable deterioration in the taste of cooked rice at doses of 20 krad [8] or 40 krad [9]. Losses of thiamine and riboflavin were found to be negligible at 100 krad for rice and at 27 krad for vitamin-rich wheat flour; inhibitory effects of irradiation on the germination of rice seed became observable at doses above 10 krad [6,8,10].

It appears that a realistic dose for grain disinfestation in Japan may fall into the range of 10 to 50 krad, judging from the results mentioned above, although definite conclusions as to the appropriate disinfestation dose must await further investigations in the new national programme.

As to the microbiological aspect, changes in the microflora of rice, and the radiosensitivity of component organisms isolated, have been studied [11,12]. The microflora of unirradiated, husked rice consisted predominantly of chromogenic Pseudomonas and fluorescent Pseudomonas, and partly of Aerobacter, Micrococcus and Brevibacterium. Survivors after irradiation were found to be mainly chromogenic Pseudomonas and fluorescent Pseudomonas at 0.2 Mrad, and radioresistant red Pseudomonas and yeasts at 0.5 Mrad, or more. In the case of polished rice, similar results were obtained, although Bacillus was found among survivors. Moulds, mainly Penicillium sp., contaminating imported rice, were not found at 0.2 Mrad, or more.

A potential subject for radiation treatment has been suggested as the rice which is used for the Sake-brewing industry, based on the fact that 1 Mrad can destroy all existing bacteria and moulds and decrease the viscosity of the rice; also that, at this dose, no significant influences on enzyme activity of 'rice-koji' prepared and 'Moto' production have been found [13].

Irradiation of the soybean and azuki bean were also studied, to control insect and microbial spoilage, and somewhat higher doses, 0.1 Mrad for soybean and 0.1 to 1 Mrad for the azuki bean, were recommended [14,15].
Fish irradiation

The effects of gamma irradiation at 1 Mrad on the quality and storage of fish were examined with 22 different species of raw fish and shellfish [16].

At a dose of 1 Mrad, it was shown that acceptability of fish and shellfish was decreased immediately after irradiation, and also during subsequent storage at refrigerator temperature. Discolouration by irradiation appeared more pronounced in species rich in muscle pigment, such as tuna and skipjack, than in those with white muscle, like sea bass, greenfish, barracuda, and porgy. Change in the odour of fresh meat immediately after irradiation was observed as a disappearance of the characteristic odour of fresh meat and the development of radiation off-flavour, although the latter was not so remarkable in most cases. As to fatty fish, a rancid odour always developed on irradiation, followed by discolouration of the flesh.

The translucent nature of raw muscle tissue, which is characteristic of flat fish of high freshness, is lost after irradiation, and a chalky, yellow tone appears on the surface of flesh, but not inside. Such a change was not observed for squid, octopus, prawn, white clam, baby clam, abalone, and oyster. Certain protein denaturation may be involved in the loss of the translucent appearance of the flesh of bony fish. When cooked, both a rancid odour and browning of flesh became evident, while off-flavour was decreased. Little effect of radiation on the texture of the flesh was observed with raw and cooked samples.

During storage, the development of a rancid odour and browning of the irradiated flesh were observed; browning was spread out from the surface to the inside of the flesh. Furthermore, the changes occurring during storage were enhanced when cooked. A storage test at 1 Mrad indicated that shelf life at refrigerator temperature could be prolonged for more than one month for most species of fish, but not for white clam, baby clam, oyster and prawn. The specific spoilage patterns of irradiated abalone and octopus were observed [16].

Another study obtained similar results concerning the radiation effect on the quality of fish at sterilization dose [17-20]. With lower doses, between 0.15-0.25 Mrad, the shelf life at refrigerator temperature (2-4°C) of tuna flesh was extended for two to three weeks [20]. The irradiation of oyster in saline at 0.35 Mrad was found feasible to decrease bacterial counts, without any considerable side reaction [21].

The degeneration of oils by radiation is one of the difficulties in fish irradiation. The colour of the fatty abdominal flesh of tuna irradiated at 1 Mrad became dark brown, with an offensive odour, the oil of the flesh turning rancid. On the other hand, irradiated fish sausages did not show any remarkable changes as to palatability, despite the presence of an amount of fat [22]. Oils in the irradiated fish flesh were prevented from oxidation by pre-treatments of vacuum packaging, gas-phase exchange with CO₂, ascorbic acid [23] and an antioxidant (BHA) [24, 25]. The feasibility of vacuum packaging in fish irradiation was observed with the storage of plaice flesh [26] and salt-and-dried fish [24].

Browning in irradiated fish is also of considerable importance in the practical use of radiation for fish preservation [16]. Rancidity might be suggested as a factor responsible for the discolouration by radiation [27-29]. However, some other causes could be considered also, because such
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a lean flesh as the Japanese sea bass gave remarkable browning, almost to the same extent as that of fatty fish; and because dried squid also turned an intense brown on irradiation, even after extracting solubles with ether or acetone. The effect of free sugar might not need further consideration as far as the browning of fish flesh is concerned [30]. However, amino acids enhanced the discoloration of fatty materials by radiation [31].

In connection with the nutritional value, the destruction of amino acids in aqueous solution and changes in amino-acid composition were found to be insignificant at 1.4 Mrad with yellowfin tuna, and total nitrogen was 722 mg/100 g flesh for the irradiated sample and 748 mg/100 g for the un-irradiated control [32]. Degradation of trimethylamine oxide in irradiated fish, such as pollack, squid and shark [33], and radiolysis of trimethylamine [34], were studied. The radiation chemistry of muscle pigment, myoglobin, isolated from tuna and whale has received attention from the viewpoint of colour change in fish irradiation [35, 36].

From the earlier stage of irradiation research in Japan, the potentiality of the radiation treatment of processed products of fish and shellfish has been shown with fish sausage [22, 37], Kamaboko, and other fish-paste products [38-44]. From these experiences in fish irradiation, it is considered that a possible application would be the combination of low-dose irradiation of vacuum-packaged raw fish, and subsequent storage at refrigerator temperature. The goal appears to be shelf life for four weeks. The maximum of the appropriate doses would be 0.5 Mrad for white-fish and flounder and 0.2 Mrad for tuna. Current technical problems to be solved in fish irradiation are: (a) keeping the freshness of raw fish by radiation in competition or combination with refrigeration and freezing techniques; (b) bulk irradiation, dealing with the whole body rather than the consumer pack; (c) irradiation of processed fish products, such as cooked flesh and fish paste; (d) prevention of enzymic spoilage for long-term storage; (e) inhibition of undesirable side reactions; and (f) utilization of quality changes in fish by radiation.

Irradiation of vegetables and fruit

Fundamental studies on the sprout inhibition of potatoes and onions by radiation have been conducted using some varieties of these root crops cultivated in Japan [45-51]. The results obtained with Irish Cobbler potatoes, the main variety grown in the country, are as follows [45, 47, 48, 51]: (a) the sprout-inhibiting action of radiation on potato tubers was more effective during the dormant period soon after the harvest than at the beginning of the sprouting period, or later; (b) irradiation during the dormant period at 7 krad completely inhibited elongation of the very short sprouts which appeared after irradiation; (c) the dose-rate effect and physiological changes in oxygen uptake, sugar content and ascorbic acid concentration after irradiation were indicated.

With onion bulbs irradiated at 3 to 15 krad, a similar effect of the time of irradiation on sprout inhibition was observed [49]. Before the presprouting period, the sprouting of onion bulbs was completely inhibited, even at a dose as low as 2 or 3 krad, for a variety of Senshu-nakadaka [45, 49]. However, higher doses were required at a later stage. One of the problems in onion irradiation appears to be the browning of the inner
buds of onion bulbs, caused by radiation [45]. But the injured parts did not extend to the outside of the buds, and the browned part was smaller when irradiated at the earlier period of storage. Significant influences of radiation on the characteristic flavour, taste and colour of onion bulbs and their biochemical changes were not found throughout the experiment, except the browning of inner buds [45, 46]. The loss in weight of irradiated onion bulbs during storage was less than in the unirradiated control [49]. A method of early detection for the inhibition of sprouting was proposed [52].

The national research programme on potato and onion irradiation is now being designed as the first project, in which further investigations are expected to obtain more detailed information on the appropriate dose for sprout inhibition with some main varieties in Japan, and on other problems. Losses during storage are estimated to be about 2–2.5% potatoes, 3,500,000 tons a year, and appreciable amounts of onions, 860,000 tons a year.

The irradiation of sweet potatoes at 12 to 20 krad was found to be effective for the prevention of sprouting, without any appreciable changes in appearance, taste and vitamin contents [53] and, in addition, nutritional values of sweet-potato starch were somewhat improved by irradiation at these doses [54]. The possibility of applying radiation to the sterilization and preservation of raw, sweet potatoes as a material for alcohol fermentation, without decrease in sugar yields in amylolysis, was studied [55].

Low irradiation, at doses somewhat higher than those for potatoes and onions, was also effective for the inhibition of rooting and sprouting in chestnuts, but it appeared to be difficult to use radiation for the control of harmful insects [47, 48, 56-60].

Another possible application of radiation to vegetables and fruits would be to regulate ripening, the potentiality of which was found in tomatoes and pears [47, 48, 61]. It is an interesting fact that a remarkable decrease in the soluble tannin content of Japanese persimmon, within a few days after irradiation by 0.3 to 0.6 Mrad, was found [47, 60, 62].

Preventing the microbial spoilage of fruit by irradiation at lower doses was studied with strawberries, grapes and oranges [48, 51, 60, 63-65]. Some difficulties, however, still remained to be solved for practical application, although some extent of the feasibility of radiation treatment was observed in the extension of storage period.

Irradiation of meats and other miscellaneous products

Radiation effects on meats, such as beef, pork and chicken, have been investigated by means of physico-chemical, chemical and microbiological methods, and also organoleptic tests [66-75].

Polarographic studies on irradiated raw meat showed that characteristic changes in the shape and crossing points of protein waves were observed with water extracts from irradiated samples after storage at room temperature, but not with NaCl extracts [76, 77], and these changes were due to the denaturation of water-soluble proteins in the actin fraction of the irradiated meat [78]. These changes at 1.5 to 2 Mrad are quite similar to those observed with beef-protein solutions incubated with pepsin, particularly irradiated pepsin. Therefore, the polarographic change with irradiated stored beef may be partly explained by the increased activity of proteolytic enzymes

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in beef by irradiation [76,79]. The potentiality of refrigerator-temperature storage after irradiation, especially at low-dose levels of 0.2-0.6 Mrad, was indicated with beef, pork and chicken meats [80,81].

The effects of gamma irradiation at 4 Mrad on the chemical properties of actin and actomyosin during the aging of meats have been studied [82]. Actomyosin, especially a long-term extracted one, was very sensitive to radiation, while actin was not so sensitive. The results suggest that depolymerization must have taken place in the actomyosin molecule by irradiation of meat. The effects of radiation on the chemical properties of actomyosin in meat appeared more remarkable at 'rigor off' than immediately after slaughter, or at maximum rigor. Increase in the water-holding capacity of meat by irradiation was indicated in another study [83], in which the volume of juice released from irradiated meat, on cooking, was found to be less than that from the unirradiated control. Characterization of the off-flavour components of irradiated beef has been investigated with volatile fractions in collaboration with the group of the Massachusetts Institute of Technology, Cambridge, in the United States of America [84,85]. Evidence was presented that n-nonanal, phenylacetaldehyde and methional are of primary importance in beef irradiation off-flavour [86].

Radiation effects on some processed foods, such as 'Namaage', fried bean curd [87,88], and some other Japanese foods [89], canned foods [90] and bread [91,92], were also studied.

**RADIATION TREATMENT IN RELATION TO PUBLIC HEALTH**

Studies on food irradiation from the viewpoint of public health have not been many in Japan in the past. However, these will increase, because of the significance of food irradiation. Two studies are mentioned here.

**Destruction of parasites**

To eliminate *Toxoplasma* (a parasite of man and pig) in pork, by irradiation, a basic study was done with inoculated experimental animals — mouse and guinea-pig — and pork from a toxoplasmous pig found in a butchery [93]. The minimum doses required for destruction of the infectivity of *Toxoplasma* were 10-11 krad for the proliferative RH strain, and 33-36 krad for cysts of the Bv strain in mouse brain. The radiosensitivity of cysts in muscle was between those of the above two forms of *Toxoplasma*, the destruction dose being 11-19 krad. The difference in destruction dose for cysts of the Bv strain in brain and muscle might be explained by differences in the nature of the surrounding tissue and the density of cyst distribution.

**Radiation sensitivity of *Clostridium botulinum*, Type E toxin**

The research group at the National Institute of Health conducted a study on the radiation destruction of toxin produced by *Clostridium botulinum* Type E, and its radioprotective factors [94]. In Japan there are some incidences of food poisoning caused by uncooked foods — for example 'Izushi', which is made from boiled rice and raw fish, which are sometimes subject to Type E botulism. The *Clostridium botulinum* Type E toxin was reported to be more sensitive to radiation than the Type A toxin of the same species [95,96].
The D<sub>0</sub>-value dose required for 90% destruction of *Clostridium botulinum* Type E toxin was found greatly dependent upon the medium at the time of irradiation — 1.7 Mrad for cell suspension, 0.21 Mrad for cell extracts, and 0.04 Mrad for the purified precursor in acetate or phosphate buffer.

Activation of the Type E toxin by trypsin increased its radiosensitivity in cell suspension, but had no influence on other preparations. Radiosensitivity of the Type E toxin appeared to be dependent upon toxin concentration and existing substances and their concentrations, as well as on the degree of polymerization of toxin molecules, which is 11.58S in the case of the Type E toxin used here. Although the Type E toxin was found to be quite radiosensitive in the pure state, as mentioned above, it was difficult to destroy the toxin in foods, and such high resistance of the toxin to radiation might be due to the protective actions of certain amino acids and purine bases.

**UTILIZATION OF CHEMICAL EFFECTS OF RADIATION ON FOOD AND ASSOCIATED MATERIALS**

**Agar extraction**

Radiation treatment of marine algae in the agar-extraction process, as a substitute for sulphuric acid treatment in the traditional method, was found to be advantageous for improving the yield and quality of the product [97]. Moreover, the filtration procedure can be done more easily by the method of water extraction from the irradiated algae than by the ordinary acid-extraction method. The fact that increase in the efficiency of extraction by irradiation was greater with unleached algae than with leached, suggested that the leaching of materials with water prior to irradiation could be omitted to simplify the process for agar extraction. Organic impurities and pigments contained in unleached algae can be removed afterwards in the process of freezing and drying.

The yield of agar extracted was linearly increased with increasing dose. However, the appropriate dose range would be 0.5 to 0.7 Mrad, because the jelly strength of the product was considerably decreased at doses above these. In fact, another study [98] showed that irradiation of red seaweed did not increase the jelly-forming property of extracted mucilage due to the de-esterification of its sulphate group, but led to degradation of the main chain at higher doses. Semi-industrial-scale irradiation also showed the feasibility of the laboratory test mentioned above [97].

On the other hand, it was found that jelly units (product of yield and jelly grade) of the pectin extracted from Satsuma orange, *Citrus unshiu*, were not improved by irradiation for manufacturing pectin [99].

**Aging of alcoholic beverages**

Changes in the quality of various alcoholic beverages, and acceleration of their aging by gamma irradiation, have been investigated [100-103].

Organoleptic results with Sake showed that the occurrence of unpleasant off-flavour and deterioration in quality were unavoidable at doses above 50 krad, while at doses less than 40 krad, the quality was usually
improved. It should be noted that development of the off-flavour was completely avoided up to 0.2 Mrad by the substitution of air with oxygen, although colour change was stimulated by this treatment. Methionine in Sake may be responsible for the development of radiation off-flavour.

Remarkable improvement in quality has been obtained with Shochu spirit, a Japanese distilled liquor prepared from rice or sweet potatoes. Bitterness and a too-strong odour of immature Shochu were markedly decreased, and its flavour became mellow with increasing dose. A dose range of 0.2 to 0.4 Mrad has been recommended for the artificial aging of Shochu.

Radiation effects on whiskey and brandy were also interesting. When samples already stored for several years in a wooden barrel were irradiated, the overall preference was not improved by irradiation, in spite of distinct mellowness in taste, probably because of decrease in the aroma of whiskey and brandy by radiation.

Thus, another experiment is in progress. To examine the possibility of shortening the aging period, newly-prepared distillates of malt whiskey and brandy, filled into new wooden barrels made of Japanese oak, were irradiated with 0.19 – 0.50 Mrad for whiskey and 0.14 – 0.45 Mrad for brandy, respectively. Chemical and physico-chemical analysis and sensory tests have been carried out at intervals of several months during storage over a period of three years. Sensory evaluation tests have so far shown the improvement in quality of irradiated whiskey and brandy during storage, especially mellowness in taste.

Other studies

The degradation of molecules and destruction of the mycell structure in rice and potato starch [104-106], denaturation of the casein fraction in milk [107-110] and increase in enzyme susceptibility of proteins [111] by irradiation, have been investigated also. Future problems would be to examine the availability of these radiation-chemical effects which are brought about in foodstuffs, for instance, decrease in viscosity, increase in water absorption capacity and susceptibility to enzymes of starch and protein, although larger doses above 10^5 rad are required for these effects. Susceptibility to amylase of amylose prepared from potato starch was found to decrease by irradiation, being different from that of irradiated starch [112].

FUNDAMENTAL STUDIES

Chemical aspects

The radiation chemistry of amino acids, proteins and enzymes has been extensively investigated in order to understand the initial steps of the biological effect of radiation, as well as changes in foodstuffs. By means of chromatography and spectrophotometry, productions of α-keto acids and ammonia by radiation were evidenced in aerated aqueous solutions [113-115]. The mechanism for oxidative radiolysis of these solutions containing an amino acid, such as alanine, valine or glutamic acid, has been postulated as follows:
Formations of various keto acids from other parent amino acids were also found through the chromatography of 2,4-dinitrophenylhydrazones [115-116]. The reaction system for the radiolysis of peptides may involve hydrolysis of the constituent amino acid, followed by production of the corresponding keto acid (4-6) as well as the direct formation of keto acid from parent peptide by oxidative deamination of fragmentary amino acid (7, 8), [114, 115, 117].

\[
\begin{align*}
H_2NR\text{CHCOOH} + OH &\rightarrow H_2N\text{R'CHCOOH} + H_2O \quad (1) \\
H_2NR\text{CCOOH} + HO_2 &\rightarrow HN=\text{RCCOOH} + H_2O_2 \quad (2) \\
HN=\text{RCCOOH} + H_2O &\rightarrow \text{RCOOOH} + NH_3 \quad (3)
\end{align*}
\]

In aqueous solutions, methionine, arginine and histidine were found to be radiosensitive, while tyrosine, proline and alanine were relatively resistant. Among the constituents of the proteinase, tyrosine, phenylalanine and arginine of the proteinase were found to be radiosensitive, while proline, histidine and threonine were comparatively resistant [118]. Studies on radiolytic oxidation of the sulfhydryl group in cysteine and enzymes such as alcoholdehydrogenase and urease, have indicated that these enzymes were most radiosensitive and the lost activities were found to correspond to the decrease in the sulfhydryl group [119].

High radiosensitivity was found with S-containing amino acids in aqueous solution and radiolysis processes of cystine and methionine were discussed [120, 121]. The ESR method has been employed to study the role of free radicals in enzyme inactivation and the radiation effect on peptide linkage [122-125].

With non-SH enzyme, destruction of the tertiary structure of protein molecules in the radiation inactivation of α-amylase [126] and chymotrypsinogen [127, 128] has been noted. Inactivating effects of radiation on Takamylase [129] and Streptomyces protease [130] in an aqueous system are modified by the addition of various inorganic salts and organic reagents. Radiosensitivities of vitamins such as vitamin A and β-carotene [131], thiamine [132, 133], riboflavin [134], vitamin B6-group substances [135], ascorbic acid [136-138] and folic acid [139] were determined. The polarographic behaviour of irradiated albumin solution [140] and the formation of reductones from sugars [141] were also investigated.

Physical and chemical changes in wheat flour subjected to doses of \(10^4\) to \(10^7\) rad have been investigated with starch and gluten fractions [6, 142-148]. Deleterious effects of radiation on wheat flour were hardly found at the disinfestation dose of about 25 krad in respect of pH, maltose value, β-amylase activity, viscosity, reflectibility, spectrophotometric behaviour and thiamine destruction, but the maximum viscosity remarkably decreased at 10 krad and more.

The results obtained by chemical and physico-chemical determination at 0.35 Mrad and more suggest that radiation damage in wheat starch may involve the depolymerization of starch molecules and oxidation in glucose.
moiety, and that they are similar to those obtained with rice and sweet-potato starch. Radiation effects on wheat gluten were observed with decreases in elastic and cohesive properties, cleavage of S-S linkage and susceptibility to the proteolytic enzyme. Denaturation of wheat gluten at higher doses was explained by the structural change of the protein molecule in gluten, involving random depolymerization.

At doses of less than 1 Mrad, changes in the rheological properties of irradiated gluten might be brought about mainly by the cleavage of hydrogen bonding, the rearrangement and subsequent structural change.

Microbiological aspects

The radiosensitivities of microorganisms in Sake, Soysauce, Miso and other Japanese foods, were determined and the mean lethal dose for these organisms was found to lie within the range of 0.01-0.13 Mrad [149, 150].

The effects of temperature, pH values and nutritional substances supplemented during post-irradiation incubation on the survival of irradiated bacteria were determined with Proteus morganii, E. coli, Serratia marcescens, Bacillus subtilis and Bacillus mesentericus [151-154]. The results revealed that environmental conditions optimal for the growth of spore-lating bacteria were optimum for the colony formation of irradiated cells of these organisms, while the recovery of irradiated cells by post-irradiation treatments under suboptimal conditions was observed with non-spore-lating bacteria.

In the study on the effects of growth conditions on the radiosensitivity of yeasts, the effects of pre-incubation time and starvation procedure were indicated [155]. Data on bacteria were obtained with a cell concentration effect in irradiated cells of E. coli [156] and the radiosensitivity of a synchronized culture of a psychrophilic bacterium, Pseudomonas fluorescens [157]. Some observations were also made on the growth of irradiated yeast, mould and bacterial cells by means of microscopy, determinations of macromolecular synthesis and genetic analysis [158-162].

The radiation sensitivity of bacteria in frozen states was determined in collaboration with the Low Temperature Research Station at Cambridge in the United Kingdom [163, 164]. Dose-reduction factors afforded by freezing were found in correlation with radiosensitivity at room temperature of three strains, B/r, B and Bs of E. coli, but the same relationship did not hold among different species of food microorganisms [165]. The effects of radiation on the production of carotenoids [166] and lipids [167] by Rhodotolula sp. have been studied.

The enhancing effects of chemical reagents on radiolethality in bacteria and yeasts have also been investigated with inorganic and organic halides [168-183] and organic acids [186, 187]. The effects of sodium chloride have two aspects, one is the enhancement after irradiation of microorganisms in growth and the other is concerned with the action during irradiation [168-170, 188]. The mechanism of enhancement by post-treatment with NaCl may be ascribed to increase in cell permeability by radiation, as previously described [1].

On the other hand, the enhancing effect of sodium chloride during irradiation, which is observed with chloride concentrations above 0.2 or 0.3 M, has been explained by the free radical model [169]. The enhancing effect is due to the action of chloride ions, but not to that of sodium ions [172].
Attacking species may be atomic chlorine or the short-lived transient Cl₂ produced by the following spur reactions [178, 189]:

\[
\begin{align*}
H_2O &\rightarrow H_2O^+ + e^- \quad (9) \\
H_2O^+ + H_2O &\rightarrow H_2O^+ + OH \quad (10) \\
Cl^- + H_2O^+ + OH &\rightarrow Cl + 2H_2O \quad (11) \\
Cl + Cl^- &\rightarrow Cl_2^- \quad (12)
\end{align*}
\]

In addition, the possible chloride concentrations inside cells, >~0.2 M, required for these spur reactions in the neutral aqueous system, was indicated at chloride concentrations outside cells, >~0.3 M, by means of the isotopic experiment, using 36Cl-labelled NaCl [178].

The shape of the survival curve was changed from the exponential type to the sigmoid type by the presence of chloride ions [169, 178]. This fact suggests that the lethal action of radiation may exert its toxic influence in the presence of chloride ions in a different way from that in the absence of chloride ions. The mechanism may involve the multi-hit events by atomic chlorine and/or Cl₂ transient at some certain non-chromosomal but essential structures, probably located near the cell surface. This view is supported by some observations, such as no direct correlation between cell death and mutation induction [190], the radioprotective effect of chloride on thermal denaturation of isolated DNA [191] and the remarkable inhibition of protein synthesis by irradiation with chloride ions [159, 192].

Other halide ions, such as bromide, iodide and fluoride ions, were also found to be synergistic, although the mechanisms of their actions appeared to be considerably different [172, 193]. Results indicating similar synergistic effects of chloride and iodide on yeast cells were obtained [183, 185, 187]. The counteracting effects of organic compounds, or free radical scavengers, on these enhancing reagents [194] suggest one of the basic problems in the application of chemical sensitization to food radiation technology.

Conclusion

It is to be hoped that the national research programme will soon begin to promote this important field in Japan, including the study of wholesomeness and economics. The first project in the programme will be the sprout inhibition of potatoes and onions. Rice and sea foods are also under consideration.

Besides these practical research projects, pioneering efforts to extend the technical feasibility of radiation processing should be made through fundamental studies in connection with radiation biology and radiation chemistry.

Many problems remain to be overcome before successful practical application is possible. The exchange of further information on food irradiation and international co-operation in the promotion of the peaceful uses of atomic energy in the food industry are desirable.
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FOOD IRRADIATION RESEARCH
AND PILOT FACILITIES IN OPERATION
OR PLANNED IN INDIA

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Abstract — Résumé — Аннотация — Resumen

FOOD IRRADIATION RESEARCH AND PILOT FACILITIES IN OPERATION OR PLANNED IN INDIA. The use of cobalt-60 gamma radiation has been studied for (a) delayed ripening in certain tropical fruits; (b) sterilization, with combined use of mild heat, of fruits and vegetables; (c) extension in shelf life of semi-dried fruits; and (d) sprout inhibition in potatoes and onions.

The technological merits of gamma-radiation processing for sea foods have been assessed by sensory evaluation for organoleptic attributes, bacterial load, chemical indices of spoilage and qualitative and quantitative shifts in spoilage flora.

Radiation pasteurization (0.4 Mrad) augments the storage life of Bombay duck for 21 and 45 d, respectively, when stored at 10-12°C and 0-4°C, as against rapid purification of the fish within 3 d.

A combination process, consisting of blanching (4 min), followed by low-dose irradiation (0.15 Mrad), extends the storage life of shrimps for 90 d at 0-4°C. Without the blanching step, shrimps keep well for 60 d; the unirradiated control spoils within 3 d.

A dehydro-irradiation process, developed for Bombay duck and shrimps, prolongs the storage life of the semi-dried products (40% moisture) at room temperature (25-28°C) for over 150 d. The process has been studied in relation to the tolerance radiation dose, the synergistic effect of sorbic acid, improvements in quality by other physical and chemical treatments, and the type of packaging material.

The onset of mould and oxidative undesirable flavours in cheese can be retarded for about 20 d at room temperature by the combined use of low doses of radiation (0.1 and 0.2 Mrad) and sorbic acid-coated wrappers.

Radiation damage to fish proteins has been studied for the degree of scission, aggregation, unfolding effect and electrophoretic mobility.

Promising results have been obtained on the application of radiation for disinfestation of grains and the extension in storage life of Indian bread. With irradiated wheat, compositional changes and nutritional studies are being continued.

Irradiation facilities, present and planned, are described. The Food Irradiation and Processing Laboratory, to be completed shortly, will house a cobalt-60 package irradiator (100 000 Ci), a cobalt-60 portable grain irradiator (28 000 Ci) and other facilities for food processing, analytical and research laboratories. The package irradiator is designed for a throughput of 100 lb/h at 0.5 Mrad and the portable irradiator could handle 500 lb/h of grain at 15 krad.

RECHERCHES SUR L'IRRADIATION DES DENRES ALIMENTAIRES ET INSTALLATIONS PILOTES EN SERVICE OU A L'ETUDE EN INDE. On a étudié la possibilité d'utiliser l'irradiation gamma au cobalt-60 aux fins suivantes: a) retardement de la maturation de certains fruits tropicaux, b) traitement combiné pour la stérilisation des fruits et légumes comportant irradiation et traitement thermique à faible tempéra­ture, c) prolongation de la durée de conservation des fruits semi-déshydratés, d) arrêt de la germination des pommes de terre et des oignons.

L'intérêt technique du traitement des produits alimentaires d'origine marine par irradiation gamma a été déterminé d'après différents facteurs: évaluation sensorielle des qualités organoleptiques, compte de la population bactérienne, indices chimiques de détérioration et modifications qualitatives et quantitatives de la flore comestible.

La radiopasteurisation (0.4 Mrad) porte à 21 et 45 jours la durée de conservation du « Bombay duck » à des températures de 10-12°C et 0-4°C respectivement, alors que ce painon non traité se péritilise rapidement en trois jours.

Un traitement combiné par échaudage (4 min) puis irradiation à faible dose (0.15 Mrad) prolonge jusqu'à 90 jours la durée de conservation des crevettes à 0-4°C. Sans échaudage, les crevettes se conservent bien pendant 60 jours; les témoins non irradiés s'altèrent en trois jours.
Désiré d’irradiation pour le « Bombay duck » et la crevette, porte à plus de 150 jours à la température ambiante (25-28°C). Différents aspects de ce procédé ont été étudiés, en particulier la dose de rayonnements admissibles, l’effet concomitant de l’acide sorbique, les améliorations de la qualité des produits au moyen d’autres traitements physiques et chimiques et le type d’emballage.

En combinant l’irradiation à faibles doses (0,1 et 0,2 Mrad) et l’utilisation d’emballages enduits d’acide sorbique, il est possible de retarder d’environ 20 jours à la température ambiante, l’apparition dans les fromages de moisissures et d’altérations de la saveur par oxydation.

On a étudié les effets nuisibles des rayonnements sur les protéines du poisson en vue de déterminer notamment le degré de scission et d’agglutination, l’effet de débroussis et d’acidité électrophorétique.

L’utilisation des rayonnements pour la désinfection des céréales et la prolongation de la durée de conservation du pain a donné des résultats encourageants. On étudie les effets de l’irradiation sur les composants et les qualités nutritives du blé.

Le mémoire décrit les installations d’irradiation en service et à l’étude. Le laboratoire d’irradiation et de traitement des denrées alimentaires, qui sera bientôt terminé, contiendra un irradiateur au cobalt-60 pour produits empaquetés (100 000 Ci), un irradiateur portatif au cobalt-60 pour céréales (28 000 Ci) et des installations annexes de laboratoire pour l’analyse, la recherche et le traitement. L’irradiateur pour produits empaquetés doit avoir une capacité de 45 kg/h sous 0,5 Mrad et l’irradiateur portatif pourra traiter 225 kg de céréales à l’heure, sous 15 Mrad.

**IRRADIACION DE ALIMENTOS EN LA INDIA: INVESTIGACIONES Y PLANTAS PILOTO EN SERVICIO O EN PROYECTO**

- Retrasar la maduración de ciertas frutas tropicales;
- Estereilizar frutas y verduras, en combinación con un tratamiento térmico moderado;
- Prolongar el período de almacenamiento de frutas semidesecadas;
- Inhibir la germinación de patatas y cebollas.
Se han evaluado las ventajas tecnológicas que ofrece el tratamiento por irradiación gamma de alimentos de origen marino, habiéndose analizado las propiedades organolépticas, la carga bacteriana, los indicios químicos de descomposición y las variaciones cualitativas y cuantitativas de la flora causante de la descomposición.

La radiopasteurización (0,4 Mrad) prolonga el período de almacenamiento del Harpodon neherens de Bombay hasta 21 días, cuando se conserva a 10-12°C, y hasta 45 días, si se conserva a 0-4°C, mientras que el mismo pescado sin irradiar se descompone rápidamente en tres días.

El tratamiento combinado consistente en calentamiento preliminar (4 min) seguido de irradiación en pequeña dosis (0,15 Mrad) prolonga el período de almacenamiento de los camarones hasta 90 días, si se conservan a 0-4°C. Si se suprime el calentamiento preliminar, los camarones se conservan bien durante 60 días; los testigos no irradiados se descomponen en tres días.

Un tratamiento de deshidratación-irradiación, ideado para el Harpodon neherens de Bombay y los camarones, prolonga el período de almacenamiento de los productos semidesecados (40% de humedad) a la temperatura ambiente (25-28°C) hasta 150 días. Este tratamiento se ha estudiado en relación con la dosis de irradiación tolerada, el efecto sinérgico del ácido sódico, el mejoramiento de la calidad por medio de otros tratamientos físicos y químicos y el tipo de envase.

La aparición de mohos y de olores desagradables por oxidación en el queso puede retardarse hasta unos 20 días a la temperatura ambiente mediante el empleo combinado de bajas dosis de irradiación (0,1 y 0,2 Mrad) y de envolturas impregnadas de ácido sódico.

Se han estudiado los daños causados por las radiaciones en proteínas de pescado analizando el grado de escisión y de agregación, el efecto de desarrollo y la movilidad electroforética.

El empleo de las radiaciones para desinfectar cereales y prolongar el período de almacenamiento del pan de maíz ha dado resultados prometedores. Se están realizando estudios sobre los cambios de composición y las propiedades nutritivas del trigo irradiado.

Se describen las instalaciones de irradiación presentes y futuras. Pronto estará terminado el Laboratorio de irradiación y tratamiento de alimentos que comprenderá un irradiador compacto de cobalto-60 (100 000 Ci), un irradiador portátil de cereales de cobalto-60 (28 000 Ci) y otras instalaciones de tratamiento de alimentos, así como laboratorios de análisis y de investigación. El irradiador compacto tiene una capacidad de producción de 100 lib. /h a 0,5 Mrad, y el irradiador portátil puede tratar 500 lib. /h de grano a 15 krad.

INTRODUCTION

At the Atomic Energy Establishment Trombay various fundamental and applied aspects of the radiation preservation of fruit and vegetables, sea food, dairy produce, cereals and cereal-based foods are being studied. With tropical produce, and under tropical conditions, there are special problems of handling, packaging, transportation and storage, especially of raw materials.

Promising results obtained on the applications of cobalt-60 gamma radiation for the preservation of fruit and vegetables have been presented elsewhere [1]. This paper deals with some of the fundamental and applied aspects of radiation effects on the preservation of sea food, milk products, cereals and cereal products. A brief account of food irradiation facilities in operation and now under way at the Trombay Establishment is also included.

RADIATION PRESERVATION OF FISH

Since sterilized fish obtained by using a high radiation dose is associated with undesirable changes in flavour [2], rendering the product unacceptable, radiation pasteurization has been adopted to extend the shelf life of locally available and commercially important fish. Initially, emphasis has been given to non-fat fish, like Bombay duck and shell-fish, shrimps and clams. These studies will be extended to medium and high-
fat fish like pomfrets, mackerels and sardines. It has been possible to preserve fish in 'fresh-like' forms or, in combination with blanching and/or mild drying, as products with improved qualities and extended shelf life.

Radiation pasteurization of Bombay duck (Harpodon nehereus)

Conventional methods do not readily lend themselves for the preservation of Bombay duck for the reasons shown in Table I. In view of the shortcomings of the conventional methods, therefore, the radiation pasteurization process was studied, using cobalt-60 gamma rays. It was observed that exposure to 0.4 Mrad augments storage life to about 21 and 45 d, respectively, when stored at 10°C and 2-3°C. Total bacterial counts and chemical indices based on bacterial metabolism were evaluated for their relationship to organoleptic attributes [3-4].

The organoleptic scores of irradiated and unirradiated samples showed striking differences (Table II). While unirradiated samples became unacceptable within 3 d, fillets irradiated with 0.25 Mrad rated 'high for about 14 d. The odours that developed thereafter were not as putrid as in the controls. Samples exposed to higher radiation doses (0.5 and 1.0 Mrad) had a low initial rating on account of the radiation odour. After storage for about 8 d, acceptability increased with disappearance of radiation odour.

The total bacterial counts in control samples increased from $10^4$ to $10^9$/g during 14 d at 10-12°C (Fig.1). Irradiation of fillets reduced the number of bacteria to $10^2$ to $10^5$/g. However, owing to the rapid growth of the surviving bacteria, counts as high as in the spoiled unirradiated samples were reached within 7 d, even though acceptability of the fish was quite high. The relationship of organoleptic score to bacterial load, with reference to growth and decline phases is shown in Fig.2.
### TABLE II. ORGANOLEPTIC SCORING OF IRRADIATED AND NON-IRRADIATED BOMBAY DUCK FILLETS (STORED AT 10-12°C)

<table>
<thead>
<tr>
<th>Period of storage (d)</th>
<th>Control</th>
<th>Score with treatment at</th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>(0.25 Mrad)</td>
<td>(0.5 Mrad)</td>
<td>(1.0 Mrad)</td>
<td></td>
</tr>
<tr>
<td>Zero (h)</td>
<td>10</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>6</td>
<td>9</td>
<td>8</td>
<td>7</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>3</td>
<td>9</td>
<td>8</td>
<td>7</td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>0</td>
<td>8</td>
<td>9</td>
<td>8</td>
<td></td>
</tr>
<tr>
<td>14</td>
<td>-</td>
<td>6</td>
<td>9</td>
<td>9</td>
<td></td>
</tr>
<tr>
<td>21</td>
<td>-</td>
<td>5</td>
<td>8</td>
<td>9</td>
<td></td>
</tr>
<tr>
<td>30</td>
<td>-</td>
<td>3</td>
<td>7</td>
<td>9</td>
<td></td>
</tr>
<tr>
<td>40</td>
<td>-</td>
<td>0</td>
<td>5</td>
<td>8</td>
<td></td>
</tr>
</tbody>
</table>

Comparative characteristics based on Miyauchi et al. [5]

<table>
<thead>
<tr>
<th>Score</th>
<th>Characteristics</th>
</tr>
</thead>
<tbody>
<tr>
<td>10</td>
<td>Odour and flavour components of products of best quality.</td>
</tr>
<tr>
<td>9</td>
<td>Loss, in part, of fresh odour and flavour but not distinguished by new.</td>
</tr>
<tr>
<td>7-8</td>
<td>First, significant change; degree of odour and flavour change slight but consistently apparent in irradiated samples; irradiation odour predominant.</td>
</tr>
<tr>
<td>5-6</td>
<td>Moderate degree of change; increased intensity and occurrence of additional components but normal desirable characteristics still dominant.</td>
</tr>
<tr>
<td>3-4</td>
<td>Strong degree of change; abnormal, undesirable components dominant in contrast to normal components; loss in palatability definite.</td>
</tr>
<tr>
<td>1-2</td>
<td>Extreme degree of change.</td>
</tr>
<tr>
<td>0</td>
<td>Too poor to evaluate.</td>
</tr>
</tbody>
</table>

The levels of volatile-reducing substances (VRS) failed to show correlation with the organoleptic score in irradiated Bombay duck. Thus, while a VRS value of 26 mg% connoted spoilage in unirradiated samples, irradiated ones with even higher values were highly acceptable. This discrepancy may be attributed to the low proportion of hydrogen sulphide, mercaptans and carbonyl compounds responsible for putrid odours, in
FIG. 1. Bacterial load in irradiated and unirradiated Bombay duck fillets stored at 10 - 12°C. The bacterial load was determined on the minced-muscle sample, homogenized in sterile tap-water and the number of colonies determined by the pour-plate method, using tryptone glucose yeast agar containing 9% NaCl. The results are expressed as cpg of original sample.

FIG. 2. Relationship between bacterial count and organoleptic score in irradiated and unirradiated Bombay duck fillets.

The total viable counts were determined as shown under Fig. 1. Rise in the bacterial count until it reached maximum during the storage period has been referred to as the growth phase. Reduction in the bacterial count thereafter is considered as the phase of decline.
the VRS of irradiated fish, in contrast to their higher percentages in unirradiated fish muscle.

Tyrosine equivalent values during storage showed irregular trends and did not therefore serve as suitable indices of incipient spoilage in irradiated fillets.

Trimethyl amine nitrogen (TMAN) values in unirradiated samples increased rapidly from 1.1 to 2.2 mg% within 5 d of storage at 10-12°C. The increase of TMAN in irradiated fillets (0.25 Mrad) was rather slow, the value being only 1.6 mg%, even after 15 d storage.

A linear relationship was observed between the total volatile basic nitrogen (TVBN) content and storage period with unirradiated and irradiated samples, a value of 30-40 mg% being suggestive of spoilage in both the cases. However, the rate of formation of TVBN was less with increase in radiation dose. The relationship between bacterial growth in fish muscle and TVBN formation is shown in Fig. 3.

Thus, it may be seen that bacterial load, VRS and tyrosine equivalent did not relate with acceptability. TMAN and TVBN contents appeared to be better indices of organoleptic ratings.

Qualitative and quantitative changes in the microflora

The lack of correlation between bacterial counts, VRS, tyrosine equivalent values and organoleptic scoring may be due to qualitative and quantitative changes in the microflora in irradiated fish. These are shown in Table III for fish, fresh as well as stored at 10-12°C for 4 d (unirradi-
ated) and 14 d (irradiated), the total bacterial counts in the latter cases being similar.

Selective changes in bacterial groups resulting from the irradiation of different fish species have also been reported [7-10]. This selection in the flora is influenced by radiation dose, type of fish, storage condition, radiation sensitivity and the proportion of spoilers. Thus, in Bombay duck irradiated with 0.4 Mrad and stored for 14 d, Gram-negative organisms of the type Proteus, and Aeromonas are completely eliminated and the residual flora consist of Gram-positive cocci and rods.

**TABLE III. PREDOMINANT MICROFLORA OF BOMBAY DUCK**

<table>
<thead>
<tr>
<th>Conditions</th>
<th>Microflora</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fresh</td>
<td>Cocci (55%), Pseudomonas (20%), Flavobacter (7%), Microbacterium (5%), Achromobacterium (7%), Bacillus (2.8%)</td>
</tr>
<tr>
<td>Spoiled</td>
<td></td>
</tr>
<tr>
<td>Stored at 10-12°C for 4 d</td>
<td>Cocci (35%), Aeromonas (22%), Proteus (43%)</td>
</tr>
<tr>
<td>Unirradiated</td>
<td></td>
</tr>
<tr>
<td>Stored at 10-12°C for 14 d</td>
<td>Cocci (86%), Microbacterium (7%), Bacillus (7%)</td>
</tr>
<tr>
<td>Irradiated</td>
<td></td>
</tr>
</tbody>
</table>

**TABLE IV. STORAGE PROPERTIES OF BOMBAY DUCK**

<table>
<thead>
<tr>
<th>Characteristics</th>
<th>Unirradiated</th>
<th>Irradiated (0.5 Mrad)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Shelf life</td>
<td>3 d at 0-4°C</td>
<td>21 d at 10-13°C</td>
</tr>
<tr>
<td></td>
<td></td>
<td>40 d at 0-4°C</td>
</tr>
<tr>
<td>Odour</td>
<td>Putrid; offensive</td>
<td>Lack of putrid odour;</td>
</tr>
<tr>
<td></td>
<td>odour on storage</td>
<td>slight radiation odour in the beginning</td>
</tr>
<tr>
<td>Nature of drip</td>
<td>Turbid and slimy</td>
<td>Clear</td>
</tr>
<tr>
<td>Nature of bacterial growth</td>
<td>Immediate rapid</td>
<td>Rapid growth of some</td>
</tr>
<tr>
<td></td>
<td>growth</td>
<td>selected colonies</td>
</tr>
<tr>
<td></td>
<td></td>
<td>after initial lethal</td>
</tr>
<tr>
<td></td>
<td></td>
<td>effect</td>
</tr>
<tr>
<td>Predominance of spoilage bacteria</td>
<td>Micrococi, Proteus,</td>
<td>Pigmented and non-</td>
</tr>
<tr>
<td></td>
<td>Aeromonas</td>
<td>pigmented Micrococi</td>
</tr>
</tbody>
</table>
These changes in the profile of microbial genera resulting in suppression of spoilage odours, with concomitant rise in bacterial load approaching those of spoiled samples, should, therefore, be reckoned before adopting the known chemical indices [3, 4] of spoilage for irradiated fish. Further studies on the metabolism of radiation survivors would be of value in devising alternate chemical indices for the evaluation of radiation-processed fish products.

The altered properties of Bombay duck stored after irradiation may be summarized in Table IV.

Radiation pasteurization of shrimps - development of a combination process

Shrimps account for nearly 17.5% of the total catch of fish in India. Because of high perishability, maintenance of sea-fresh quality during their transit and distribution poses a problem of growing importance. Presently, a large part of the catch is either dried or frozen, an equal amount is consumed fresh, and a small proportion is canned.

The use of radiation pasteurization for enhancing the storage life of shrimps to various periods has been reported with doses ranging from 0.15 to 0.75 Mrad [11-13]. However, some of the limitations in the satisfactory utilization of radiation for the extension of shelf-life in shrimps arise from radiation-induced flavours, activity of autolytic enzymes and choice of proper storage temperature. Pasteurization doses of radiation cannot inhibit the activity of autolytic enzymes [14] and deterioration in the quality of the shrimps could hamper shelf life, apart from bacterial spoilage.

Various combination treatments are being tried on fishery products for reducing radiation dose and the side effects produced by it and for enhancing shelf life. Irradiation in the frozen state and the combined use of a broad spectrum antibiotic with low doses of radiation are among these [13, 15-16].
### TABLE V. ORGANOLEPTIC CHANGES IN IRRADIATED SHRIMPS BEFORE AND AFTER COOKING

<table>
<thead>
<tr>
<th>Radiation dose (Mrad)</th>
<th>Changes in organoleptic characteristics</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Raw</td>
<td>After cooking</td>
</tr>
<tr>
<td></td>
<td>Colour</td>
<td>Flavour</td>
</tr>
<tr>
<td>0.15</td>
<td>Normal</td>
<td>Normal</td>
</tr>
<tr>
<td>0.25</td>
<td>Normal</td>
<td>Detectable radiation off-odour</td>
</tr>
<tr>
<td>0.5</td>
<td>Normal</td>
<td>Slight radiation off-odour</td>
</tr>
<tr>
<td>0.75</td>
<td>Slight reddish tinge</td>
<td>Distinct radiation off-odour</td>
</tr>
<tr>
<td>1.00</td>
<td>Reddish tinge</td>
<td>Distinct radiation off-odour</td>
</tr>
</tbody>
</table>

* Peeled and de-veined fresh shrimps, exposed to stated radiation doses were examined for colour and flavour changes before and after cooking. The shrimps were cooked at 15 lb steam pressure for 10 min.

A process, based on the advantages [17] of radiation, in combination with heat and refrigeration storage, has been developed for extending the shelf life of tropical shrimps, and is described here.

In preliminary studies, the optimum tolerance dose for fresh shrimps was first ascertained from organoleptic observations before and after cooking (Table V). Samples exposed to 0.25 Mrad had lower acceptability on account of 'radiation odour' and fading of the characteristic red colour on cooking.

In contrast to the rapid spoilage of unirradiated shrimps within 3-5 d, irradiation (0.15 Mrad) extended their shelf life by 10-15 d and 21-28 d, respectively, when stored at 10-12°C and 2-4°C (Fig. 4). Although blanching for only 4 min could bring about an extension in the shelf life of shrimps for more than 25 and 60 d, respectively, at these two storage temperatures, the quality of the product was much inferior as it acquired...
a slimy touch and musty off-odour. Combined heat and radiation-treated shrimps, however, had good flavour and texture for about 60 d at 10-12°C and for 130 d at 2-4°C. The lower temperature had the added advantage of excluding the growth of anaerobic, toxic, spore-forming bacteria of the Clostridium type [18], if any. The treatment of shrimps with heat, after sealing with brine in it caused small amounts of cooked drip.

As with irradiated Bombay duck, there was lack of correlation between the rise in bacterial load and retention of organoleptic attributes for irradiated shrimps stored at 10-12°C or 2-4°C. The organoleptic score, on a 9-point hedonic scale for colour, texture, flavour and taste, did not decline below 7 throughout the storage period, being higher for the samples given blanching and irradiation treatment. Within 3 d, the un-irradiated samples exhibited a low score of 3 and reached the spoilage values for TMAN (12-15 mg%) and TVBN (> 30 mg%). For the irradiated samples stored either at 10-12°C or 0-4°C, TVBN did not appear to be a good index of spoilage, the values being above 30-50 mg% when the bacterial load exceeded 10^7/g. TMAN values for irradiated samples, however, did not rise appreciably at 10-12°C, being less than 3 mg% at 0-4°C. With combined blanching and radiation treatment, there was a prolonged lag phase in bacterial growth followed by a gradual increase in counts to 2 X 10^4/g after 10 weeks, which declined thereafter. The production of TMAN was suppressed throughout the storage period of 130 d at 0-4°C, indicating that TMAN was a better index for evaluating the quality of shrimps.

The processing of shrimps by the combined use of radiation (0.15 to 0.25 Mrad) and blanching thus results in a product with high acceptability and a shelf life of 130 d at 0-4°C; without the blanching step, irradiated shrimps store well for 30 d.

**Dehydro-irradiation process for the preservation of shrimps and Bombay duck**

Commercially available sun-dried shrimps and Bombay duck rate very poor in texture, colour, flavour, and reconstitution properties. The quality of these products can be improved either by freeze-drying or vacuum-drying. However, dehydration being an exponential function of time, the cost of the process for a product of 5-10% moisture will be very high. As shown in Table VI, products containing 30-50% moisture take much less time for dehydration, exhibit better reconstitution properties and excel in texture. However, such products are prone to rapid spoilage by moulds and bacteria. Ionizing radiation therefore offers prospects for the preservation of such perishable products. A study was undertaken to develop a dehydro-irradiation process, taking into consideration factors related to improvement in reconstitution properties and retention of colour, flavour, and texture. Studies have also been made on the effects of low, as well as high doses of radiation, the synergistic effects, if any, of using radiation coupled with sorbic acid, known for its bacteriostatic and fungistatic action, and the type of suitable packaging material.

Fresh shrimps were steamed for 10 min to inactivate proteolytic enzymes, and then dehydrated to 40% moisture level. Shrimps were sealed in polythene bags (100 and 700 gauge), poly laminated cellulose or cellophane bags and exposed to 0.25, 0.50 and 0.75 Mrad.
The unirradiated shrimps showed onset of mould within 4 d and developed strong ammoniacal odour after 7 d on storage at room temperature (28-30°C). Shrimps exposed to 0.25 Mrad developed mould and ammoniacal odour after about 15 d.

Neither mould attack nor ammoniacal odour was observed in semidried shrimps exposed to 0.50 and 0.75 Mrad up to 80-90 d, but the original orange-red colour of the shrimps had completely faded.

The bacterial load of the unirradiated semi-dried shrimps was very high (4.0 × 10⁸/g). Products exposed to 0.5 and 0.75 Mrad showed reduction in bacterial load to the extent of 2.6 × 10⁶/g and 3.7 × 10⁴/g respectively, and reached the spoilage level after 35 and 75 d. Unirradiated shrimps showed a rapid increase in the levels of TMAN and TVBN while the irradiated products reached the spoilage values gradually.

Since semi-dried shrimps showed a considerable bleaching of colour with radiation doses of 0.5 and 0.75 Mrad, it was proposed to use a lower radiation dose (0.25 Mrad) in combination with sorbic acid. Also, since the semi-dried products, stored at room temperature for 80-90 d, showed low acceptability on account of poor reconstitution properties, physical and chemical treatments were varied to avoid excessive cooking losses and to modify the factors affecting the water-holding capacity of tissues. To select the best heat treatment, different periods of steaming, boiling, or moist-heating at lower temperatures were tried. Shrimps given these treatments were then dehydrated to 40% moisture level. The rates of reconstitution were determined after soaking the products in water at room temperature for 1, 2 and 3 h. Steam-cooking for 10 min, boiling in water for 3 or 5 min and heating at 60°C or 80°C, did not improve the reconstitution values. Among the treatments tried, boiling in water or saturated salt solution for 15 and 30 s, and heating at 80°C for 5 min in water or 10% salt solution, gave higher reconstitution values and lower

### Table VI. Dehydration Time and Reconstitution Properties of Semi-Dried Shrimps

<table>
<thead>
<tr>
<th>Moisture content (%)</th>
<th>Time taken for dehydration (h)</th>
<th>Water uptake (g) per g dry material</th>
<th>Shelf life (d)</th>
</tr>
</thead>
<tbody>
<tr>
<td>20</td>
<td>14</td>
<td>0.9</td>
<td>30-35</td>
</tr>
<tr>
<td>30</td>
<td>9</td>
<td>1.2</td>
<td>6-7</td>
</tr>
<tr>
<td>40</td>
<td>7</td>
<td>1.4</td>
<td>4-5</td>
</tr>
<tr>
<td>50</td>
<td>6</td>
<td>2.0</td>
<td>4-5</td>
</tr>
</tbody>
</table>

a) Semi-dried shrimps prepared by steam-cooking for 10 min and then dehydrating to various moisture levels in a hot-air drier at 50°C.

b) Expressed as the total water content per gramme of dry material on 3 h rehydration in water at room temperature (28-30°C).

c) As determined from onset of mould.
TABLE VII. EFFECTS OF PHYSICAL AND CHEMICAL TREATMENTS ON THE RECONSTITUTION PROPERTIES OF SEMI-DRIED SHRIMPS (40% MOISTURE)

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Cooking loss (%)</th>
<th>Water uptake/g of dry shrimps</th>
</tr>
</thead>
<tbody>
<tr>
<td>Steam-cooking for 10 min</td>
<td>50</td>
<td>1.45</td>
</tr>
<tr>
<td>Boiling (100°C) in water for 15 s</td>
<td>14</td>
<td>2.2</td>
</tr>
<tr>
<td>Boiling (100°C) in water for 5 min</td>
<td>40</td>
<td>1.50</td>
</tr>
<tr>
<td>Heating (80°C) in water for 5 min</td>
<td>30</td>
<td>2.0</td>
</tr>
<tr>
<td>Heating (80°C) in 10% NaCl for 5 min</td>
<td>27</td>
<td>1.8</td>
</tr>
</tbody>
</table>

Pealed and de-veined fresh shrimps given above treatments were dried to 40% moisture level.

a) Cooking losses are expressed as percentage loss in weight of fresh shrimps after treatment.
b) Expressed as the total water content per gramme of dry material on 3 h rehydration in water at room temperature.

cooking losses, as shown in Table VII. Although boiling in water for 15 s gave low cooking losses and the highest water uptake for the semi-dried product, the heat treatment was insufficient to arrest tissue proteolytic activity. Hence, this treatment was not considered for further storage experiments. Restriction of cooking losses avoids excessive leaching of soluble nitrogen, flavour components, vitamins and minerals.

Shrimps given dip in sorbic acid (0.5%) followed by heating at 80°C for 5 min in water, or in 10% salt solution, were also dehydrated to 40% moisture. The irradiation of shrimps after sorbic acid and 10% salt treatment was most effective against bacterial damage and mould growth, when stored at room temperature (Table VIII). There was no ammoniacal odour characteristic of the spoiled unirradiated product, and the retention of colour was also good for about 150 d. Among the packaging materials tested, polylaminated cellulose films, moisture-resistant and sealable, and polyethylene bags (700 gauge) were found to be most effective in retaining the moisture. Such products exhibited about 5% loss in moisture as against 10-12% in products stored only in polythene (100 gauge) or cellophane wrappers.

Development of a semi-dried Bombay-duck product

Semi-dried Bombay duck fillets containing 40% moisture were prepared by steaming for short intervals and dehydrating at 50°C in a hot-air drier or in a vacuum oven. The onset of mould in these products was
### TABLE VIII. COMBINED EFFECTS OF SORBIC ACID AND LOW-DOSE IRRADIATION ON THE STORAGE LIFE OF SEMI-DRIED SHRIMPS (40% MOISTURE) AT 28-30°C

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Storage properties of semi-dried shrimps</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Bacterial count/g</td>
<td>Shelf life (d)</td>
</tr>
<tr>
<td>Steam-cooking 0 rad for 10 min</td>
<td>$1.8 \times 10^8$</td>
<td>5-6</td>
</tr>
<tr>
<td>Sorbic-acid dip prior to heat treatment in water at 80°C for 5 min</td>
<td>$2.0 \times 10^3$</td>
<td>35-40</td>
</tr>
</tbody>
</table>

Sorbic acid solution (0.05%), pH 6, was used as a dip, followed by heat treatment in water or 10% salt solution. The shrimps were then dehydrated to 40% moisture. Samples given sorbic-acid dip after heat treatment spoiled within 14 d. The samples, which showed augmented storage life over 150 d, had a low bacterial count ($4 \times 10^4$ g) and did not show any mold growth.

Prevented for over three months at room temperature by irradiation (0.5-1.0 Mrad) as with shrimps. These products exhibited better texture, colour and reconstitution properties than the commercially available sun-dried products.

However, irradiation caused more browning of air-dried samples than vacuum-dried samples during storage at room temperature. This indicated that oxidative changes induced during hot-air drying were further accelerated by radiation. Experiments are in progress to reduce this oxygen effect by suitable chemicals for glazing the surface of fish products.

### RADIATION PRESERVATION OF MILK PRODUCTS

Pasteurization and sterilization of milk and milk products by irradiation have received considerable attention. Although onset of mold attack on cheese can be prevented by high doses of radiation (1 to 2 Mrad),
the resulting product loses its organoleptic attributes by developing disagreeable oxidation flavours. A simple procedure, with combined use of low doses of radiation (0.1 to 0.2 Mrad) and sorbic acid-sprayed cellophane wrappers [19] has been developed [20] for the preservation of cheddar cheese. This treatment retards the development of the 'coconut-like' rancid odour and mould growth on cheese stored at room temperature for about 20 d, as against rapid spoilage of samples without the sorbic-acid-sprayed wrappers or those exposed to low doses of radiation only.

Since the significance of carbonyl compounds in flavour studies is well recognized, the extent of carbonyls produced from cheese was determined. Both the volatile (which arise from radio-chemical degradation of lipids) and acid soluble (derived from amino acids and proteins) carbonyls were determined as a function of radiation dose. The acid-soluble carbonyls increased from 15 μg (0.1 Mrad) to 55 μg (1.5 Mrad) per gramme of cheese sample while, for the corresponding radiation doses, the volatile carbonyls showed a marked increase from 20 μg to 375 μg. Studies are in progress to characterize the carbonyl compounds and to determine the pattern of radiation degradation of possible precursors which contribute to flavour changes.

PHYSICO-CHEMICAL ALTERATIONS IN IRRADIATED FISH PROTEINS

The nature of the compounds which give rise to 'irradiation odour' in fish samples, exposed to gamma radiation above the tolerance dose (0.5 Mrad), is as yet obscure. It was therefore of interest to ascertain the type of changes in the major proteins of Bombay duck and shrimps. Radiation damage to aqueous solutions of proteins have been characterized in terms of aggregation and scission [21, 22]. However, these effects vary with different species of fish.

The fractions containing sarcoplasmic proteins and fibrillar proteins, together with sarcoplasmic proteins, were isolated from fresh Bombay duck and shrimps, using specific extractants [23, 24]. These fractions were then irradiated with doses varying from 0.2 to 1.0 Mrad. Aggregation of proteins was observed only in the irradiated fraction containing sarcoplasmic, together with fibrillar proteins. The degree of scission of these proteins, measured by the increase in non-protein nitrogen content, indicated that both these protein fractions had undergone cleavage to the extent of 30-40% with 1 Mrad, but the sarcoplasmic proteins from shrimps did not develop the intense 'radiation odour' observed with Bombay duck. Likewise, the fibrillar proteins of shrimps showed more aggregation than those of Bombay duck. Irradiated aqueous solutions of proteins apparently show considerable unfolding as has been found from their increased (50 to 70-fold) susceptibility to trypsin and chymotrypsin hydrolysis. They get separated earlier on sephadex G-100 columns and have lower electrophoretic mobility than the unirradiated proteins.

Preliminary studies on the nature of nucleases and hydrolases of shrimp muscle show certain differences in the enzymic equipment different from those of lysosomal origin.
RADIATION DISINFESTATION OF STORED GRAIN PESTS

Insect sterilization and pest control aspects have received considerable attention at the Biology Division of the Trombay Establishment. Since a wide spectrum of insect pests causes damage to stored grains, detailed investigations have been carried out on the effects of gamma radiation on the developmental stages, viz., eggs, larvae and pupae, with special reference to viability, larval mortality, pupation rate and adult emergence. Considerable differences in the sterilization dose were noted among the females (6000 rad) and males (16 000 rad) of the Khapra beetle, a pest on wheat grain. The effective lethal dose for rice weevils of all age groups was found to be 5000 rad. The flour beetle (Tribolium castaneum), the fig-moth (Ephestia cautella) and the lesser grain borer (Rhizoportha dominica) appeared to be relatively resistant, the sterilizing dose being near to 10 000 rad. Gamma radiation has advantages over chemical fumigation in that it could sterilize eggs as well as adult insects and does not leave any toxic residues.

RADIATION PRESERVATION OF CEREAL PRODUCTS

Gamma irradiation of Indian (unleavened) bread, chapatis nans, and alu parotha packaged in polythene bags, increases their storage life. Non-irradiated controls, and those receiving 100 krad spoil within 5 d. Chapatis and nan irradiated with 250 krad could remain in good condition for 10 and 14 d, respectively; those receiving 500 krad and above are without mould growth even after 8 to 10 weeks' storage.

At all times, up to six weeks, irradiated chapatis are acceptable organoleptically. Studies on the irradiation of chapatis, prepared by the incorporation of antioxidants, have shown that, both with respect to thiobarbituric acid values and organoleptic tests, these are acceptable even after storage for seven weeks.

COMPOSITIONAL CHANGES IN IRRADIATED WHEAT

There are reports that radiation treatment may alter the physico-chemical properties of starch and protein in wheat flour. Since quality in wheat for bread-making is determined, among other things, by its amylase and, to a less extent, protease activities, it was of interest to ascertain if these are influenced by irradiation.

Diastatic activity, expressed as 'Maltose value', of wheat flour irradiated with gamma rays at dose levels from 20 to 200 krad increased significantly. This could arise from increased susceptibility of the starch to enzyme action, or from the stimulation of amylase activity. It was, however, observed that alpha and beta amylases were quite resistant to ionizing radiation, whether present in bound form in grain or in aqueous solution, where the effect is mainly indirect. When alpha or beta amylase in wheat flour was selectively inactivated (the former at 0°C for 30 min at pH 3.4, and the latter by heat at 70°C and pH 6.5) and then subjected to amylolysis with an external source of enzyme, an appreciable increase in maltose liberation was observed in irradiated samples. This
further confirms the increased susceptibility of irradiated wheat starch to enzyme action.

Laboratory germination tests on irradiated seeds revealed that activities of alpha and beta amylases were unchanged during 24 h. of germination, after which they were significantly reduced. It is to be ascertained whether irradiation impairs release of latent amylases on germination or inhibits their de novo synthesis. Susceptibility to irradiation was more pronounced at 20 and 30% moisture levels than at 10% moisture level.

Work is in progress to study the sensitivity of wheat starch to radiation degradation by characterizing the breakdown products of starch. A method has been worked out to study the action pattern of wheat amylases and to separate the products of enzymatic hydrolysis.

**NUTRITIONAL EVALUATION OF RADIATION-STERILIZED WHEAT GRAINS**

Nutritionally adequate diets containing 75% wheat, irradiated with cobalt-60 gamma rays at 20 or 200 krad dose levels, have been fed to rats and mice of both sexes, as test animals. With young rats, the growth rate of the first generation showed no difference between experimental and control groups. The ratio of body weight gain to food intake (food efficiency ratio) was also not changed. Specific organ weights, as well as haematological, biochemical and histological data, did not reveal any adverse effect of irradiated diet in first-generation animals.

With mice, their fertility and average litter number, growth and survival, have been used as criteria of reproductive performance. In two generations, no differences due to feeding diets containing irradiated wheat were observed.

Feeding will be continued for four generations. Experiments are also planned, using irradiated cereals and legumes in prevailing low-quality Indian diets.

**FOOD IRRADIATION FACILITIES AT TROMBAY**

Researches in food irradiation were initiated in 1959 with gamma rays from reactor fuel rods serving as the radiation source when the level of neutrons was low, as during the shut-down condition of the reactor. Since 1964, these experiments have been intensified and are in progress with facilities of cobalt-60 gamma cells (22.5 kCi, 1.5 Mrad/h; 3.9 kCi, 0.1 Mrad/h, and 3.7 kCi, 0.5 Mrad/h).

Recognizing the importance of studies on the application of irradiation procedures for food preservation and processing, the construction of a separate Food Irradiation and Processing Laboratory has also been undertaken and will soon be completed. This laboratory will be concerned with research and developmental work on food preservation and processing procedures that will involve the application of radiation, either gamma rays (cobalt-60) or fast electrons (linear accelerator, linac). Irradiation facilities will be for batchwise or continuous operation and
will permit pilot-scale operations on the basis of which processes can be evaluated for their economic feasibility.

This laboratory will house a cobalt-60 (100 kCi) package irradiating plant with a processing rate of 100 lb/h at 0.5 Mrad, and a cobalt-60 (28 kCi) portable grain irradiator which will handle 500 lb of grains, or other free-flowing material per hour at 15 krad.

The cobalt-60 package irradiator has been designed to permit delivery of radiation doses of from 5 Mrad to 5 krad by suitable speed variation of the conveyor mechanism and by change of source strength. The speed range will be controlled pneumatically and will cover 1 to 120 boxes of 10 lb/h. The source pencils will be in two independent racks so that either 100% of the activity or 12% of the activity can be exposed by means of a selector switch at the control panel. The source, when not in use, will be shielded under 18 ft of deep water. The cobalt cell will have a special chilling device (10°C) around the source rack when required.

This source will be used for experimental work for the gamma irradiation of foods, particularly fish, meat products, fruit, vegetables, cereal products and other food commodities. Sterilization of surgical materials will also be made possible with this facility.

The portable cobalt-60 grain irradiator will have a self-contained biological shielding and will make possible outdoor experiments, thus providing flexibility for trials under conditions peculiar to the application of irradiation procedures for grain disinfestation in India.

 Provision has been made in the control area of the building for the future addition of a fast electron machine. There will be a large laboratory equipped with plant and machinery for various unit operations in food processing: drying, evaporation, concentration, filtration, refrigeration, etc. The associated research laboratories in the building will carry facilities for work in food science, nutrition, quality control, food irradiation, food engineering, packaging, dosimetry, and other studies. Taste-test and organoleptic evaluations will be carried out in modern kitchen and testing laboratories. Facilities for the storage of foodstuffs, processed and fresh, at controlled environmental temperatures, which will include cold rooms and experimental cold cells, have also been provided.

The location of the Food Irradiation and Processing Laboratory will also permit maximum utilization of the facilities in the Division's nearby well-equipped Biochemical Laboratories. Also available at Trombay are the Biology Group's cobalt-60 (500 Ci) gamma field and the field station for experimental work on crop plants and mutants of economic value as well as the Experimental Animal House.

ACKNOWLEDGEMENT

The authors' thanks are due to their colleagues in the Division of Biochemistry and Food Technology who have shared in the experimental work reported here.
REFERENCES


СОСТОЯНИЕ И ПЕРСПЕКТИВЫ ПРИМЕНЕНИЯ ИОНИЗИРУЮЩИХ ИЗЛУЧЕНИЙ ДЛЯ ОБРАБОТКИ ПИЩЕВЫХ ПРОДУКТОВ В СВЯЗИ С ИХ ХРАНЕНИЕМ

В. И. РОГАЧЕВ
ВСЕСОЮЗНЫЙ НАУЧНО-ИССЛЕДОВАТЕЛЬСКИЙ ИНСТИТУТ КОНСЕРВНОЙ И ОВОЩЕСУШИЛЬНОЙ ПРОМЫШЛЕННОСТИ
МОСКВА, СССР

Abstract — Résumé — Аннотация — Resumen

THE USE OF IONIZING RADIATION AS A MEANS OF PROCESSING FOODSTUFFS FOR STORAGE: PRESENT STATUS AND FUTURE PROSPECTS. The use of ionizing radiation for processing foodstuffs is being studied in the USSR, particularly in connection with the following: (a) prevention of sprouting in potatoes and onions; (b) disinfestation of foodstuffs; (c) suppression of microbe activity; either sterilization or partial inhibition of microflora activity to prolong the shelf life of various foodstuffs; and (d) alterations in the ripening time of fruits and vegetables after picking and/or harvesting.

The paper reports the status of work performed in the USSR during recent years on each of these general topics, and the prospects for the practical application of irradiation to a number of products are considered. Among the products in question are meat and meat products (raw and cooked semi-finished products, sausage products), domestic poultry, various fruits and vegetables, potatoes, grain, dehydrated products (dried fruits and vegetables, dried food concentrates).

Practical methods of irradiating potatoes and onions to prevent sprouting during storage have already been developed, and very soon it will be possible to use radiation for the disinfection of foodstuffs on an industrial scale.

UTILISATION DES RAYONNEMENTS IONISANTS POUR LA CONSERVATION DE PRODUITS ALIMENTAIRES: SITUATION ACTUELLE ET PERSPECTIVES. Les études sur l'utilisation des rayonnements ionisants pour la conservation des produits alimentaires se poursuivent en URSS dans les domaines suivants: a) prévention de la germination des pommes de terre et des oignons; b) désinsection des produits alimentaires; c) élimination de l'activité biologique des micro-organismes en vue de la stérilisation ou de l'élimination partielle de l'activité biologique de la microflore en vue de prolonger les délais de conservation de divers produits alimentaires; et d) modifications des délais de maturité après récolte des fruits et légumes.

Pour chacun de ces domaines, l'auteur indique l'état des travaux effectués en URSS pendant ces dernières années et examine les perspectives d'utilisation des rayonnements pour un certain nombre de produits.

Au nombre de ces produits figurent la viande et les préparations à base de viande (produits crus ou semi-préparés, charcuterie), volaille, divers fruits et légumes, pommes de terre, céréales, produits déshydratés (fruits et légumes séchés, produits alimentaires secs concentrés).

Outre les méthodes d'irradiation qui ont déjà été mises au point pour empêcher la germination des pommes de terre et des oignons lors du stockage, il sera possible de recourir prochainement à l'irradiation pour la désinfection industrielle de produits alimentaires.

СОСТОЯНИЕ И ПЕРСПЕКТИВЫ ПРИМЕНЕНИЯ ИОНИЗИРУЮЩИХ ИЗЛУЧЕНИЙ ДЛЯ ОБРАБОТКИ ПИЩЕВЫХ ПРОДУКТОВ В СВЯЗИ С ИХ ХРАНЕНИЕМ.

Изучение применения ионизирующих излучений для обработки пищевых продуктов проводится в СССР в следующих направлениях: а) предотвращение прорастания картофеля и лука; б) дезинфекция пищевых продуктов; в) подавление жизнедеятельности микроорганизмов стериллизации или для частичного подавления жизнедеятельности микроорганизмов с целью удлинения сроков хранения различных пищевых продуктов; г) изменение сроков послеуборочного созревания плодов и овощей.

По каждому из этих направлений в докладе сообщается состояние работ, выполненных в СССР за последние годы, рассматриваются перспективы практического применения облучения для ряда продуктов.

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К числу этих продуктов относятся мясо и мясопродукты (сырые и кулинарно подготовленные полуфабрикаты, колбасные изделия), битая домашняя птица, разнообразные плоды и овощи, картофель, зерно, обезвоженные продукты (сушеные фрукты и овощи, пищевые концентрированные сухие продукты).

Кроме уже разработанных для практического использования способов облучения картофеля и лука с целью предупреждения прорастания при хранении, в ближайшее время возмож но применение облучения для промышленной дезинсекции пищевых продуктов.

Большое внимание, уделяемое в СССР использованию атомной энергии в мирных целях, способствовало широкому развитию научно-исследовательских работ по облучению пищевых продуктов. Эти исследования, проводившиеся в различных аспектах (микробиологические, физиологические, биохимические, физико-технические, радиационно-технологические, конструкторские), но по единому плану, позволили комплексно решить многочисленные вопросы практического использования ионизирующих излучений для обработки сельско-хозяйственного сырья и продуктов его переработки. Для проверки результатов лабораторных исследований была создана большая универсальная опытно-производственная установка для облучения пищевых продуктов, что обеспечило всестороннюю проверку разработанных способов и условий облучения с целью их последующего промышленного применения.

К настоящему времени рекомендовано промышленное использование ионизирующих излучений в следующих направлениях:

1. Облучение картофеля и лука для предотвращения их прорастания при хранении.

Изучены теоретические основы и механизмы подавления прорастания, установлены оптимальные условия и режимы облучения, проверенные на специальной опытно-промышленной установке, выявлена экономическая эффективность процесса, выяснена безвредность для питания, пищевая ценность и качество облученного картофеля и лука, установлена возможность использования этих продуктов для промышленной переработки.

В 1958 году государственными органами здравоохранения СССР дано разрешение на употребление в пищу облученного картофеля. Признано целесообразным организовать облучение картофеля и лука в первую очередь для сырья, поступающего на промышленную переработку. Работы по созданию таких установок начаты в 1965 году.
2. Облучение сушенных фруктов, сушеных овощей и пищевых концентрированных продуктов с целью их дезинсекции.

Закончены научно-исследовательские работы, позволяющие установить оптимальные дозы облучения, гарантирующие отмирание основных видов насекомых вредителей сушенных продуктов, выявлена экономическая эффективность радиационной дезинсекции, изучены химические изменения, происходящие при облучении, пищевая ценность и безвредность облученных сушенных продуктов. Министерство здравоохранения СССР выдало разрешение на использование в пищу облученных сушенных фруктов. Сконструирована специализированная установка для облучения сушенных фруктов, создаваемая при консервном заводе.

3. Радиационная дезинсекция зерна.

На основании проведенных энтомологических, биохимических и др. исследовательских работ была создана специальная опытная установка полупромышленного типа. На этой установке проверены режимы облучения, разработанные в лабораторных условиях, в результате чего получены данные, необходимые для проектирования установок промышленного типа.

Министерством здравоохранения СССР дано разрешение на употребление в пищу отдельных партий облученного зерна.

4. Облучение спелых плодов, ягод и овощей для удлинения сроков хранения

В результате обширных физиологических, биохимических и микробиологических исследований разработаны теоретические основы и технологические условия облучения спелых плодов, ягод и овощей. Найденные при этом оптимальные дозы облучения позволяют задержать развитие микрофлоры без глубоких физиологических нарушений в плодах и без ухудшения их качества.

В течение 1964 и 1965 гг. были облучены товарные партии земляники, малины, абрикосов, персиков, винограда, сливы, томатов. Министерством здравоохранения СССР выдано разрешение на реализацию этих облученных партий. В 1966 г. будет проведено еще раз облучение крупных партий плодов и ягод с целью окончательной разработки предложений для практического использования этого метода.

5. Облучение мяса и мясных продуктов для удлинения сроков хранения

Проведены биохимические, микробиологические и технологические исследования, которыми установлена перспективность практического использования облучения битой птицы, расфасованного мяса, разнообразных мясных полуфабрикатов, полукопченных колбас, копченой грудинки и т.п. изделий. Установлена экономическая эффективность применения облучения этих изделий. Министерством здравоохранения СССР выдано разрешение на употребление в пищу опытной товарной партии облученных мясных продуктов.

В 1965 году была изготовлена опытно-производственная партия мясных полуфабрикатов, реализованная через вагоны-рестораны железных
дорог. Получены исключительно хорошие отзывы потребителей о качестве продуктов, изготовленных из этих полуфабрикатов. Работниками ресторанов подтверждена эта оценка и высказаны благоприятные отзывы об удобстве пользования такими полуфабрикатами и надежности их хранения.

Для окончательного подтверждения ранее полученных результатов в 1966 году будут облучены крупные товарные партии мясных полуфабрикатов с реализацией их через рестораны и магазины. На основании полученных результатов будут подготовлены предложения о создании специализированных промышленных установок для облучения мяса и мясных продуктов.

По всем перечисленным направлениям использования ионизирующих излучений, установлена целесообразность практического применения радиационного метода обработки и намечены пути промышленного использования.

Кроме этого ведется научно-исследовательская разработка других областей применения ионизирующих излучений, к числу которых относятся стерилизация пищевых продуктов, обработка для ускорения и улучшения технологических процессов, а также для улучшения качества продукции.

**DISCUSSION**

**E. JOSEPHSON:** I wonder whether you could outline briefly for us the procedures that must be followed in the Soviet Union to obtain approval from the health authorities for the consumption of irradiated foods. You seem to be moving ahead so rapidly in the matter of obtaining clearances that I think we in other countries might well profit by your experience and learn how to speed up our approval procedures.

**V.I. ROGACHEV:** In fact the procedure is quite strict. Before irradiated foodstuffs can be released for public consumption they must undergo stringent spot tests (short-term tests), as well as long-term tests, to make sure that they are wholesome and not toxic. This work is carried out at special institutes of the Ministry of Health.

**P. LEVEQUE:** Would it be possible to obtain a bibliography showing the most important papers published in the Soviet Union on this general subject? It would be especially useful as a supplement to the Bulletin d'information pour l'irradiation des aliments.

**V.I. ROGACHEV:** Yes; the most complete bibliographical lists of work published in the Soviet Union will be found in the Referativny žurnal (Journal of abstracts) and the Letopis' žurnalnyh statej (Yearbook of articles in periodical publications).

**R.S. KAAN:** I gather the USSR Ministry of Health has a provisional licensing system whereby irradiated products can be tested on a limited scale. One rather envies your ability to do this kind of consumer testing. Does the Ministry of Health consider only wholesomeness and nutritional value in deciding whether to issue a temporary licence, or does it also give weight to economic factors at this stage?

**V.I. ROGACHEV:** The Ministry's main concern is to make sure that the products are safe, wholesome and of good quality, but it does also take technical and economic considerations into account.

**G. MOCQUOT:** Is the public notified by any sort of label that the products have been irradiated?
V.I. ROGACHEV: No, the licences issued by the Ministry of Health carry no labelling requirement. In fact this is not necessary in the Soviet Union, because no new process is approved and no new product allowed on the market until the Ministry of Health has given its permission; in other words, the existing controls are quite adequate to ensure that all technical requirements are observed. The Soviet consumer can therefore rest assured that considerations of health will have been given all due consideration before a product is released for sale.

M. DEL VAL: Have irradiated sea foods yet been licensed for public consumption in the USSR?

V.I. ROGACHEV: No, not yet.
ECONOMICS OF FOOD IRRADIATION

(Session VIII)
Abstract — Résumé — Аннотация — Resumen

ECONOMICS OF GRAIN IRRADIATION. After three years, in which preliminary designs were prepared, a grain irradiation plant has been designed and is being built into an existing silo installation. From this experience actual costs of plant construction are available for a plant using cobalt-60 and this experience is incorporated in estimates for machine installations for high grain throughput.

Costs are compared for plants of comparable complexity and they indicate those areas in which each type of plant is pre-eminently suitable and those areas where either type may be best, dependent upon local site conditions, the standard of local technology and methods of operation.

The two plants compared are described in sufficient detail to enable the precise extent of the equipment supply covered by the costs to be appreciated. The accounting methods employed have been discussed with industrial accountants to ensure that they are acceptable to the potential users. The methods employed are explained so that they can be applied to problems of a similar nature.

ASPECTS ECONOMIQUES DE L'IRRADIATION DU GRAIN. Après trois années d'étude de plans, on a entrepris la construction d'une installation d'irradiation de grains dans un silo préexistant. On dispose maintenant de chiffres sur le coût de la construction d'une installation utilisant le cobalt-60 et on les applique pour évaluer les frais d'installation de machines permettant le traitement des céréales en grandes quantités.

La comparaison des prix de revient pour deux installations de complexité analogue indique les secteurs dans lesquels chaque type d'installation convient le mieux ainsi que les secteurs où les deux types d'installation peuvent être utilisés selon les conditions locales, le niveau technique local et les méthodes d'exploitation.

Les deux installations comparées sont décrites avec suffisamment de détails pour que l'on sache avec précision quel matériel est inclus dans le calcul des coûts. Les méthodes de comptabilité employées ont été étudiées avec des comptables industriels pour s'assurer qu'elles sont acceptables pour les utilisateurs éventuels. Les méthodes sont en outre expliquées, afin que l'on puisse les appliquer à des problèmes analogues.

ЭКОНОМИКА ОБЛУЧЕНИЯ ЗЕРНА. Спустя три года, в течение которых были подготовлены эскизные проекты, была сконструирована установка по облучению зерна, которая в настоящее время устанавливается в существующую установку по силосованию. На основе этого опыта в настоящее время известна действительная стоимость сооружения предприятия, использующего установку кобальт-60; этот опыт включается в смету на установку машин по обработке зерна высокой пропускной способности.

Приводится сравнение стоимости для предприятий сравненной сложности и она определяет те области, в которых каждый вид предприятия является наиболее подходящим, и те области, в которых наилучшим могут явиться предприятия другого типа в зависимости от условий месторасположения, условий местной технологии и методов обработки.

Два сравниваемых предприятия описываются довольно подробно с целью предоставления возможности точного определения объема поставок оборудования, входящих в число подлежащих учету расходов. Использованные методы калькуляции были обсуждены с бухгалтерами, работающими в области промышленности, с тем, чтобы получить уверенность в их пригодности для потенциальных потребителей. Использованные методы объясняются таким образом, что они могут быть применены к проблемам аналогичного характера.

ASPECTOS ECONOMICOS DE LA IRRADIACION DE GRANOS. Después de tres años de estudios preparatorios se ha proyectado una instalación de irradiación de granos que se está montando en un silo ya en uso. Sobre la base de la experiencia adquirida se calcula el costo real de construcción de una instalación que
utilice cobalto-60; dicha experiencia se aprovecha asimismo para calcular el costo de instalaciones destinadas a tratar grandes cantidades de grano.

Se comparan los costos correspondientes a dos tipos de instalaciones de complejidad semejante; por este procedimiento se determina en qué regiones resulta más apropiado cada uno de ellos y en cuáles cualquiera de los dos puede ser el más indicado, según las condiciones de emplazamiento, el nivel tecnológico local y las métodos de explotación.

Estos dos tipos de instalación se describen con suficiente detalle para que se puedan apreciar claramente los elementos de equipo que corresponden a los costos indicados. Los métodos de contabilidad se han discutido con contables industriales a fin de tener la seguridad de que son aceptables para los posibles usuarios. Se explican los métodos seguidos para que puedan aplicarse a problemas análogos.

1. INTRODUCTION

There are two commonly accepted sources for industrial irradiation, cobalt-60, and particle accelerators of one kind or another. Each type of source has its own distinct properties and each type has its protagonists. At international conferences the two camps put forward their claims in a way which makes it difficult for the potential user to make a realistic comparison between the two sources.

It would seem from the exchanges between these two camps that there is little common ground in the choice of fundamental criteria for the calculation of their economics and, in particular, that the methods of amortization used may be widely different in the two cases. It is, of course, of academic interest to compare the costs of 1 kW of energy emitted by each of the two types of sources, but as the absorption efficiencies of the irradiation from the two sources can vary very greatly, economics based on the emitted energies can have little value for the industrialist.

Because cobalt-60 and machines have different fields of application, although in many areas these fields overlap, The Nuclear Chemical Plant Ltd. (NCP) have decided that it is logical to offer plants using both isotopic and electron sources. One of the fundamental exercises that is necessary for a proper evaluation of the field of application of each system is a realistic comparison of the cost of them.

It is clear that, due to the different properties of the two radiations, the material handling problems are very different for cobalt-60 and electron irradiation facilities. In this paper the authors compare the economics of the irradiation of grain by cobalt-60, and by an electron accelerator.

The design of the cobalt-60 grain irradiation plant on which the economic assessment is based is developed from a plant offered to a South African concern in 1962. The design of a grain irradiator incorporating a machine has been prepared for comparison with it.

The operating cost comparison developed from these two designs has been extended so that the comparison between cobalt-60 and electron machine irradiation plants can be applied to other systems, where the efficiency of radiation absorption is known. The operating costs have been presented graphically for different absorption efficiencies for each of the two sources. The efficiencies taken are gross efficiencies and the radiation absorbed uneconomically above the minimum desired dose for the process is included in this value.
2. SOURCE COMPARISON

The two sources being considered in this economic comparison are cobalt-60 of United Kingdom origin and particle accelerators, in particular the 'Dynamitron'. It is probably worth while to repeat the comparative merits of the two sources, the economic merits of which become more obvious at the end of the paper (see Table A).

TABLE A. COMPARISON OF SOURCES

<table>
<thead>
<tr>
<th>Item</th>
<th>Cobalt-60</th>
<th>Particle accelerators</th>
</tr>
</thead>
<tbody>
<tr>
<td>Radiation</td>
<td>γ-rays of 1.17 and 1.33 MeV</td>
<td>Commonly electrons of energies up to 10 MeV and more; also X-rays from conversion</td>
</tr>
<tr>
<td>Radiation characteristics</td>
<td>High penetration</td>
<td>Low penetration, high penetration with X-rays</td>
</tr>
<tr>
<td>Emission reliability</td>
<td>Absolute</td>
<td>Variable and design-dependent</td>
</tr>
<tr>
<td>Plant shutdown</td>
<td>By shielding source</td>
<td>By switching off the accelerator by one push button or safety trip</td>
</tr>
<tr>
<td>Labour requirement</td>
<td>Medical plants operate with limited supervision, the main labour requirement being for loading and off-loading product material (15 h/week [1]). Grain plants should operate similarly.</td>
<td>Normally one operator per shift, although this may not be necessary after operating experience</td>
</tr>
<tr>
<td>Treatment method</td>
<td>In large packages or in bulk</td>
<td>In thin layers or films and packages or large bulk when using X-rays</td>
</tr>
</tbody>
</table>

A further direct comparison was considered but this became more difficult the closer it was examined. Electron machines cover a whole spectrum of electron energies from hundreds of kilovolts to 10 MeV, and higher energies. Each energy level has its own field of application from the treatment of films to the treatment of thick packages, either using radiation directly or converting electrons to X-rays and applying these [2]. The comparison is further complicated by the increase in cost of a kilowatt of electrons with increase in electron energy.

A table of the characteristics of various types of electron accelerators has been presented by Koch and Eisenhower [3] showing this, and that the capital cost per kW for Dynamitron accelerators was lower than those of
<table>
<thead>
<tr>
<th>Source type</th>
<th>Energy (MeV)</th>
<th>Power (kW)</th>
<th>Cost ($/kW)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dynamitron</td>
<td>1.5</td>
<td>15</td>
<td>6 100</td>
</tr>
<tr>
<td>&quot;</td>
<td>3.0</td>
<td>30</td>
<td>5 000</td>
</tr>
<tr>
<td>Insulating-core transformer</td>
<td>0.5</td>
<td>10</td>
<td>10 000</td>
</tr>
<tr>
<td>Linac</td>
<td>5.0</td>
<td>30</td>
<td>8 000</td>
</tr>
<tr>
<td>&quot;</td>
<td>5.0</td>
<td>30</td>
<td>(2 000) b)</td>
</tr>
<tr>
<td>&quot;</td>
<td>10.0</td>
<td>5</td>
<td>50 000</td>
</tr>
<tr>
<td>&quot;</td>
<td>10.0</td>
<td></td>
<td>(22 000) b)</td>
</tr>
<tr>
<td>Resonance transformer</td>
<td>1.0 (peak)</td>
<td>4</td>
<td>17 750</td>
</tr>
<tr>
<td>&quot;</td>
<td>2.0 (peak)</td>
<td>10</td>
<td>13 100</td>
</tr>
<tr>
<td>Van de Graaff</td>
<td>1.5</td>
<td>25</td>
<td>24 000</td>
</tr>
<tr>
<td>&quot;</td>
<td>4.0</td>
<td>40</td>
<td>39 000</td>
</tr>
<tr>
<td>Cobalt-60</td>
<td></td>
<td></td>
<td>33 000</td>
</tr>
<tr>
<td>Dynamitron (X-rays)</td>
<td>3.0</td>
<td>30 (1.86) a)</td>
<td>80 700</td>
</tr>
<tr>
<td>Linac (X-rays)</td>
<td>5.0</td>
<td>30 (3.3) a)</td>
<td>72 700</td>
</tr>
<tr>
<td>&quot;</td>
<td>10.0</td>
<td>5 (0.95) a)</td>
<td>263 000</td>
</tr>
<tr>
<td>&quot;</td>
<td>10.0</td>
<td>25 (4.75) a)</td>
<td>116 000</td>
</tr>
</tbody>
</table>

a) X-ray energies
b) Projected capacities and costs
competitive machines then in production. This table is extended (see Table I) to show the comparative costs of machines, cobalt-60, and X-rays produced from various accelerator sources. The X-ray figures are based on data [3] presented for the forward efficiency from tungsten targets.

From these figures it can be seen for the irradiation of thick packages and on the basis of the energy emitted by the sources only, that cobalt-60 should offer the most economic answer at all throughputs corresponding to the power outputs of machines presently available.

For the treatment of thin films, a low-energy machine is the logical choice, whereas for packages or where material for irradiation can be presented in a manner suitable for each source, then the choice will be dependent on local factors and throughput, with machines offering greater economy at high throughputs, as is shown later for grain irradiation.

There are other differences which have to be considered when making a choice between cobalt-60 and machine installations.

A cobalt-60 plant is designed in source plaque capacity and conveyor system speed range for the maximum plant throughput envisaged for the plant during its life, but it is only necessary to load the plant with the cobalt quantity required to meet immediate demand. To meet increases in demand, more cobalt is loaded into the plant and the plant user will try to ensure that this quantity is adequate for his needs throughout the subsequent year.

With a machine plant, however, the geometry of the material to be irradiated will determine the electron energy which must be available from the machine, whatever the throughput required. For ultimate economy in operation it would be necessary to purchase a machine capable of processing the maximum throughput envisaged, or it would be possible to duplicate the installation when demand warranted this, although the processing costs for a given throughput would be higher as a result. If the former choice were made, the plant operator would be committed to a capital cost appropriate to a throughput, which might be many times his initial throughput. It would be possible for him to follow any changes in demand without changing his plant, but merely by alteration of his hours of working, or the beam current of his machine, or both.

Each type of installation has its own type of flexibility, but it may be concluded that a cobalt plant may offer the lower initial capital cost and a machine the lower capital and operating cost at high throughput where the throughput of a plant changes greatly with its age, a condition which applies to medical irradiation plants in the United Kingdom.

Where a new product or a new method of processing is introduced, this mode of throughput increase with plant age is probable, but where irradiation replaces an existing control method, as in grain handling, for example, the plant should have a relatively constant throughput with plant age.

The capital costs for the machine installation for grain irradiation are considerably higher than those presented by Koch and Eisenhower because:

(a) They are costs for an installation outside the United States, and consequently include insurance, freight and other charges;

(b) They are costs for a machine installation with all its necessary accessories, such as gas supply, gas recovery system, beam bending
and scanning equipment for double-sided bombardment of a grain film.

(c) Of the general price increase since the paper was written.

To make the facility as comparable as possible with a cobalt facility, which can be started up immediately whenever required, an 'Auto-start' system has been included in the machine cost. It may take typically 15 min to obtain full beam power from a machine when starting from scratch, though only minutes when starting from a stand-by condition.

3. ECONOMIC CRITERIA

It has been accepted for a long time that the accelerator was the source of irradiation most suited to intermittent operation, because it can be switched on and off at will, and because of the method sometimes employed for amortizing the cost of the machine and its installation.

For a cobalt-60 installation it has become accepted that normal industrial criteria should be applied for the amortization of the plant and that the plant should be amortized over a period of five to fifteen years as may be appropriate.

In some calculations of machine economics the capital cost of the machine and its installation is amortized over a number of hours of operation. This method of amortization corresponds to amortizing the cost of a car over two hundred thousand kilometers or the cost of a chemical plant over, say, forty thousand hours of operation, irrespective of how long it takes to achieve the mileage or the number of hours of operation. This method of amortization ignores the utilization factor of the plant and the fact that the equipment is becoming out of date even when it is not in use.

The amortization of such equipment has been discussed with industrialists and they have indicated that the hour method of amortization sometimes applied to machines is unacceptable and that such equipment would have to be amortized over a fixed period of years for accounting purposes, if for no other. Consequently, the authors applied the same criteria to both the cobalt-60 and the electron accelerator plants, i.e. an amortization period of ten years and an interest rate of 6%.

This application of a fixed period of amortization for a machine installation immediately transforms the economic picture. All irradiation facilities are high capital cost items and in consequence they must be used for the maximum number of hours per year to obtain the best economics from them. It is also advantageous, from the electron machine point of view, to operate in this way, due to the improved reliability resulting from continuous operation as compared with the on-off operation method which the usual method of accounting presupposes.

The method of accounting for cobalt plant and cobalt itself has been presented before [4,5] and the method has been used in assessing the economics of cobalt-60 grain irradiation plant. The method of cost assessment assumes that cobalt-60 will have value when the cobalt plant is shut down, and that only 25% of the cost of the initial cobalt charge is amortized. Interest is of course charged at full rate on 75% of the capital cost of the cobalt invested and at a reducing rate on the 25% which
is amortized. Although it may be considered by machine manufacturers that this is a 'fiddle' it should be pointed out that credit has already been allowed on the cobalt returned from research irradiators.

Operating costs for both plants are based on the use of normal factory personnel. Maintenance time for the 'Dynamitron' installations when fully employed is estimated at 200 h/yr for the 1.5-MeV and 300 h/yr for the 3.0-MeV machine. Maintenance costs have been taken at a figure that the manufacturers are prepared to accept on a contract basis. It is consequently unnecessary for the user to employ skilled maintenance personnel whose services are required periodically only.

To ensure comparability, each plant has been costed on the basis of a turn-key project and has been designed for the maximum throughput discussed, i.e. 150 ton/h for cobalt-60 (Table II), 200 ton/h for the 1.5-MeV accelerator (Table III), and 400 ton/h for the 3-MeV machine (Table IV). This means that the plants are operating very much under capacity at the lower cobalt and power ratings.

Although it may appear from this that the costs developed for the smaller throughputs are unduly high, it should be realized that the same number of drawings will be required in the design of plants of different size, although the scale on the drawing may be different. The physical dimensions of the plants for the range of throughputs discussed are, in fact, very similar.

4. GRAIN IRRADIATION PLANT USING COBALT-60

The irradiation plant has been designed to treat a maximum of 50 ton/h of wheat with a minimum dose of 16 000 rad. The maximum source plaque capacity is approximately 360 000 Ci on the basis of cobalt currently available. The irradiation facility consists of a concrete tower, with the irradiation plant at low level, and two 125-ton feed hoppers at high level, the whole being designed to present a unified external appearance. Conveyors feed the grain through a system of sieves and chutes into the feed hoppers. The grain is removed from the irradiation plant by worm conveyor, which feeds to a chain conveyor, which returns the grain to the silo installation.

The grain irradiation facility illustrated (Fig. 1) is designed to ensure as nearly as possible that the grain being irradiated receives a uniform dose at the maximum reasonable efficiency. This is achieved by providing a series of annular grain flow channels which are constructed from a suitable alloy, the channels being located within the encast steel sleeve of the irradiation plant building. The channels permit the grain being treated to flow downward by gravity without restriction or hold-up of the grain, thus avoiding unnecessary dose variation. Each channel is wide enough to prevent any form of blockage, and the width has been based on tests and calculations carried out by NCP and the United Kingdom Atomic Energy Authority (UKAEA) Research Laboratories at Wantage to provide a dose variation of within ± 20%.

Below the grain flow channels is the flow regulator, which is driven by a motor and gear unit having an infinitely variable speed control. A change in speed of the regulator would increase or decrease the throughput of the grain, and decrease or increase the dose received by the grain
<table>
<thead>
<tr>
<th>Cost items</th>
<th>Plant throughput 50 ton/h</th>
<th>Plant throughput 100 ton/h</th>
<th>Plant throughput 150 ton/h</th>
</tr>
</thead>
<tbody>
<tr>
<td>Plant cost for maximum capacity of 150 ton/h</td>
<td>$210,000</td>
<td>$210,000</td>
<td>$210,000</td>
</tr>
<tr>
<td>Source loaded</td>
<td>275,000 Ci</td>
<td>550,000 Ci</td>
<td>820,000 Ci</td>
</tr>
<tr>
<td>Source loaded</td>
<td>$140,000</td>
<td>$250,000</td>
<td>$380,000</td>
</tr>
<tr>
<td><strong>Operating costs</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Plant amortization 10 yr</td>
<td>$21,000</td>
<td>$21,000</td>
<td>$21,000</td>
</tr>
<tr>
<td>Interest (9% falling)</td>
<td>$6,300</td>
<td>$6,300</td>
<td>$6,300</td>
</tr>
<tr>
<td>Cobalt replacement</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>12.5% including</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>32500 transport</td>
<td>$20,000</td>
<td>$34,100</td>
<td>$50,300</td>
</tr>
<tr>
<td>Interest on cobalt</td>
<td>$5,300</td>
<td>$11,250</td>
<td>$17,100</td>
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<tr>
<td>5% on 75%</td>
<td>$1,050</td>
<td>$1,875</td>
<td>$2,850</td>
</tr>
<tr>
<td>Amortization on 25% cobalt-60, 10 yr</td>
<td>$3,500</td>
<td>$6,225</td>
<td>$9,500</td>
</tr>
<tr>
<td><strong>Operating time</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>h/yr</td>
<td>2,000</td>
<td>4,000</td>
<td>6,000</td>
</tr>
<tr>
<td>Labour</td>
<td>$600</td>
<td>$1,200</td>
<td>$1,800</td>
</tr>
<tr>
<td>Services</td>
<td>$575</td>
<td>$1,150</td>
<td>$1,725</td>
</tr>
<tr>
<td>Maintenance</td>
<td>$600</td>
<td>$1,200</td>
<td>$1,800</td>
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<tr>
<td><strong>Total cost</strong></td>
<td>$59,925</td>
<td>$82,450</td>
<td>$108,825</td>
</tr>
<tr>
<td><strong>Throughput/yr</strong></td>
<td>ton x 10^3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>2</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>2</td>
<td>4</td>
<td>6</td>
<td>3</td>
</tr>
<tr>
<td>3</td>
<td>6</td>
<td>9</td>
<td>9</td>
</tr>
<tr>
<td><strong>Cost/ton</strong></td>
<td>$0.60</td>
<td>$0.31</td>
<td>$0.21</td>
</tr>
<tr>
<td><strong>Cost/Trhd lb at 50% E</strong></td>
<td>$0.065</td>
<td>$0.043</td>
<td>$0.037</td>
</tr>
<tr>
<td>Cost items</td>
<td>Plant throughput (67 ton/h)</td>
<td>Plant throughput (123 ton/h)</td>
<td>Plant throughput (200 ton/h)</td>
</tr>
<tr>
<td>--------------------------------</td>
<td>-----------------------------</td>
<td>-----------------------------</td>
<td>-----------------------------</td>
</tr>
<tr>
<td></td>
<td>Corresponding beam power (5 kW)</td>
<td>Corresponding beam power (10 kW)</td>
<td>Corresponding beam power (15 kW)</td>
</tr>
<tr>
<td>Capital costs</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Plant cost for 200 ton/h capacity</td>
<td>$207,000</td>
<td>$207,000</td>
<td>$207,000</td>
</tr>
<tr>
<td>Dynamitron 1.5 MeV installation</td>
<td>$315,800</td>
<td>$315,800</td>
<td>$315,800</td>
</tr>
<tr>
<td>Operating costs</td>
<td></td>
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<td></td>
</tr>
<tr>
<td>Plant amortization 10 yr</td>
<td>$36,580</td>
<td>$36,580</td>
<td>$36,580</td>
</tr>
<tr>
<td>Interest (8% falling)</td>
<td>$10,974</td>
<td>$10,974</td>
<td>$10,974</td>
</tr>
<tr>
<td>Operating time h/yr</td>
<td>2,000</td>
<td>2,000</td>
<td>2,000</td>
</tr>
<tr>
<td>Services</td>
<td>$2,140</td>
<td>$2,140</td>
<td>$2,140</td>
</tr>
<tr>
<td>Labour</td>
<td>$3,500</td>
<td>$3,500</td>
<td>$3,500</td>
</tr>
<tr>
<td>Maintenance</td>
<td>$6,650</td>
<td>$9,300</td>
<td>$12,100</td>
</tr>
<tr>
<td>Total Cost</td>
<td>$59,944</td>
<td>$68,834</td>
<td>$68,834</td>
</tr>
<tr>
<td>Throughput/yr ton x 10^5</td>
<td>1.33</td>
<td>2.67</td>
<td>4.0</td>
</tr>
<tr>
<td>Cost/ton</td>
<td>$0.46</td>
<td>$0.26</td>
<td>$0.19</td>
</tr>
<tr>
<td>Cost/MBld 1b at 50% E $</td>
<td>0.063</td>
<td>0.035</td>
<td>0.026</td>
</tr>
<tr>
<td>Cost Items</td>
<td>Plant throughput (333 ton/h)</td>
<td>Plant throughput (266 ton/h)</td>
<td>Plant throughput (400 ton/h)</td>
</tr>
<tr>
<td>----------------------------------</td>
<td>-----------------------------</td>
<td>-----------------------------</td>
<td>-----------------------------</td>
</tr>
<tr>
<td></td>
<td>Corresponding beam power (10 kW)</td>
<td>Corresponding beam power (20 kW)</td>
<td>Corresponding beam power (30 kW)</td>
</tr>
<tr>
<td>Capital costs</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Plant cost for 400 ton/h capacity</td>
<td>$232 000</td>
<td>$232 000</td>
<td>$232 000</td>
</tr>
<tr>
<td>Dynamitron 3 MeV installed</td>
<td>$272 000</td>
<td>$272 000</td>
<td>$272 000</td>
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<tr>
<td>Operating costs</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Amortization 10 yr</td>
<td>$50 400</td>
<td>$50 400</td>
<td>$50 400</td>
</tr>
<tr>
<td>Interest (6% falling)</td>
<td>$15 120</td>
<td>$15 120</td>
<td>$15 120</td>
</tr>
<tr>
<td>Operating time h/yr</td>
<td>2 000</td>
<td>4 000</td>
<td>6 000</td>
</tr>
<tr>
<td>Services</td>
<td>$5 400</td>
<td>$10 800</td>
<td>$16 200</td>
</tr>
<tr>
<td>Labour</td>
<td>$3 500</td>
<td>$7 000</td>
<td>$10 500</td>
</tr>
<tr>
<td>Maintenance</td>
<td>$10 550</td>
<td>$15 350</td>
<td>$20 400</td>
</tr>
<tr>
<td>Total cost</td>
<td>$84 970</td>
<td>$98 870</td>
<td>$112 020</td>
</tr>
<tr>
<td>Throughput/yr ton x 10^3</td>
<td>2.67</td>
<td>5.33</td>
<td>8.0</td>
</tr>
<tr>
<td>Cost/ton</td>
<td>$0.32</td>
<td>$0.18</td>
<td>$0.14</td>
</tr>
<tr>
<td>Cost/mixed lb at 50% efficiency</td>
<td>$0.047</td>
<td>$0.027</td>
<td>$0.020</td>
</tr>
</tbody>
</table>

Accordingly, the flow control is also designed to compensate for the decay of the cobalt-60 source.

Removable roof plugs above the irradiation zone provide easy access to the top of the annular channels, enabling them to be withdrawn if necessary. The drive to the grain flow regulator is transmitted from outside the building and the regulator itself is designed as an integral unit. Access to it is by a plug door at the base of the irradiation plant and this allows ready access to the regulator for inspection, adjustment and minor maintenance. The whole unit may be withdrawn.

The cobalt-60 source is loaded into standard-type Wantage source rods and these are loaded into a source plaque. The source plaque is designed in such a way that it can be loaded and reloaded as required in a manner which has been proven in irradiation plants of United Kingdom design. The plant is provided with interlock and safety equipment which has become standard on industrial cobalt-60 irradiation facilities.
5. DYNAMITRON GRAIN IRRADIATION FACILITY

A grain irradiation facility for an electron accelerator must provide a very different form of grain flow from that provided for a cobalt-60 plant. Electrons have very limited penetration and a 3-MeV Dynamitron appears to provide the minimum in electron energy and penetration for handling approximately 400 tons/h of grain [6]. With 3-MeV electrons, the grain has to be irradiated from both sides. To achieve a grain flow of 400 tons/h the grain falls under gravity from a height of approximately 6 m in the form of a 'curtain'. The electron beam will have to be split so that the grain can be irradiated from both sides and each beam will have to be provided with scanning equipment. The grain throughput is proportional to the beam power and capacities up to 800 tons/h, or more, from one machine will soon be possible.

In presenting this grain irradiation plant it has been considered desirable to provide a basic description of the Dynamitron which forms the major cost component of the installation. The other major cost component is the building housing the accelerator and the gravity-fall grain-handling facility shown in Fig. 2.

The items included in the total cost of the installation are a flat-sided hopper feeding the grain channel, the channel itself and a conveyor for transferring grain from the irradiator to the site conveyor system.

The plant cost is for a turn-key project and includes the necessary electrical service facilities for the plant and an appropriate interlock system.

The Dynamitron (covered by patents throughout the world) accelerator distinguishes itself from other similar units in that it combines the high current output associated with a Cockroft-Walton, without its excessive physical size, and compactness of construction associated with electrostatic generators, without their limitation on power output. The Dynamitron's power is derived from an RF oscillator running at approximately 125 kcps. Its output is fed from the oscillator to a toroidal coil and a set of RF electrodes (see Fig. 5) which form the tuning circuit of the oscillator (see Fig. 3). The RF electrodes, or 'D's, and the toroidal coil, are mounted within a pressure vessel, which is maintained at approximately 65 psi of pure sulphure hexafluoride gas. An intense RF field is set up within the pressure vessel. (Effectively, no RF energy is radiated externally).

The voltage generator of the Dynamitron must be considered as a separate entity, and it consists of a string of cascaded rectifiers which, when run at normal maximum output, add 50 kV per stage. The number of stages is, therefore, directly proportional to the desired ultimate voltage. The machines are designed for approximately 30% over-voltage capability to ensure that they will run coolly and reliably for long periods when in continuous use. The RF power is radially coupled into corona rings (see Fig. 4), which are in turn connected to the rectifiers. The filaments of the rectifiers are also heated by RF through a ferrite core transformer mounted integrally within the metal cone at the base of the rectifier tubes. For greater working efficiency, the rectifiers are arranged in such a way that they receive their full working temperature at approximately one third of the rated output of the machine. In order to protect them a zener diode module is connected across the filaments. The

The entire system is cooled by means of a water-cooled heat exchanger and blower system at the end of the vessel, which is mounted behind the toroidal coil. The rectifiers are supercooled with SF₆ by means of small plastic tubes which connect between the base of the rectifier and a manifold lying underneath the corona rings. Connected to the last stage of the cascade rectifier column are the high voltage terminal (see Fig. 5).
and a resistor chain to ground. At the lower end of this chain, a sampling voltage is taken and fed back to the oscillator, which receives a reference voltage from the control console and compares the output from the sampling resistor to the reference voltage fed in from the console. By this means
FIG. 5. Pressure vessel with mounted dee's
the high voltage may be set precisely and left for the machine to control. One of the most important features of the 'Dynamitron' is that the voltage generator, with its inherent automatic voltage stability system, is completely independent of load changes and line changes up to ± 10%.

It is important to note that the voltage droop of the 'Dynamitron' when drawing power is independent of the number of stages, and therefore its useful voltage range is considerably in excess of other high power accelerators which conform to the $n^3$ law, i.e. the voltage droop upon drawing current is proportional to the cube of the number of stages of rectifiers.

The beam system, as previously mentioned, is completely independent of the voltage generator. The high voltage terminal (see Fig. 5) contains its own power supply, consisting of an alternator contained within the high voltage terminal, driven by a shaft through the length of the accelerator column from a motor mounted at the ground end of the machine. The controls for setting up the parameters within the high voltage terminal are contained at the control console. The acceleration tube, which is of the re-entrant type and affording complete shielding to the glass insulating rings, is mounted down the centre of the rectifier column. At the high voltage end will be found the electron gun and its associated lenses, and the ground end is connected to a manifold and centering coils to ensure that the beam is correctly focused to the scanning system. A second voltage divider board is mounted along the length of the beam tube and connected to each stage.

At the ground end of the vessel the beam is taken out of the machine through a drift tube connected to the vacuum system with automatic gate valves and measuring devices located close to the vessel. The gate valves and pumps, giving a vacuum of approximately $10^{-6}$ mm of mercury, are arranged in an easy manner to facilitate protection during start-up and shut-down phases of operation, and automatic closure of the valves in the event of an accidental vacuum leak occurring anywhere in the system. At the far end of the vacuum system, a drift tube may be connected, of any convenient length, to a scanning system. This consists of scan coils, chamber and a horn of convenient dimensions adjustable at will (normally 2 × 24 or 2 × 48 in.). At the far end of the scan horn, a titanium window is mounted, of approximately two thousandths of an inch thickness, which is cooled by a blast of air from blower motors. It is normally fitted with a water-cooled gate-valve so that the irradiation can be absorbed during the initial start-up phases of operation.

All the necessary meters and knobs are housed within the control console, to which are also connected the various safety circuits required by law and automatic shut-down devices. It is also possible to have the console supplied with automatic shut-up and control systems.

6. COST CONCLUSIONS

From Fig. 6, showing the cost of grain treatment against the annual grain throughput, two things can be seen:

1. That for both types of plant the costs fall quite markedly at low throughputs with increased plant utilization. It is consequently advantageous
to use both cobalt and machine plants for as many hours per year as possible;

2. That treatment costs at a throughput of 50 ton/h are almost independent of source, although, for the same annual throughput at this tonnage per hour level and high utilization, cobalt is slightly cheaper. At approximately 100 ton/h cobalt is more expensive at low load factors but of the same order of cost at high levels of utilization.
The cross-over point for cobalt and machine costs is shown more clearly in Fig. 7. This demonstrates that cobalt plants are cheaper at low throughputs and shows the cost penalty in operating at low radiation absorption efficiencies. This latter point should be of special interest to potential plant users, as the efficiency of radiation utilization is often markedly affected by the volume of the product before and after packaging.

Experience has shown that the cost of irradiation plant for different applications is very similar, as the majority of their features are common to all applications. The costs presented in Fig. 7 can be used in consequence as a basis for evaluating the cost treatment of medical products, foodstuffs, grain etc.

REFERENCES


DISCUSSION

E.G. HOFMANN: I might just point out that there are powerful X-ray generators, useful irradiation tools, with capacities corresponding to 60Co sources of up to 100,000 Ci. For this power range the effective cost, calculated from the useful radiation power, is about 7.5 cents (US) per Mrad/lb.

B.D. BAINES: Yes; but as far as we can see from the efficiencies calculated so far X-rays simply could not be competitive. Your figure of 7.5 cents, for example, is more than twice as high as the lowest figure we have obtained.

E.G. HOFMANN: Perhaps you could tell me on what dose your efficiency calculations were based. At a dose of 20 krad, for example, the throughputs given in your Tables would correspond to something like 100% source efficiency; but as cost data are usually based on a source efficiency of 50%, I think that in practice the costs might be somewhat higher and the throughputs lower than your figures suggest.

Now, a useful capacity of up to 500 tons/h is sometimes needed at ports and the sources you have discussed would be too small for this; more powerful equipment would be required. Do you have any ideas, or any definite information, about equipment that could handle such large throughputs?
B.D. BAINES: The efficiency of the $^{60}$Co plant was calculated for a minimum dose of 16 krad (not 20), a figure based partly on experimental work done at Wantage. For the mean dose anticipated, then, efficiency works out at about 70%, and for the minimum dose of 16 krad at about 56%. As it happens, the efficiencies calculated for the machines turned out to be almost exactly the same.

With regard to the second part of your question, there are already machines with a beam current greater than 20 kW which could presumably be used for throughputs of up to, say, 700 tons/h.
ECONOMICS OF FOOD IRRADIATION

UNITED STATES DEPARTMENT OF COMMERCE,
BUSINESS AND DEFENSE SERVICES ADMINISTRATION,
WASHINGTON, D.C., UNITED STATES OF AMERICA

Abstract — Résumé — Аннотация — Resumen

ECONOMICS OF FOOD IRRADIATION. This paper reviews and evaluates current developments relating to the prospects for commercial food irradiation within the United States.

The study recognizes that one cannot generalize about the prospects for food irradiation either by process or product. Both technical and economic potentials vary widely for different food products subjected to the same or different types of treatment. Food irradiation processes and products are evaluated.

Recent studies concerned with the economics of food irradiation are briefly reviewed and evaluated and findings and conclusions relating to economic potentials summarized. Industry reactions to a proposed pilot plant meat irradiator, sponsored by the U.S. Army and U.S. AEC and coordinated by the Department of Commerce, are discussed and factors which will determine the future direction, extent and commercial success of food preservation by ionizing irradiation are analysed.

Developments in all these categories are essential for success, and if not achieved would be limiting factors. Nevertheless, the successful and profitable marketing of irradiated foods must finally be dependent upon customer acceptance and favourable cost versus benefit relations.

Benefits will include lower costs and higher profits through spoilage reductions, extensions of shelf-life and shipping distances, market expansions, and quality improvements. Ultimately, the economic success of this new technology must depend upon the clear demonstration that these benefits will exceed the additional processing costs by a margin sufficient to induce the necessary private investments and willingness to accept related risks in this new field.

ASPECTS ECONOMIQUES DE L'IRRADIATION DES DENREES ALIMENTAIRES. Les auteurs exposent et évaluent les faits les plus récents concernant les perspectives de l'irradiation industrielle des aliments aux États-Unis.

Ils reconnaissent que l'on ne peut pas faire de généralisation en ce qui concerne les perspectives de l'irradiation des produits alimentaires, ni pour un même procédé, ni pour un même produit. Les possibilités techniques et économiques varient considérablement pour divers produits alimentaires soumis à un même traitement ou à des traitements différents. Les procédés d'irradiation et les produits sont évalués.

Des études récentes ayant trait aux aspects économiques de l'irradiation des produits alimentaires sont brièvement analysées; les conclusions sur les possibilités économiques sont résumées. Les auteurs étudient les réactions des milieux industriels à l'égard d'un projet d'installation pilote d'irradiation de la viande, patronné par l'Armée américaine et la CEA des États-Unis et coordonné par le Département du commerce. Les facteurs qui détermineront l'orientation, l'ampleur et le succès commercial de la conservation des aliments par les rayonnements ionisants sont analysés.

Les progrès dans les quatre domaines cités sont essentiels au succès de l'irradiation des aliments: sinon, les facteurs en question limiteraient le développement de cette technique. La commercialisation des produits alimentaires irradiés ne sera finalement possible et rentable que si le consommateur accepte la marchandise et s'il s'établit un rapport favorable entre les avantages et le coût des opérations.

Parmi les avantages escomptés figurent la diminution du prix de revient et l'augmentation du profit dus à la réduction des pertes par détérioration, l'augmentation de la durée de conservation et du périmètre de distribution, l'expansion du marché et l'amélioration de la qualité. Finalement, pour assurer le succès économique de cette technique nouvelle, il faudra montrer clairement que ces avantages dépasseront suffisamment les frais supplémentaires de traitement pour susciter les investissements privés nécessaires et faire accepter les risques inhérents au procédé.

ЭКОНОМИЧЕСКИЕ АСПЕКТЫ ОБЛУЧЕНИЯ ПИЩЕВЫХ ПРОДУКТОВ. В данном докладе дается обзор и оценка проводящихся в настоящее время работ, имеющих отношение к перспективам коммерческого облучения пищевых продуктов в Соединенных Штатах.

В исследовании признается, что нельзя обобщать данные в отношении перспектив облучения пищевых продуктов ни на основе процессов, ни на основе продуктов. Как техничес-
кий так и экономический потенциалы имеют широкий диапазон изменений в отношении различных пищевых продуктов, которые подвергаются тем же или различным видам обработки. Дается краткий обзор и оценка последних исследований в отношении экономических аспектов облучения продуктов питания, а также кратко излагаются выводы и заключения относительно экономических потенциалов. Приводится обсуждение реакций представителей промышленности на предлагаемый опытный облучатель мяса, заказчиками которого являются американская армия и Комиссия по атомной энергии США; координация осуществляется Министерство торговли; анализируются факторы, которые определяют будущее направление, масштаб и коммерческий успех сохранения пищевых продуктов с помощью ионизирующего облучения.

Работы во всех этих категориях являются существенными для достижения успеха, в противном случае они являются тормозящими факторами. Тем не менее, успешный и выгодный общий облученных пищевых продуктов, в конечном итоге, должен быть поставлен в зависимость от акцептации потребителем и выгодного взаимоотношения между стоимостью и прибылью.

К выгодам следует отнести более низкую стоимость и более высокую прибыль в результате сокращения порчи, увеличения сроков хранения и расстояния перевозок, расширения рынка и улучшения качества. Наконец, экономический успех этой новой технологии должен зависеть от ясного доказательства того, что эти выгоды превысят дополнительные расходы по обработке на какую-то сумму, которая будет достаточной для стимуляции необходимых частных капиталовложений и готовности пойти на соответствующий риск в этой новой области.

ASPECTOS ECONOMICOS DE LA IRRADIACION DE ALIMENTOS. En la memoria se trata de los progresos realizados en los Estados Unidos en lo que respecta a la irradiación comercial de alimentos y se examinan sus perspectivas.

En la memoria se reconoce la imposibilidad de generalizar en lo que respecta a las perspectivas de la irradiación de alimentos, bien se trate de los procesos de producción o de los productos acabados. Son muy variadas las posibilidades técnicas y económicas que se ofrecen para los distintos productos alimenticios sometidos a tratamientos idénticos o diferentes. Se evalúan los productos y los procesos de irradiación, se exponen y analizan brevemente algunos estudios recientes sobre los aspectos económicos de la irradiación de alimentos y se resumen los resultados y conclusiones referentes a las posibilidades económicas. Se examinan las reacciones de la industria a la propuesta de construir una instalación experimental de irradiación de carne, patrocinada por el Ejército y la Comisión de Energía Atómica de los Estados Unidos, y coordinada por el Departamento de Comercio. Se analizan los factores que determinarán la orientación futura, el alcance y el éxito comercial de la conservación de alimentos por irradiación.

La evolución favorable de todos estos factores es imprescindible para el éxito, pues de lo contrario constituirán otros tantos elementos restrictivos. De todas formas, el éxito y la rentabilidad de la comercialización de los alimentos irradiados dependerá, en último término, de la aceptación de los consumidores y de que las relaciones costo-beneficio sean favorables.

Entre los beneficios cabe citar: menor costo y mayor rentabilidad por la disminución de la proporción de productos estropeados, prolongación del período de almacenamiento y de las distancias de envío, expansión de los mercados y mejoramiento de la calidad. En definitiva, el éxito económico de esta nueva técnica dependerá de que se demuestre claramente que los beneficios serán superiores a los gastos en un margen suficiente para inducir a los particulares a efectuar las inversiones necesarias y aceptas los riesgos inherentes a esta nueva industria.

The production, processing, preservation, packaging, storage, transportation, and sale of food products is the largest and most significant of man's enterprises. U. S. consumers alone spend more than $90 billion for food products, approximately one-fifth of their total disposable income. In the United States, almost four million establishments and more than 12 million people are engaged in the production, processing, and distribution of food.

Within an industry of this magnitude and scope, the potentials for food irradiation might well be considered limitless. However, it must be recognized that there will not be universal applications of this technique to all foods. Applications and potentials vary widely for different food products and radiation processes.
For those products and processes for which radiation is technically feasible, commercialization will depend on demonstrated tangible benefits to processors and consumers -- benefits which outweigh added costs.

This paper examines the prospects for the commercialization of food irradiation by answering three questions: (1) What are the benefits of food irradiation to food processors and consumers? (2) What are the economic potentials for the irradiation of selected food products within the United States? and (3) What are the obstacles to commercialization? This paper also describes factors, derived from recent experience in connection with the proposed pilot plant meat irradiator, which are pertinent to these questions.

**BENEFITS**

Those engaged in the food business may expect:

1. Savings from reductions in spoilage and refrigeration requirements;
2. Reductions in the incidence of food-borne diseases and parasites;
3. Market expansion through extensions in shelf life and shipping distances, increased variety of product choice, and new products;
4. Expanded export potentials; and
5. Market stabilization through the reduction of market gluts and shortages.

Consumer benefits will be:

1. Extension of quality;
2. Reduction in food-borne hazards to health;
3. Development of new and more convenient foods;
4. Increased variety of available foods; and
5. Availability of a more nutritious diet in many countries of the world.

One of the more significant aspects of food irradiation is its potential for expanding international trade. Perhaps its most significant aspect is its potential for bolstering the world's inadequate food supply -- a food supply which, because of the population explosion, must be much more than doubled by the year 2000 if living standards are to be raised to acceptable levels. [1]
A number of foods today are excellent candidates for commercial irradiation, and their technology has been or will soon be established. In the United States some of these are: poultry, meat, marine products, strawberries, dehydrated vegetables, and bananas. Their economic potentials are briefly reviewed here.

POULTRY: The poultry industry in the United States is a highly integrated and specialized industry with well designed processing plants, highly mechanized and automated. Fresh chilled chickens, which accounts for about 65-80% of the approximately 2.5 billion birds sold annually in the United States, are shipped whole, packed in ice, and also as parts packed in consumer trays under refrigeration.

Further processing is becoming commercially attractive. Such processing may be precooking, breading, deboning and rolling, and packed, frozen and canned. The interest in convenience packaging is due to the poultry industry's low profit margin. Any process which adds value and widens the profit margin is attractive.

In general, poultry products move from the processing plant directly to large retailers, and usually through wholesalers to hotels and restaurants. Retailers are interested in maintaining quality, but are more interested in larger, faster turnover than in extended shelf life.

A radiation facility integrated into an existing processing line is highly feasible. A plant producing fresh packaged poultry would require few changes, other than installation of an irradiator, to produce radiopasteurized products.

Pasteurization at 100-250 Krads would add two weeks' shelf-life. Additional in-plant shelf-life would help processors who supply supermarket chains with fresh chicken for their monthly promotional sales. This would permit sufficient inventory build-up during slack time to eliminate overtime during periods of peak demand.

Radiosterilization of poultry is more complex. For sterilization at 4.5 to 5.6 Mrads, the chicken must be enzyme inactivated by heating to an internal temperature of 80°C, vacuum packed and then irradiated while the chicken is held at a temperature ranging from -5°C to -40°C. Processors that freeze or can poultry would be able to irradiate poultry with the addition of an irradiation facility with few changes in their existing process equipment. Radio-sterilized chicken is more fresh-like than thermally processed chicken, and can also be packed in flexible containers.

The benefits of shelf-stable poultry meat may include:

1) Savings from the elimination of refrigeration in storage, transportation, and retail display;

2) Chicken irradiated at ambient temperatures is acceptable. However, irradiation in the range of -5 to -40°C yields a better product.
(2) Space savings in home refrigerators;

(3) Elimination of Salmonellae; and

(4) New markets for nonperishable poultry, especially where refrigeration is limited.

MEAT: The meat industry in the United States is a complex of firms ranging from very large and integrated down to small specialized operations. They slaughter and process. Many only slaughter and ship chilled carcasses to jobbers, wholesalers, and plants which process the meat into consumer items. In general, it is the retail grocer or butcher who cuts the carcass into individual cuts for the housewife. There has been a growing interest in reducing the carcass to retail sized cuts at a central point either at the packing house or at the wholesale level. This procedure has had little development because the present system is working efficiently and there is opposition to change.

Radiation sterilization of uncured meats would require a meat cutting and packaging operation at the packing plant or processing establishment, enzyme inactivation, and irradiation at temperatures ranging from ambient down to -40° to -80° C for certain cuts of beef.

Enzyme inactivation yields a cooked or partially cooked product. This can present problems when we recognize the fact that the consumer is accustomed to and demands "fresh" meat. Yet the United States consumer also demands more convenience in foods - prepared and pre-cooked foods which are quick and easy to serve. This may be the opening where sterilized meat will make its initial entrance into the market, slowly at first, but with assurance and firmness.

Even though the problems involved in irradiating and marketing enzyme inactivated sterilized meats may be greater than for the other products, the elimination of refrigerated transportation and storage requirements may be highly significant in many areas of the world.

Cured meats present fewer problems. The commercial prospect appears particularly bright for radiosterilized canned or flexibly packaged ham. About 500 million pounds of canned hams were consumed in the United States last year. Most of them were heat pasteurized and required refrigeration.

Consumers generally find the heat pasteurized canned ham more attractive than its heat sterilized, overcooked counterpart. The higher processing temperatures for achieving sterility result in adverse

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2 Irradiation at ambient temperatures yields acceptable sterilized bacon, ham, and uncured pork. However, improved products are obtained if irradiated at temperatures of from +20° to +20° C for bacon; and -5° to -40° C for ham and uncured pork.
changes in flavor, texture, and appearance. On the other hand, acceptance of the heat pasteurized ham is limited because of its refrigeration requirement. The larger sizes take up too much space in the home refrigerator.

Radiosterilized hams incorporate the best features of both heat processed varieties and are comparatively simple to process. Commercially prepared cured hams require no further enzyme inactivation and may be irradiated at a dose ranging from 3.5 to 5.6 Mrads at ambient temperatures. Canned hams so processed at the U. S. Army Natick Laboratories have been stored for as long as two years at temperatures ranging from 20° to 37° C and have maintained excellent flavor and appearance.

Petitions for the approval of radiosterilized hams will be submitted to the U. S. Food and Drug Administration (FDA) and the U. S. Department of Agriculture (USDA) within the next few months. It is expected that such hams will be one of the mainstays of the Pilot Plant Meat Irradiator discussed later in this paper.

MARINE PRODUCTS: Work by the U. S. Bureau of Commercial Fisheries on pasteurization of marine products has been successful. Last year a petition was submitted to FDA for approval for public consumption of haddock, codfish, sole, flounder, pollack, and ocean perch. Approval is expected this year. Fish may be the first irradiated food offered commercially in the United States.

Total consumption of fishery products in the United States has increased with population growth, but per capita consumption has been steady at about 10.5 pounds per year. Of this, about 5.8 pounds has been of fresh and frozen fish and about 4.3 pounds of canned products. The rest consists of smoked, cured, and other products.

There are very few large firms in the U. S. fishing industry and the methods of fishing generally differ from those employed in other important fishery countries. U. S. fishing vessels typically make short trips lasting from one to two weeks as contrasted to Japanese vessels which may stay at sea as long as three years. The Japanese use a "mother" ship equipped to process fish on board and smaller ships to shuttle supplies out to sea and the processed fish back to port.

Because of their short shelf-life of 4-6 days, fresh fish must be sold close to port or transported quickly by air to inland points. The high cost of air transport limits this type of shipment in the United States to special high cost items. Usually the fresh fish is ice-packed in bulk and moves quickly through jobbers and wholesalers who buy at the dock and sell to retail outlets and restaurants within a limited area. The distribution system works well.

Irradiation at pasteurization doses can extend the shelf-life of properly refrigerated fresh fish for about 30 days. Since irradiation does not improve, but only maintains quality, the sooner irradiation
takes place after the fish are caught, the better. For this reason the shipboard irradiator was developed. However, the shipboard irradiator may at first have only limited commercial use because:

1. most U.S. fishing fleet vessels are too small for an irradiator;
2. it is costly to rebuild and modify a ship for such a facility; and
3. irradiators are too expensive for most independent fishermen.

The alternative is shore based units. The most strategic location may be at dock-side where processors as well as fresh fish merchants can gain the advantage. Some processors anticipate benefits from a more even supply of high quality raw products.

There is a definite interest in the United States at all market levels in a process that will extend quality and shelf-life of fresh items, but the potential market for fresh ocean fish in the interior of the country is unknown.

For some species of low-value fish, the cost of irradiation may be prohibitive, but for high-value items such as pasteurized halibut, shrimp, lobsters, crabs, clams, and oysters, and shelf stable shrimp and cod fish cakes, irradiation may be economically feasible.

The most effective means of introducing radiopasteurized fish into the market may be through the institutional trade (hotels, restaurants, hospitals) which is a sizeable consumer.

STRAWBERRIES: A petition was submitted to the FDA on April 29, 1966 for the approval of radiopasteurized strawberries for public consumption.

If fresh strawberries are irradiated at 200 Krads and handled under usual marketing conditions, spoilage losses can be reduced from 15% to about 5% depending upon the quality of the berries when packaged. This reduction of spoilage loss would be sufficient to pay the cost of irradiation, according to a study by the U.S. Department of Agriculture. Other benefits would include: less in-store sorting and culling, and reduction or elimination of carbon dioxide gas as a mold inhibitor.

DEHYDRATED VEGETABLES: Irradiation of dehydrated vegetables by electron beam or gamma rays will tenderize and reduce rehydration and cooking time of the vegetables from the usual 10 to 15 minutes to less than three minutes. A U.S. patent on the process has been granted covering lima beans, okra, corn, potatoes, green beans, celery, green and red bell peppers, peas, carrots, beets, onions, lentils, leeks, and cabbage. A petition has been submitted to FDA for approval of this process.

Dehydrated vegetables are primarily used as ingredients in dry soup mixes which ordinarily contain a variety of vegetables. Being a raw material, the dehydrated vegetable would move to the irradiation source for processing and then to the manufacturer of the final food product. No consumer problem is foreseen since increased demand for convenience foods will create a market for irradiated dehydrated vegetables.
Consumer benefits are decreased cooking time and more tender and flavorful vegetables. Irradiation will enable the development of dry soup mixes in which all the vegetables become tender at the same cooking time.

BANANAS: Irradiation processing of bananas to inhibit early ripening is in the initial stages of research and looks promising.

The banana industry in the United States is comprised essentially of two firms: the Standard Fruit and Steamship Company and the United Fruit Company. They also serve other markets, primarily Europe and Japan.

Bananas are cut from the stalks while still green and are usually packed in boxes weighing approximately 40 pounds which are then moved by rail to coastal loading stations. Today, specially designed ships load 25,000 to 150,000 boxes in eight to twelve hours. A trip to the United States takes from three to 14 days, depending on port location. The bananas are sold to jobbers, wholesalers, and large retailers. After purchase in the green condition, the fruit is ripened in specially-built ripening rooms.

Weather and shipping conditions are largely responsible for fluctuations of two to three million boxes monthly in United States ports. As a result the price received for a box of bananas in recent years has varied from $1.20 to $3.50.

In the production and marketing of bananas, timing the cutting to prevent premature ripening during shipment and distribution is critical. Irradiation may solve the timing problem and allow a delay in cutting of from one to two weeks over present practices. This could result in two to five pounds additional yield per stalk for most varieties.

The introduction of irradiated bananas would not change the present marketing system. It could (1) improve the logistical efficiency of shipping and distribution; (2) reduce or eliminate premature ripening during shipment; (3) even out some of the variations in supply and price of bananas at U.S. ports; and (4) result in savings to the industry of from $250,000 to $500,000 annually on labor costs required to make week-end and late loadings of bananas that must be shipped without delay. [2]

OBSTACLES TO COMMERCIALIZATION

Thus the outlook for the products mentioned above is auspicious; but there are other factors which will determine the rate and extent of commercialization. Among the more important factors are: (1) the approval of irradiated foods by Governmental regulatory agencies; (2) consumer reaction; and (3) costs.

REGULATORY AGENCY APPROVAL: Irradiated bacon, wheat and wheat products; and potatoes, and several packaging materials are now
approved in the United States. Petitions for approvals have been submitted on oranges, strawberries, fish, dehydrated vegetables, and additional packaging materials. Petitions for approvals of approximately 34 additional products are scheduled for submission within the next five years.

Business firms will not commit capital for the irradiation of foods not approved for public sale. Moreover, market testing which should precede capital commitments must await Government approvals. Consequently, the lack of approvals is the first barrier of commercialization. Time and research will eliminate this barrier.

CONSUMER REACTION: The reaction of consumers to irradiated foods is an unsolved problem affecting commercialization. As yet, no reliable measure of consumer reaction has been made. Until irradiated foods have actually been tested in the market, it will be impossible to measure the effect consumer fear of radioactivity might have on acceptance of the foods.

Should there be substantial consumer resistance, it will be necessary to undertake educational and promotional programs beyond those normally associated with the introduction of new products. The cost of marketing irradiated foods would be increased and this could be a determining factor in the economics of success.

On the other hand, American consumers have always been receptive to new and better food products. Consequently, with FDA and USDA (in the case of meat and poultry) assurance of wholesomeness, it appears that consumer acceptance can be obtained if benefits exceed added costs.

COSTS: Precise food irradiation costs cannot be determined until commercial facilities have been built and operated. However, some indication of costs and identification of the major factors which will influence costs can be determined on the basis of the operation of experimental and research facilities and calculated estimates.

It appears likely that beef can be sterilized at 5 Mrads at -80°C for approximately 9.7¢ per pound of product. This estimate is based upon the projected operation of a 4.8 Megacurie cobalt 60 facility utilized 6000 hours annually at 20% source efficiency with a throughput of 2000 lbs per hour.

Where isotopes are used as a source, the most significant cost item is the source itself which includes both the price of the isotope and efficiency of utilization of the energy emitted. In the 9.7¢ per pound estimate cited above the amortization and replenishment cost of cobalt 60 alone would be 5.0¢ based on an installed price of 55¢ per curie. Increasing source efficiency from 20% to 40% would reduce this cost to 2.5¢ per pound.

Even more important than the efficiency of utilization as a cost factor is the price of the cobalt 60. Should it be possible to reduce the
price to 25¢ per curie encapsulated and installed, its cost would be approximately 2.2¢ per pound at 20% efficiency and 1.1¢ per pound at 40% efficiency. It is thus apparent that the price of the isotope and efficiency of its use will be major factors in determining the economic feasibility of food irradiation. These comparisons are shown in greater detail in Table I.

The cost estimate discussed above applies to sterilization at -80° C. The radiosterilization of certain cuts of beef may require irradiation at this temperature. Recent research indicates temperatures in the -40° to -80° C range will be sufficient for acceptable beef.

**TABLE I**

Total Cobalt 60 Costs and Total Operating Cost Per Pound of Product [4]
(Beef Radiosterilized at 5 Mrads, 2000 lbs./hr., 6000 hrs./yr. at -80° C).
(Cents per pound)

<table>
<thead>
<tr>
<th>Source Efficiency</th>
<th>16%</th>
<th>20%</th>
<th>24%</th>
<th>28%</th>
<th>32%</th>
<th>36%</th>
<th>40%</th>
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</thead>
<tbody>
<tr>
<td>Total Operating Costs a.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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</tr>
<tr>
<td>At 55¢ per curie</td>
<td>10.9</td>
<td>9.7</td>
<td>8.8</td>
<td>8.2</td>
<td>7.8</td>
<td>7.5</td>
<td>7.2</td>
</tr>
<tr>
<td>At 25¢ per curie</td>
<td>7.5</td>
<td>6.9</td>
<td>6.6</td>
<td>6.3</td>
<td>6.1</td>
<td>5.9</td>
<td>5.8</td>
</tr>
<tr>
<td>Total Cobalt Costs b.</td>
<td></td>
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<tr>
<td>At 55¢ per curie</td>
<td>6.2</td>
<td>5.0</td>
<td>4.1</td>
<td>3.5</td>
<td>3.1</td>
<td>2.8</td>
<td>2.5</td>
</tr>
<tr>
<td>At 25¢ per curie</td>
<td>2.8</td>
<td>2.2</td>
<td>1.9</td>
<td>1.6</td>
<td>1.4</td>
<td>1.2</td>
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</tr>
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a. Does not include provision for return on investment.
b. Installed price. Amortization of initial loading 10 years straight. Annual replenishment 14%.

The amortization of investment in cryogenic equipment, if used in treating large volumes, will amount to only a fraction of a cent per pound. Estimates of the cost of the liquid nitrogen required range from less than 1¢ to over 2¢ per pound of treated product.

Except for processing at the U. S. Army Natick Laboratories on a research level, no experience in irradiation of meat products at cryogenic temperatures has yet been obtained, and no commercial equipment has yet been built. Future developments in cryogenics should lower the ultimate cost of radiosterilized meat products requiring irradiation at subfreezing temperatures. The cost of pasteurizing food (300 000 to 500 000 rads) should be less than one-tenth the cost of radiosterilization because of the increased through-put and reduction of cryogenic requirements. The cost should be even lower for lower dose treatments such as sprout inhibition, ripening control and insect disinfestation.
In addition to the use of gamma radiation from radio-isotopes, foods may be irradiated with electron beams from high energy electron accelerators, or by the conversion of such beams to X rays. Both of these methods appear to be feasible and promising. Electron beams will be used to irradiate relatively thin packages of food since the penetration of electron beams is limited to 1 cm per 2 MeV. The highest level of electron energy thus far cleared for food irradiation in the United States is 10 MeV, which means that electron beams can be used only on packages of approximately 5 cm in thickness on one pass, or approximately 10 cm if irradiated from both sides. The cost of sterilization by electron beams with 5 cm penetration at -80 °C should be less than 5¢ per pound at a through-put of 2000 lbs per hour.

The radiation pasteurization of foods with electron beams at 300 000 to 500 000 rad levels should be possible for less than 0.5¢ per pound. The same limit of thickness mentioned above will prevail.

If electron beams are converted to X rays, a penetration equal to that of cobalt 60 can be obtained. However, the energy loss in conversion from electron beams to X rays is considerable, with resulting increases in cost. It has been calculated that the forward efficiency for X ray production with a tungsten target might range from 6.2% at 3 MeV to 19% at 10 MeV. Higher efficiencies might be obtained with other target materials such as gold. Further research will be necessary before the full potential of food sterilization by the conversion of electron beams to X rays will be known.

It appears probable that isotopes, electron beams, and X rays will all eventually be employed in food irradiation. The selection of source will depend upon the characteristic of the product and the types of process involved.

PILOT PLANT MEAT IRRADIATOR

The industry-Government pilot plant meat irradiator project is an example of how irradiation benefits, product potentials, and obstacles are affecting commercialization of food irradiation in the U.S. Although the project is directed specifically to commercialization of radio-sterilized meats, many of the factors affecting establishment of the meat pilot plant will be identical to those affecting commercialization of other irradiated foods.

In 1956 the Interdepartmental Committee on Radiation Preservation of Food was formed in the United States to promote commercialization of radio-preserved foods as an important segment of the nation's Atoms-for-Peace Program. The Committee, chaired by the Department of Commerce, is comprised of representatives from ten Federal agencies.

During the March 1965 meeting of the Committee, the need for a pilot meat irradiator was discussed. In June 1965 the idea was supported in testimony before the Joint Committee on Atomic Energy, Congress of the United States.
As a result, the U. S. Department of Defense (DOD), the U. S. Atomic Energy Commission (AEC), and the U. S. Department of Commerce co-sponsored an industry-Government conference on a pilot plant meat irradiator in September 1965.  

Executives of more than 40 companies and trade associations in the meat, poultry, and radiation equipment industries heard the major objectives of the project outlined:

(1) to introduce and test shelf-stable foods in rations for the Armed Forces in quantities larger than are possible with existing ionizing facilities; (2) to develop processing methods and solve potential problems associated with scaling-up from laboratory to commercial production; (3) to obtain processing costs and project the economics of the process under anticipated conditions of full commercial production; and (4) to investigate, test, and develop a civilian commercial market for radiosterilized foods.

The DOD promised to support a plant with an annual capacity of one million pounds of sterilized meat and poultry items approved by the FDA and USDA by the purchase of about 300,000 pounds each year for three years.

The Atomic Energy Commission promised to supply the radiation source for the facility and provide assistance in supporting engineering and design.

The conferees were invited to make personal evaluations of the acceptability of irradiated foods, by sampling hors d'oeuvres prepared from shelf-stable meats, poultry, and seafood irradiated at the U. S. Army Natick Laboratories.

The food was delicious and the response gratifying. Some of the conferees, remembering the flavor of earlier experimental products, were frankly amazed at the progress demonstrated.

Following the conference, industry reaction was reviewed and the Government's approach evaluated. Because of favorable industry response, an Interagency Task Force representing Commerce, Army and AEC was formed to establish the pilot plant.

From November 1965 through March 1966, the Task Force held meetings throughout the country with more than 80 organizations which had expressed interest in building and operating the plant.

Factors affecting establishment of the pilot plant emerged from the meetings. The more significant follow:

(1) The major obstacle to private investment in a pilot plant, as proposed at the conference, is the difficult prospect of selling about 700,000 pounds of irradiated meat per year in an untried market.
(2) Lack of knowledge of consumer reaction to irradiated food contributes to this problem. However, many believe the use of irradiated food by the Armed Forces will help accustom the civilian population to their use and help reduce consumer resistance.

(3) Reliance on estimates, rather than experience for capital and processing costs is another obstacle. These costs are especially critical in an industry which counts profits in fractions of a cent per sales dollar.

(4) Small- to medium-sized, specialized meat packers usually show more interest in participating in the project than do the larger, more highly diversified firms.

(5) Many small and medium sized meat packers exhibit a strong interest in radiopasteurization. Interest is particularly high among poultry packers and processors of prepared items such as frankfurters and luncheon meats.

(6) In the larger firms, there is often competition within the same company for project dollars. Radiation processing is but one of many innovations being considered.

(7) Some companies, reluctant to invest in radiation facilities, are willing to buy custom radiation services.

The Interagency Task Force is exploring methods of surmounting these obstacles mentioned above. Results will be reflected in a formal request for proposals which the AEC plans to issue to industry during the summer of 1966.

Fortunately for the success of the project, there are companies which are more concerned with the potential benefits of radiation processing than the immediate problems of production and marketing. To these companies, radiation presents a solution to existing problems, an opportunity for better products and profits: They believe the opportunity is worth the risk.

Because of this, the Task Force is confident that the AEC's forthcoming request for proposals will result in a number of responses from industry, that the pilot plant will be established, and its objectives attained.

In summary, the outlook for commercialization of food irradiation in the United States is favorable. Anticipated benefits to producers, distributors, and consumers are significant. The economic potentials for individual selected products appear to be excellent. The obstacles to be overcome are not insurmountable. Government approvals for some products have been obtained, others are in process, and many more are planned. Consumer acceptance, while still an unknown, should follow Government assurance of wholesomeness and adequate educational and promotional programs. Present cost estimates ap-
We stand on the threshold of the commercialization of a new process for food preservation which offers substantial benefits to the economies of all nations. This program merits increased efforts and support if its full potentials are to be realized.

REFERENCES


CONSIDERATIONS ECONOMIQUES SUR LE TRAITEMENT PAR IRRADIATION

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Abstract — Résumé — Аннотация — Resumen

ECONOMIC ASPECTS OF RADIATION TREATMENT. In May 1963, at the Conference held by the International Atomic Energy Agency on the Industrial Uses of Large Radiation Sources, there was considerable discussion of costs. This general exchange of views led to a number of assessments of the cost of treatment by radioactive sources and machines.

After three years it seems appropriate to review the basic hypotheses, and in particular to take account of the drop in price of radioisotopes, especially $^{137}$Cs.

This affects the cost both of the installed kW and of the KWh of energy produced. In the light of the experience gained in the past three years it is possible to define the efficiencies and the load factors observed in plants at present in operation. It is true that in most cases these are treating medical equipment and supplies, but the problems are comparable.

CONSIDERATIONS ECONOMIQUES SUR LE TRAITEMENT PAR IRRADIATION. En mai 1963, lors de la Conférence organisée par l'IAEA sur l'emploi des sources de rayonnements intenses dans l'industrie, un large débat s'était engagé sur les prix de revient. De cette confrontation générale, on a pu tirer quelques évaluations du coût de traitement par sources radioactives et machines.

Il est bon, trois ans après, de revoir les hypothèses de base et surtout de tenir compte de l'abaissement du prix des radioéléments et tout spécialement du $^{137}$Cs.

Ceci influe à la fois sur le prix du kW installé et du kWh d'énergie produit. A la lumière de l'expérience acquise pendant ces trois dernières années, il est possible de préciser les rendements et facteurs de charge observés dans des installations actuellement en fonctionnement. Il s'agit ici de vrai, dans la majorité des cas, de traitements d'accessoires médicaux, mais les problèmes sont comparables.

ЭКОНОМИЧЕСКИЕ АСПЕКТЫ ОБРАБОТКИ ПРОДУКТОВ МЕТОДОМ ОБЛУЧЕНИЯ. В мае 1963 года во время работы Конференции по промышленному применению мощных источников излучения, организованной МАГАТЭ, развернулась большая дискуссия по вопросу себестоимости. В результате общего мнения можно сделать некоторые оценки стоимости обработки радиоактивными источниками и устройствами.

Желательно по истечении трех лет пересмотреть основные гипотезы и учесть снижение стоимости радиоэлементов, и в особенности цезия-137.

Стоимость радиоэлементов оказывает влияние сразу на стоимость 1 кВт установленной мощности и киловатт/часа производимой электроэнергии. В свете полученного в течение последних трех лет опыта имеется возможность уточнить производительность и коэффициент нагрузки действующих в настоящее время установок. Речь идет в большинстве случаев об обработке вспомогательного медицинского оборудования, но все эти проблемы сравнимы.

CONSIDERACIONES ECONOMICAS SOBRE EL TRATAMIENTO POR IRRADIACION. En la Conferencia sobre las aplicaciones industriales de las fuentes de radiación de elevada intensidad, celebrada en mayo de 1963 bajo los auspicios del OIEA, se inició un amplio debate sobre los precios de costo. De esta confrontación general se pudieron sacar varias conclusiones sobre el costo del tratamiento por medio de fuentes radiactivas y máquinas.

Es conveniente, tres años después, revisar las hipótesis fundamentales y, sobre todo, tener en cuenta el abaratamiento de los radiocismientos, en particular, del $^{137}$Cs.

Esto influye a la vez sobre el precio del kilovatio instalado y del kilovatio-hora de energía producido. La experiencia adquirida en estos tres últimos años permite precisar los rendimientos y factores de carga observados en instalaciones actualmente en servicio. Es cierto que en la mayoría de los casos éstas consisten en instalaciones de tratamiento de accesorios médicos, pero los problemas son análogos.
A l'occasion de la réunion d'un groupe d'étude organisée par l'AIEA, en mars 1964, sur les aspects économiques de l'emploi des radioisotopes, j'ai eu l'occasion de jeter les bases du calcul du prix de revient des irradiations par sources ou accélérateurs [1]. Je rappelle que ce calcul avait pour but de dégager deux ordres de grandeur de prix: le prix du kW installé, qui donne une idée des investissements nécessaires, et le prix du kWh produit par la source, qui permet d'accéder au coût du traitement pourvu que l'on se fixe le rendement de la source et son facteur de charge.

Ce mode de présentation a le grand avantage d'être très général et il permet d'utiliser les quelques données économiques que l'on possède et qui se rapportent généralement au traitement des accessoires médicaux. Ces données peuvent ainsi être transposées au traitement des produits alimentaires.

1. SOURCES RADIOACTIVES

A l'aide des données économiques dont je disposais à l'époque, j'avais trouvé la relation suivante:

\[ N = 100 \times A^{0.815} \]

\( N \) = prix total de l'installation y compris la source de cobalt normalisée à 1 $/Ci rendue dans l'installation.
\( A \) = intensité de la source de cobalt en Ci.

Depuis, un certain nombre d'informations canadiennes, américaines et anglaises m'ont permis de constater que cette approximation restait grossièrement valable, bien que le prix du cobalt installé soit maintenant voisin de 0,50 $/Ci. Cela m'avait permis de calculer que, pour une installation de 15 kW (environ 1 000 000 Ci de \(^{60}\)Co) et un facteur de charge de 6000 h/an, le prix du kWh produit était voisin de 30 F (environ 6 $).

Des calculs effectués à partir de données françaises [2] ont donné les coûts suivants pour un traitement de stérilisation à 2,5 Mrad avec un facteur de charge de 7000 h/an et un rendement énergétique de 30%:

<table>
<thead>
<tr>
<th>Production (kg/h)</th>
<th>Prix (F/kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>50</td>
<td>1,83</td>
</tr>
<tr>
<td>200</td>
<td>0,80</td>
</tr>
<tr>
<td>500</td>
<td>0,50</td>
</tr>
</tbody>
</table>

En tracant le diagramme de ces résultats à l'échelle logarithmique, on obtient une droite, et il est possible de déterminer le coût de production pour une installation de 15 kW, soit 0,44 $/kg. Ceci correspond à un prix du kWh produit de 22,6 F. Ce prix se compare aussi bien à celui précédemment donné, car avec l'hypothèse de 7000 h de fonctionnement annuel, on arrive à un prix du kWh de 26,6 F. Il semble difficile d'aller plus loin dans le calcul des prix.

J'aborderai ici rapidement le \(^{137}\)Cs, qui apparaît maintenant en grande quantité sur le marché. L'expérience est encore restreinte; en France la mise en service de l'irradiateur IRMA a permis de constater que les prix de traitement seraient semblables à ceux précédemment déterminés pour le \(^{60}\)Co.
Il est difficile de prévoir l'évolution des prix dans les années à venir car, la production des sources radioactives étant un monopole d'État, leur prix subit des variations imprévisibles.

2. ACCELERATEURS D'ELECTRONS

Toujours au cours de la même réunion, j'ai donné des chiffres fondés sur l'extrapolation d'une installation qui existait alors en France. Nous avons pu comparer récemment, entre la France et le Danemark, les prix de traitements d'accessoires médicaux effectués par accélérateurs linéaires d'électrons d'une puissance comprise entre 5 et 10 kW. De plus, l'installation de l'accélérateur CIRCE nous a donné des bases plus solides d'évaluation. Une évaluation réaliste peut se faire sur les bases suivantes:

Puissance installée: 15 kW
Nombre d'heures de fonctionnement par an: 2000
Nombre de kWh produit annuellement: 30 000
Investissement: $2,5 \times 10^6$ F ($0,5 \times 10^6$ $)

Prix du kW installé: $1,7 \times 10^5$ F ($0,34 \times 10^5$ $)

Amortissement annuel (sur 5 ans): $0,58 \times 10^6$ F ($0,12 \times 10^6$ $)

Frais annuels de fonctionnement: $0,16 \times 10^6$ F ($0,03 \times 10^6$ $)

Prix du kWh: environ 25 F ($0,03 \times 10^6$ $)

On voit donc que le prix du kWh source et accélérateur est très comparable et qu'il n'existe qu'une différence sensible d'investissement ($8 \times 10^6$ F pour la source de même puissance).

3. RENDEMENT ENERGETIQUE

Les rendements publiés pour les sources de cobalt vont de 12% (irradiateur de pommes de terre) à 50% (irradiateur pour grains en vrac). Je ne possède pas d'indication pour les accélérateurs, car ceux-ci ont été rarement employés pour le traitement alimentaire. Pour le traitement des accessoires médicaux, on arrive à des valeurs voisines de 50%, les pertes étant dues aux caractéristiques particulières de l'absorption des électrons, à l'espacement des paquets et à la géométrie du faisceau.

En conclusion on voit que la compétition entre ces deux sources de rayonnement est plus que jamais très ouverte.

REFERENCES


DISCUSSION

S. JEFFERSON: My comments relate not just to Mr. Lévéque's paper but to all that has gone before. Mr. Baines has, I think, brought out all the main points that have to be considered in any comparison of the electron and gamma-ray processes. Let me just add that it is difficult to generalize about these things; a full operational research exercise is really needed for each project. Obviously storage, handling and many other things have to be taken into account. The main thing, however, is the cost per kilowatt-hour for each type of energy, and in that connection I should like to refer you to Fig. 9 of my paper SM-73/36 in these Proceedings which shows the current estimates prepared at the Wantage Research Laboratory. Without dwelling on these figures, I might point out that the curve for electron machinery presents special difficulty because different types of equipment are required for different parts of the energy range. If a project requires energies over 10 MeV, for instance, a linear accelerator is needed, and this of course involves much higher costs than other types of equipment.

N. W. HOLM: The curves to which Mr. Jefferson has referred suggest that accelerators become competitive with $^{60}$Co sources only at very high power levels. However, I think the assumption that linear accelerators must be significantly more expensive than other equipment should be challenged. I shall base my comments on the data of Koch and Eisenhower presented in Table I of Baines and Mosely's paper (SM-73/10), taking the price of the most expensive linac and comparing capital and operational costs with reference only to the sources (shielding costs would be similar, and conveyor costs probably lower for the accelerator). The figures can be summarized in Table A.

**TABLE A. COST COMPARISON OF LINEAR ACCELERATOR (LINAC) WITH $^{60}$Co SOURCE**

<table>
<thead>
<tr>
<th>Radiation source</th>
<th>Cost ($/kW)</th>
<th>Estimated efficiency</th>
<th>Cost per kW utilized ($)</th>
<th>Operational costs ($)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$^{60}$Co</td>
<td>40 000</td>
<td>33%</td>
<td>120 000</td>
<td>85 000</td>
</tr>
<tr>
<td>Linac (5 kW, 10 MeV)</td>
<td>50 000</td>
<td>50%</td>
<td>100 000</td>
<td>45 000</td>
</tr>
</tbody>
</table>

The operational costs indicated in the last column refer only to the sources for two plants of similar capacity (e.g. 1 MCi of $^{60}$Co and a 10-MeV linac). The figure of $85 000 is an estimate for 15% replenishment of the cobalt, i.e. 150 000 Ci, encapsulated and installed. The figure of $45 000 represents spare parts, e.g. two klystrons at $12 500 each, plus a rather pessimistic estimate of about $20 000 for various other parts.

I think we must agree that, if these estimates are anywhere near the truth, a linac plant could afford some extra staff expenses and still remain highly competitive.
ECONOMIC ASPECTS OF THE FOOD IRRADIATION PROGRAMME IN ISRAEL

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Abstract — Résumé — Аннотация — Resumen

ECONOMIC ASPECTS OF THE FOOD IRRADIATION PROGRAMME IN ISRAEL. The economics of many developing countries are based on agriculture, with semi-tropical fruits as the predominant crops. The harvest and shelf-life periods are brief because of the hot and humid climate. Refrigerated storage is underdeveloped or expensive. Economically important markets are distant.

The economics of food irradiation must be surveyed on a national scale at the outset of any ambitious technological feasibility study programme. This must be followed by detailed economic feasibility studies as the programme progresses.

Such a technological-economic survey of radiation-preserved agricultural produce was made in Israel in July 1965. All items which, potentially, could benefit from irradiation (fruits and vegetables, fodder, cereals and cereal products, fish, meat, poultry and poultry produce) were examined. Crop sizes and their values for 1962/63 and 1968/69 (based on Ministry of Agriculture data) were considered. Irradiation costs were estimated on the basis of available and extrapolated data for small irradiators in the growth areas and for large irradiators in port or along main highways. Surface treatment by electron accelerators and bulk treatment of $^{60}$Co, $^{137}$Cs or X-ray sources were considered. This survey was useful in formulating the programme for detailed technological and economic feasibility studies of individual items and in forecasting research activities and commercial applications for the period up to 1971.

Preliminary results with sprout prevention in irradiated potatoes justified detailed economic surveys of the potato and onion commercial set-up as it is today in comparison to a modified set-up comprising several variants of combined irradiation and controlled temperature storage installations. The suggested set-up would reduce the expenditure for storage and handling from 15% to about 8% of the total crop value, the savings representing a net return of about 24% on the investment.

This detailed economic survey on potatoes and onions will help considerably in the rapid adoption of the irradiation technique owing to the clear advantages shown.

ASPECTS ECONOMIQUES DU PROGRAMME D'IRRADIATION DES PRODUITS ALIMENTAIRES EN ISRAEL. L'économie de nombreux pays en voie de développement repose sur l'agriculture, les fruits semi-tropicaux constituant la production essentielle. La récolte et la durée de conservation sont très brèves à cause du climat chaud et humide. Le stockage sous réfrigération est insuffisant ou très onéreux. Les marchés ayant une importance économique sont éloignés.

Avant d'étudier sérieusement la possibilité technique de recourir à l'irradiation, il faut examiner les aspects économiques nationaux de ce procédé de traitement des produits alimentaires. Il faut ensuite procéder à des études économiques détaillées sur les possibilités de réalisation, à mesure que le programme se développe.


Des résultats préliminaires, notamment l'arrêt de la germination des pommes de terre après irradiation, ont justifié une étude économique détaillée du système de commercialisation actuel des pommes de terre et des oignons, en vue de le comparer à un système modifié comportant divers types d'installations combinant...
l'irradiation et le stockage à température contrôlée. Le système suggéré ferait passer les frais de stockage et de manutention de 15% à environ 9% de la valeur totale de la récolte. Les économies représenteraient un bénéfice net d'environ 24% par rapport aux investissements.

Cette enquête économique détaillée sur les pommes de terre et les oignons contribuera beaucoup à faire rapidement adopter la technique d'irradiation dont elle a mis les avantages en évidence.

ÉCONOMISCHES ASPECTEN ISRAËLSE PROGRAMMA MET OBLIJCHEN VAN LUGEN- EN AANVERWANTE GEBRUIKEN. Economische aspecten van de gevolgen van een programma met irrigatie van dergelijke bonen en verwante bonen zijn niet in detail onderzocht. In het kader van het programma met irrigatie van deze bonen en verwante bonen is een dergelijk economisch onderzoek daartoe gepland en uitgevoerd.

При разработке любой обширной программы с целью изучения технологической целесообразности, экономические вопросы по облучению пищевых продуктов должны рассматриваться в национальном масштабе. По мере выполнения программ следует детально изучать ее экономическую целесообразность.

Такое технико-экономическое изучение вопросов сохранения сельскохозяйственных продуктов с помощью облучения было проведено в июле 1965 года в Израиле. Были изучены все пищевые продукты, облучение которых может быть экономически выгодным (фрукты, овощи, зерно, продукции из них, рыба, мясо, птица). В то же время принималась в расчет общая стоимость урожая и его стоимость за 1962 - 63 гг. и 1968 - 69 гг. (по данным Министерства сельского хозяйства). Стоимость облучения оценивалась на основании имеющихся и экстраполированных данных, полученных как на маленьких облучателях, использующихся в полевых условиях, так и на больших установках в портах и вдоль шоссейных дорог. Проводилось изучение обработки поверхности электронными ускорителями и обработки всей массы с помощью кобальта-60, цезия-137 или рентгеновских лучей. Это обследование было полезно для разработки программы детального технологического и экономического изучения целесообразности облучения пищевых продуктов, а также для выбора направления исследовательской деятельности и коммерческого применения на период до 1971 г.

Предварительные результаты опытов по предотвращению прорастания облученного картофеля продемонстрировали целесообразность проведения детальных экономических исследований существующих методов хранения картофеля и улучшения этих методов, заключающихся в совместном применении установок по облучению и хранению при заданной температуре. Применение предлагаемого метода снизило бы затраты во время хранения и транспортировки с 15% примерно до 8% от общей стоимости урожая, причем экономленные средства составили бы около 24% от новых капиталовложений.

Такое детальное экономическое обследование будет способствовать быстрейшему внедрению этого метода благодаря вышеперечисленным преимуществам.

ASPECTOS ECONÓMICOS DEL PROGRAMA DE IRRADIACIÓN DE ALIMENTOS DE ISRAEL. Son muchos los países en desarrollo cuya economía está basada primordialmente en los productos agrícolas semitropicales. Debido al clima cálido y húmedo, los períodos de recolección y conservación de estos productos son muy breves. El almacenamiento en refrigeración no se halla generalizado o resulta caro. Los mercados de importancia económica se encuentran muy alejados de las zonas de producción.

Cuando se emprende la ejecución de un programa ambicioso de estudios sobre las posibilidades tecnológicas de la irradiación de los productos alimenticios es preciso tener en cuenta los aspectos económicos de la cuestión en el plano nacional. A medida que se ejecuta el programa es preciso llevar a cabo otros estudios sobre las posibilidades económicas de la irradiación.

En julio de 1965 se llevó a cabo en Israel uno de estos estudios técnico-económico sobre la conservación de los productos agrícolas por irradiación. Se estudiaron todos los productos que podían ser objeto de este tratamiento (frutas y verduras, forrajaz, cereales y sus derivados, cárneos, volatería y sus productos). Se calculó el volumen y el valor de las diversas cosechas para los años agrícolas de 1962-1963 y 1968-1969 (partiendo de datos facilitados por el Ministerio de Agricultura). Tomando como base datos disponibles y extrapolados se calculó el costo de la irradiación tanto para pequeñas instalaciones montadas en las zonas de cultivo como para grandes plantas de irradiación instaladas en puertos o en las principales carreteras.

Se estudiaron las posibilidades del tratamiento superficial mediante aceleradores de electrones y las del tratamiento a granel con fuentes de 60Co, 137Cs y rayos X. Esta labor resultó de utilidad para la preparación del programa de estudios detallados sobre las posibilidades económicas y tecnológicas de la irradiación de diversos productos y el planeamiento de las actividades de investigación y de las actividades comerciales hasta 1971.

Los primeros resultados obtenidos irradiando patatas almacenadas para evitar su germinación justificaron que se llevaran a cabo estudios económicos detallados sobre la estructura actual del comercio de la patata y
la cebolla en relación con un sistema modificado que comprendiera diversas combinaciones de instalaciones de irradiación y de instalaciones de almacenamiento con regulación de la temperatura. La combinación propuesta reduciría los gastos de almacenamiento y acarreo entre un 15 y un 8% del valor total de la cosecha, representando estas economías una ganancia neta de un 24% sobre el capital invertido.

Este estudio económico detallado sobre las posibilidades de la irradiación de la patata y la cebolla contribuiría considerablemente a la rápida adopción de esa técnica, dadas las evidentes ventajas que ofrece.

1. INTRODUCTORY REMARKS

The United States Department of Commerce recently published a comprehensive survey of the current status and of the commercial prospects for radiation preservation of food [1], which as a preliminary report to management was intended to assist in the orderly adoptions of this new technology by food processing and related industries. In the examination of areas of potential economic impact of food irradiation, several factors were indicated as prerequisites for the successful adoption of this technology. These include the successful development of sources and facilities, the development of commercially acceptable cost data, and the determination of practical and measurable benefits in such areas as spoilage reduction, extension of shelf-life, quality improvement, market stabilization and expansion, etc. These are of paramount importance when a developing country considers venturing into this new field.

The foremost problem usually encountered is the high cost of a satisfactory large irradiation facility to permit irradiation of commercial packings of agricultural products. Another important problem is the considerable cost of the scientific and technical personnel necessary for the development of the new technology. It is difficult to start such a programme at the present state of the art, when much technological information is available, without ascertaining the support of most or all of the potentially interested producing, marketing, and processing parties in the country who could join in the common initial effort. A good example is provided by the original, and doubtlessly model, union of interested parties, the Centre Lyonnais d'irradiations atomiques in France. Such a combined set-up, which started with a common irradiation facility, is however premature for many countries lacking large industrial and agricultural concerns to bear the brunt of the initial investment and costs.

2. THE BASE FOR AN ECONOMIC EVALUATION IN ISRAEL

A much less expensive way, based on a detailed preliminary technological economic survey of the potential uses of large radiation sources in the country, is being tried out in Israel. This procedure, found valuable here, will now be discussed at some length.

In the initial stages of the programme (1964) the current world-wide status of the agricultural and industrial applications of large radiation sources was reviewed and a summarized memorandum was presented to three types of potentially interested parties, namely, the Ministries of Agriculture, Commerce and Industry, and Health, growers' organizations and marketing boards, and various private producers and processors in agriculture and industry. A series of subsequent discussions with
each of the parties contacted, as well as with the various relevant departments at research institutes (affiliated with the respective Ministries) served to crystallize local problems which might be satisfactorily solved by the radiation technique, with important economic benefits.

It became clear that the problems encountered in a developing country like Israel differ from those of the developed countries in Europe and North America. Two factors contribute to this difference: (a) the hot climate, with resultant brief harvest periods and reduced shelf life of many agricultural products because of enhanced contamination with fungi or infestation; and (b) the importance of increasing the export volume of agricultural produce, the main exportable commodities of developing countries, over great distances. Although both factors are being constantly studied, and many of the problems have found temporary, if expensive, solutions, the potential benefits of the new technology seem very promising, especially from the economic viewpoint, for example, larger amounts of the crops could be saved for human consumption; an improved distribution of locally grown products over an extended marketing period could be achieved; imports of items, such as onions, could be eliminated; the expensive refrigerated storage and shipment cost could be avoided; and air shipment for export could be replaced by the much cheaper shipment by steamer.

3. PRELIMINARY OVERALL TECHNOLOGICAL-ECONOMIC SURVEY

These discussions indicated the need for a detailed technological-economic survey, which was then carried out. Although it also included industrial applications (chemicals, plastics, wood, hospital supplies) to clarify the overall national potential for the new technology, that part of the survey is not discussed here.

The survey covered several major applications - delay of sprouting in vegetables; disinfection of cereals, cereal products and fodder; pasteurization of fruits and vegetables; pasteurization of fish, eggs, poultry and beef meat; food processing and miscellanea. It is not the purpose of this paper to present all the information obtained in the survey but to summarize the method employed and the more significant findings.

On the basis of data from Ministry of Agriculture reports (and forecasts), Tables were compiled on the crop and export volumes, the respective costs per ton, and the respective total crop and export values for 1962-1963 and for 1968-1969, assuming a lapse of at least 3 to 4 years until several of the items surveyed could benefit on a commercial scale from irradiation. The more significant of these data are presented in Table I. All items which might benefit from radiation were included. When considering preliminary estimates of the Mrad-ton cost, one can immediately eliminate those items for which this cost is inherently prohibitive (because of low item value and/or high radiation dose necessary for the particular benefit). On the other hand, items for which radiation costs are negligible, are also immediately apparent (e.g., potatoes, onions, soft fruits).

Each major item was then considered individually. Harvesting, storage, marketing, and shipping problems were discussed from the technological and economic viewpoints, evaluating the possible effect and cost of an appropriate radiation treatment.
4. THE SURVEY FINDINGS

The survey included excerpts from other published surveys of radiation economics and from irradiated food legislation (FDA1 clearances and projected petitions). Also included were details on investment and running costs for irradiation plants of different sizes, based on cobalt-60, caesium-137 and electron accelerators. It concluded with a summary of the maximum expected yearly consumption of ionizing radiation energy in Israel within the following decade, based on those items for which it is of potential use. This summary (Table II) serves to illustrate the possible interplay between the various branches for the co-ordinated full-time utilization of the industrial irradiation facilities and to single out the more important potential radiation users.

Some of the more important findings in regard to specific items are discussed below.

4.1. Vegetables and cereals

The vegetable branch constitutes the main source of employment on the Israeli farm; vegetables have a limited growth period and they are very sensitive to weather conditions, this being reflected in substantial price fluctuations. Surplus problems are alleviated by canning and drying industries. There are two brief harvest periods for potatoes, the main crop in May-June-July, and the second in December and January. Surpluses and shortages are evened out by using refrigerated storage for a period of 7 months, with 6000-7000 tons being withdrawn for marketing each month. Sprouting normally starts after 6 to 8 weeks storage at normal temperatures. The estimated irradiation cost is only about 1% of the producer cost price, whereas the monthly cost of refrigerated storage is about 5%.

Onion sprouting is a much more acute problem, necessitating imports during the spring months, with their concomitant very high prices to the consumer. The irradiation cost is again only about 1% of the cost.

The harvest period of sugar beet is very short (two months) and the very hot weather during this period contributes to very rapid decomposition of the sucrose. Thus it is impossible to extend the factory processing season in order to reduce expenses. In addition, some sugar is lost when storage at the factory is necessary before processing. Irradiation of potatoes and sugar beets in a common irradiation plant would make possible an irradiation cost of only 1% of the cost price.

All of the cereals and fodder imported to and exported from the country pass through a single central assembly, the "Dagon" silos, which have an hourly capacity of 250 ton and a total storage capacity of 40,000 ton. This constitutes an ideal site for an irradiation facility for quarantine purposes which could irradiate all the grains at a fraction of a percent of the grain value.

Several smaller silos for animal fodder are located in some of the major agricultural regions. Disinfestation problems could easily be solved by incorporating irradiation sources in the flow patterns of the

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1 FDA = Federal Department of Administration, United States of America.
2 The "Dagon" silos, Haifa, Israel.
<table>
<thead>
<tr>
<th>Item</th>
<th>Quantity (10^3 ton)</th>
<th>1962-3 Price ($/ton)</th>
<th>Crop value (10^6 $)</th>
<th>Quantity (10^3/ton)</th>
<th>1968-9 (projected) Price ($/ton)</th>
<th>Crop value (10^6 $)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Potatoes</td>
<td>109.4</td>
<td>55.8</td>
<td>6.1</td>
<td>129.4 (11.5)</td>
<td>55.8 (110)</td>
<td>7.2 (1.2)</td>
</tr>
<tr>
<td>Dry onion</td>
<td>25.5</td>
<td>56.6</td>
<td>1.45</td>
<td>40.6 (1.1)</td>
<td>53.3 (69)</td>
<td>2.2 (0.07)</td>
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<tr>
<td>Sugar beet</td>
<td>249.6</td>
<td>19.7</td>
<td>4.9</td>
<td>250.0</td>
<td>19.7</td>
<td>4.9</td>
</tr>
<tr>
<td>Wheat</td>
<td>340.4 [4/5 imported]</td>
<td>88.3</td>
<td>30.0</td>
<td>409.0 [4/5 imported]</td>
<td>88.3</td>
<td>36.0</td>
</tr>
<tr>
<td>Peanuts</td>
<td>13.0</td>
<td>243.3</td>
<td>3.2</td>
<td>15.0 (4.4)</td>
<td>243.3 (358)</td>
<td>3.65 (1.6)</td>
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<tr>
<td>Edible pulses</td>
<td>8.1 [4/5 imported]</td>
<td>245.3</td>
<td>2.0</td>
<td>9.3 [4/5 imported]</td>
<td>245.3</td>
<td>2.3</td>
</tr>
<tr>
<td>Green fodder</td>
<td>109.1</td>
<td>32.7</td>
<td>3.6</td>
<td>152.0</td>
<td>32.7</td>
<td>5.0</td>
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<td>Fermented fodder</td>
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<td>7.7</td>
<td>1.35</td>
<td>215.6</td>
<td>7.7</td>
<td>1.6</td>
</tr>
<tr>
<td>Barley</td>
<td>112.7 [2/3 imported]</td>
<td>71.7</td>
<td>-</td>
<td>59.0</td>
<td>71.7</td>
<td>-</td>
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<tr>
<td>Sorghum</td>
<td>214.3 [4/5 imported]</td>
<td>66.7</td>
<td>-</td>
<td>541.0 [5/6 imported]</td>
<td>66.7</td>
<td>-</td>
</tr>
<tr>
<td>Flour and ground products</td>
<td>254.0</td>
<td>120.0</td>
<td>30.6</td>
<td>350.0</td>
<td>120.0</td>
<td>42.0</td>
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<tr>
<td>Processed alfalfa</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>77.8</td>
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<tr>
<td>Oranges</td>
<td>560.0 (424)</td>
<td>108.4 (150)</td>
<td>60.7 (64)</td>
<td>841.0 (475)</td>
<td>83.0 (120)</td>
<td>69.7 (57)</td>
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<tr>
<td>Bananas</td>
<td>50.6 (15)</td>
<td>134.0 (123)</td>
<td>6.8 (1.85)</td>
<td>60.0 (17.3)</td>
<td>133.3 (117)</td>
<td>8.0 (2.0)</td>
</tr>
<tr>
<td>Edible grapes</td>
<td>33.9 (0.4)</td>
<td>170.3 (316)</td>
<td>5.8 (0.12)</td>
<td>46.7 (2.0)</td>
<td>108.6 (300)</td>
<td>5.1 (0.6)</td>
</tr>
<tr>
<td>Tomatoes</td>
<td>99.2 (0.05)</td>
<td>93.5 (306)</td>
<td>9.3 (0.015)</td>
<td>132.9 (1.5)</td>
<td>93.5 (250)</td>
<td>12.4 (0.38)</td>
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<tr>
<td>Item</td>
<td>1962-3</td>
<td>1968-9 (projected)</td>
<td>Crop value</td>
<td>Crop value</td>
<td></td>
<td></td>
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<tr>
<td>--------------</td>
<td>--------------</td>
<td>--------------------</td>
<td>-------------</td>
<td>-------------</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Quantity (10^3 ton)</td>
<td>Price ($/ton)</td>
<td>(10^6 $)</td>
<td>Quantity (10^3 ton)</td>
<td>Price ($/ton)</td>
<td>(10^6 $)</td>
</tr>
<tr>
<td>Peaches</td>
<td>5.7</td>
<td>307.7</td>
<td>1.8</td>
<td>16.4</td>
<td>207.7</td>
<td>3.4</td>
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<tr>
<td>Apricots</td>
<td>1.7</td>
<td>460.0</td>
<td>0.8</td>
<td>10.0</td>
<td>240.0</td>
<td>2.4</td>
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<tr>
<td>Strawberries</td>
<td>1.5 (0.02)</td>
<td>[800] (1800)</td>
<td>[1.2] (0.04)</td>
<td>3.0 (0.3)</td>
<td>[600] (1300)</td>
<td>[1.8] (0.39)</td>
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<tr>
<td>Cucumbers</td>
<td>30.0</td>
<td>155.3</td>
<td>4.65</td>
<td>44.2</td>
<td>155.3</td>
<td>6.9</td>
</tr>
<tr>
<td>Peppers</td>
<td>11.6 (0.23)</td>
<td>132.3 (340)</td>
<td>1.5 (0.08)</td>
<td>15.6 (1.5)</td>
<td>132.3 (300)</td>
<td>3.1 (0.45)</td>
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<tr>
<td>Melons</td>
<td>22.1 (1.65)</td>
<td>73.3 (170)</td>
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<td></td>
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<tr>
<td>Avocados</td>
<td>1.8 (0.37)</td>
<td>[200] (515)</td>
<td>[0.36] (0.2)</td>
<td>6.6 (3)</td>
<td>[150] (400)</td>
<td>1.0 (1.2)</td>
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<tr>
<td>Sea fish</td>
<td>6.3</td>
<td>308.0</td>
<td>1.9</td>
<td>8.8</td>
<td>308</td>
<td>2.7</td>
</tr>
<tr>
<td>Frozen fish</td>
<td>4.2 [imported]</td>
<td>-</td>
<td>-</td>
<td>4.6</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Poultry</td>
<td>67.0</td>
<td>581.0</td>
<td>39.0</td>
<td>86.9</td>
<td>581</td>
<td>50.5</td>
</tr>
<tr>
<td>Beef</td>
<td>50.5 [2/5 imported]</td>
<td>850.0</td>
<td>43.0</td>
<td>67.2 [1/4 imported]</td>
<td>850</td>
<td>57.0</td>
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</tbody>
</table>

Note: Figures in parentheses () indicate export.
TABLE II. MAXIMUM EXPECTED IONIZING ENERGY CONSUMPTION IN ISRAEL WITHIN NEXT DECADE

<table>
<thead>
<tr>
<th>Item</th>
<th>Dose (Mrad)</th>
<th>Total quantity (ton)</th>
<th>Total energy required (Mrad-ton)</th>
<th>Surface irradiation (Mrad-ton)</th>
<th>Penetrating radiation (Mrad-ton)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vegetables</td>
<td>0.01</td>
<td>520 000</td>
<td>5200</td>
<td>-</td>
<td>5 000</td>
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<tr>
<td>Grains</td>
<td>0.02</td>
<td>1 500 000</td>
<td>30 000</td>
<td>20 000</td>
<td>10 000</td>
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<tr>
<td>Citrus</td>
<td>0.2</td>
<td>700 000</td>
<td>140 000</td>
<td>15 000</td>
<td>15 000</td>
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<tr>
<td>Soft fruits</td>
<td>0.2</td>
<td>220 000</td>
<td>44 000</td>
<td>-</td>
<td>44 000</td>
</tr>
<tr>
<td>Apples and pears</td>
<td>0.2</td>
<td>90 000</td>
<td>18 000</td>
<td>15 000</td>
<td>3 000</td>
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<tr>
<td>Other food</td>
<td>0.1</td>
<td>70 000</td>
<td>7 000</td>
<td>-</td>
<td>7 000</td>
</tr>
<tr>
<td>Fish</td>
<td>0.3</td>
<td>10 000</td>
<td>3 000</td>
<td>-</td>
<td>3 000</td>
</tr>
<tr>
<td>Meat</td>
<td>0.5</td>
<td>10 000</td>
<td>5 000</td>
<td>-</td>
<td>5 000</td>
</tr>
<tr>
<td>Polyethylene crosslinking</td>
<td>8.0</td>
<td>5 000</td>
<td>40 000</td>
<td>20 000</td>
<td>20 000</td>
</tr>
<tr>
<td>P.V.C. crosslinking</td>
<td>1.0</td>
<td>15 000</td>
<td>15 000</td>
<td>7 500</td>
<td>7 500</td>
</tr>
<tr>
<td>Polyethylene polymerization</td>
<td>6.0</td>
<td>2 500</td>
<td>15 000</td>
<td>-</td>
<td>15 000</td>
</tr>
<tr>
<td>Polystyrene polymerization</td>
<td>8.0</td>
<td>2 500</td>
<td>20 000</td>
<td>-</td>
<td>20 000</td>
</tr>
<tr>
<td>Plywood and wood</td>
<td>0.5</td>
<td>20 000</td>
<td>10 000</td>
<td>-</td>
<td>5 000</td>
</tr>
<tr>
<td>Tiles</td>
<td>6.0</td>
<td>1 000</td>
<td>6 000</td>
<td>-</td>
<td>3 000</td>
</tr>
<tr>
<td>Hospital supplies</td>
<td>2.5</td>
<td>8 000</td>
<td>20 000</td>
<td>-</td>
<td>20 000</td>
</tr>
</tbody>
</table>

The above figures are based on 1968 to 1969 expected production and should be regarded only as an indicator for estimation of the number of installations necessary in the case of whole-crop irradiation.

Penetrating irradiation: Assuming 33% yield and 7500 h/yr, 14 MCi of $^{60}$Co will be necessary, or alternatively half this amount, plus twelve 70-kW X-ray machines.

Surface irradiation: Assuming 80% yield and 7500 h/yr, four 10-kW, or one 70-kW, electron accelerators will be necessary. At lower yields and irradiation times these numbers will be significantly higher.
fodder through the silo. This would be at a minimum cost because of the simple design of the irradiation facility and the very efficient radiation absorption.

Under local climatic conditions, infestation of cereal products, e.g., flour, semolina, groats and ground rice, occurs mostly in retail shops, and the insects develop there or in the homes. Preliminary packing and service irradiation in central facilities would allow disinfestation at an irradiation cost of less than 1% of their values.

4.2. Fruit

Local citrus fruit is subject to quarantine requirements in many countries, despite the Israeli widespread and effective campaign against the Mediterranean fruit fly. Irradiation at low doses could provide a satisfactory solution to this problem. Higher irradiation doses, costing no more than the present diphenyl-impregnated paper treatment, would permit discontinuation of the latter and might increase the shelf life of the citrus. It would also make possible the bulk sale to supermarket chains of citrus in large shipping containers, or pre-packaged in small perforated plastic bags.

The sterile-male technique employed in eradicating the Mediterranean fruit fly from local citrus orchards has shown great promise in small-scale experiments, and large-scale study programmes should be initiated. The irradiation cost is extremely low.

Delay of ripening in bananas and avocados, which is of great importance in a hot climate, could be achieved at a very low cost by very small doses of radiation. The high price of these products, especially of the latter, justifies an irradiation facility used primarily for this purpose only; even so the irradiation cost is less than 1% of the value.

The harvest seasons of strawberries, apricots, peaches and grapes are relatively short because of the very hot weather, and consequently their shelf life is greatly shortened. A two to three-fold increase in the chilled storage shelf life, through irradiation at an irradiation cost of 1% of the product cost, promises to be a boon of great significance for both growers and processors.

With several of the above products, export problems were shown to be alleviated by use of radiation to increase the shelf life, and to make possible refrigerated or normal steamer shipment (instead of air shipment).

4.3. Fish

In recent years there has been an increase in the demand for sea fish, and forecasts indicate still further increases. It seems likely that irradiation will be very important in the sea fish economy through the possibility of marketing a product which maintains its flavour and wholesomeness for at least a week or two after the catch. The fact that ocean fish are brought to Israel from the Atlantic Ocean and the North Sea makes this method especially attractive. The irradiation cost would be 1 to 2% of their value, even with half the dose administered aboard ship and half on shore.
4.4. Poultry and chopped meat

Because of climatic conditions, the sale of slaughtered poultry, pasteurized and refrigerated, has increased very slowly. This situation could be improved if the refrigerated shelf life could be extended to 10 to 12 days by irradiation. Even in small installations this could be achieved at a cost of less than 1% of the poultry value. The same was found for minced or chopped meat.

5. IMMEDIATE PURPOSE OF THE SURVEY

On the basis of this survey, an overall programme for irradiation experiments was drawn up for the year 1965 to 1966. It contained two categories of items: Programme A — those of prime economic importance in Israeli agriculture, and for which the results of research abroad were available at the time; and Programme B — additional items that respond well to irradiation and for which adequate data are available from other countries, but the immediate investigation of which is not so urgent, and those for which existing data are not sufficient but technological-economic reasons justify tests under local conditions (see Table III). Research budgets were drawn up, itemized according to the different branches of agriculture, in order to provide estimates for the interested marketing boards and related institutions.

This overall programme served as the basis for the final programme, which was adopted after selection was made by special committees set up by the National Science Research Council. Also included was a forecast of activities in this field during 1966 to 1971 (detailed for 1966 to 1967, 1967 to 1968 and 1968 to 1971), in which were indicated the studies and actions necessary prior to commercialization and the expected budgets in order to allow proper evaluation of the economic effort by the potential supporters of the programme. Also indicated were the expected commercially exploitable processes that may be realized at various dates during this period, and the corresponding investments required.

6. DETAILED ECONOMIC SURVEY ON THE IRRADIATION OF POTATOES AND ONIONS

The promising local results on sprout prevention in irradiated potatoes obtained early in the programme indicated the desirability of two important steps toward commercialization, conceived in the above forecast of activities: (a) submission of a petition for the approval of irradiated potatoes for human consumption, as described in another paper [2] presented at this Symposium; and (b) a detailed economic feasibility study of the use of large radiation sources for sprout prevention in potatoes and onions [3].

It was apparent that great care should be given to this first economic survey of the advantages of using large radiation sources to prevent sprouting in potatoes and onions so that it might serve as a model for future surveys on other agricultural products. It was also clear that this could be a preliminary survey only as far as irradiation results, benefits and economics were concerned, and that further detailed ex-
Experimental studies would be necessary before a more conclusive economic survey is made.

The present survey on sprouting control may be considered complete only in its first part, that is in that dealing with the present production and marketing set-up for potatoes and onions. Included in it were data on the production of potatoes and onions according to local varieties, regions, and seasons (which were found to be very short) as well as their uses (consumption, export, seeds, industrial processing, surpluses and spoilage). There were also data on the harvesting, handling, grading, transporting, storage (refrigerated), marketing and other costs. These were found to be about 50% of the product value to the producer, which is about $75-90/ton. A detailed analysis was presented on the losses encountered during storage, especially with onions.

The second part of the survey, that dealing with the irradiation set-up and its economic feasibility, is still incomplete, as the effects of the irradiation on the local varieties of potatoes and onions are not yet known. Assumptions on the expected benefits with respect to sprout prevention, drying-up and weight loss, rot spoilage, potato moth development, sweetening, greening, and taste and other culinary properties, were based on preliminary experimental results and data extrapolated from experiments performed abroad. It was assumed that most or all of the benefits were conditional on the replacement of refrigerated storage by air-conditioned storage in low-cost sheds.

Technological and economic data were processed, considering several variants of processing complexes, each combining an irradiation facility and an air-conditioned storage shed. Of the possible variants those comprising one, three or seven complexes to cover the major producing areas in Israel, with capacities ranging from 50 to 5-10 ton/h, respectively, were investigated.

These data were compared with the corresponding data in conventional refrigerated storage facilities.

Despite very conservative estimates, it was concluded that the new process is definitely more economical than the present set-up with the handling, transportation and storage costs being reduced by one-third, which represents one-sixth of the product value at harvesting. Although the rate of return was highest with the variant in which three units of 10 ton/h each were used for half of the stored potato crop (29.7% on an investment of IL 4,900,000), a somewhat lower rate of return was preferred for the entire stored potato and onion crops, namely using the variant comprising three units of 10 ton/h and four units of 5 ton/h each (27.8% on an investment of IL 7,960,000). The latter variant represented a saving of IL 1,420,000 (one-third of the annual costs) and would require only minimum changes in the number and location of existing grading stations.

It is of great interest to note the surprising fact that, under local conditions, the variant incorporating a single large irradiation unit is less economical than the other variants despite the lower irradiation cost (26.3% rate of return on an investment of about IL 6,870,000); this was due mainly to differences in transportation and handling costs.

These theoretical savings must now be verified by experimental confirmation of the critical assumptions concerning the technological benefits of radiation for potatoes and onions.
# TABLE III. ITEMIZED RESEARCH AND IRRADIATION BUDGET

<table>
<thead>
<tr>
<th>Total budget (kL)</th>
<th>Equipment budget (kL)</th>
<th>Labour budget (kL)</th>
<th>Lohamers (kL)</th>
<th>Total budget (kL)</th>
<th>Total research budget (kL)</th>
<th>Total irradiation time (h)</th>
<th>Total quantity irradiated (kq)</th>
<th>Irradiations (No.)</th>
<th>Average irradiation (h)</th>
<th>Repacks (No.)</th>
<th>Storage temperatures (No.)</th>
<th>Dose rate range (Mead/3)</th>
<th>Dose rate (Mead)</th>
<th>Dose (No.)</th>
<th>Dose range (Mead)</th>
<th>Dose (No.)</th>
<th>Varieties (No.)</th>
<th>Significant irradiated sample (kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>15 000</td>
<td>3 000</td>
<td>3 000 1/2</td>
<td>4 000 1/2</td>
<td>5 000 1/2</td>
<td>200 1.5</td>
<td>300 2/3 4 2</td>
<td>0.01 - 0.25 3 0.05 - 0.125 3 2 2 30 Potatoes</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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</tr>
<tr>
<td>4 500</td>
<td>1 000</td>
<td>1 500 1/4</td>
<td>2 000 1/4</td>
<td>75 2.75</td>
<td>75 1 2 2</td>
<td>0.01 - 0.25 3 0.125 - 0.175 3 1 2 50 Onions</td>
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<td></td>
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<tr>
<td>4 000</td>
<td>125</td>
<td>2 000 1/4</td>
<td>1 250 1/8</td>
<td>100 2.2</td>
<td>80 14 1 2 1</td>
<td>0.06 - 0.25 2 0.01 - 0.2 5 2 2 40 Sugar beet</td>
<td></td>
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<td></td>
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<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2 500</td>
<td>250</td>
<td>1 000 1/8</td>
<td>1 250 1/8</td>
<td>50 0.8</td>
<td>20 14 1 1</td>
<td>0.25 1 0.01 - 0.2 5 2 2 40 Carrots</td>
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<td></td>
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<tr>
<td>800</td>
<td></td>
<td>800 1/10</td>
<td>12 0.4</td>
<td>10 14 1 1</td>
<td>0.25 1 0.01 - 0.2 5 2 2 40 Radish or beetroot</td>
<td></td>
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<td></td>
<td></td>
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</tr>
<tr>
<td>1 000</td>
<td></td>
<td>1 000 1/8</td>
<td>60 0.8</td>
<td>40 14 1 2 1</td>
<td>0.05 - 0.25 2 0.01 - 0.2 5 1 2 20 Cucumbers</td>
<td></td>
<td></td>
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*Man-day cont.*
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<td>Foder</td>
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<td>15 0.3 30 1/2 2 1 0.25 1 0.01 - 0.05 3 1 5 10</td>
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<td>Legumes</td>
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<td>15 0.6 30 1/2 2 1 0.25 1 0.01 - 0.05 3 1 5 20</td>
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<td>Dry baked products</td>
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<td>4500</td>
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<td>Dehydrated vegetables and soups</td>
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<td>1000</td>
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<td>Meat and eggs</td>
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7. CONCLUSIONS

It seems worth while to mention the general advantages of performing, at an early stage, an overall economic survey of the various aspects of an irradiation programme.

It has been proven that such a survey is especially relevant in cases, such as Israel, where agriculture is being planned on a national scale by a central authority.

This preliminary survey has been of great help in choosing the more promising items for an irradiation programme, while eliminating those for which irradiation treatment would not be more economical than conventional treatments, even though these latter items may be attractive for other reasons. Furthermore, the survey has indicated for which agricultural products grown in Israel, and which are of national economic importance, irradiation for extension of shelf life would be economically feasible. It has also indicated which other items, not of primary importance to the Israeli economy, it would be worth while to include in an irradiation programme because of their favourable response to irradiation at low cost.

The survey, therefore, was of great importance when the first research programme was being planned, and when all the relevant data were submitted for proper financial evaluation. The survey has also proven its usefulness at a more advanced stage, e.g. in the more detailed evaluation of the economic feasibility of the irradiation of potatoes and onions to prevent sprouting. Such a detailed study clearly pointed out the positive and negative aspects of the proposed method and, in particular, its economic value.

REFERENCES

[2] FOA, E., EISENBERG, E., KAHAN, R.S., LAPIDOT, M., "Issuing of Regulations on the Clearance of Irradiated Food Products on the Basis of Foreign Petitions", these Proceedings.
ECONOMICS OF FOOD IRRADIATION

H. RINDORF
A/S RADEST, HERSTEDOESTER, DENMARK

Abstract — Résumé — Аннотация — Resumen

ECONOMICS OF FOOD IRRADIATION. To-day very reliable irradiation equipment is available, and
for an industrialist it is largely an economic consideration whether he should go in for an otherwise accep-
table irradiation processing. In Denmark an industrial concern has now found it economically justifiable
to establish a multi-purpose industrial plant, equipped with an American linac, and this facility will be
able to process food.

To date, few plants in the world have recorded actual cost experiences for industrial food processing,
but cost figures from other fields may serve as a guide. In practical calculations it is convenient to divide
the work into certain typical groups, e.g. facilities for "bulk","medium", "thin", and "multi-purpose",
but food products may come under any of these headings.

Costs of irradiation depend on product properties, type of plant, annual and monthly quantities, doses,
control standards, special requirements for re-packing, or other additional handling, etc. Definite figures
for a particular case must be based on an exact calculation, but for a preliminary judgement many general
price-range indications are available to the industrialist, and for a variety of purposes it is already evident
that irradiation processing is economically sound.

Apart from plant economy it is advisable for the industrialist to study some general commercial problems
also, such as consumer preference and marketing structure, for the commodity in question. This can often
best be done by marketing a pilot production of some quantity, before final decisions are taken regarding
major investments in highly-specialized equipment. For some products market testing has already been done
with good results by existing research or production facilities, and indeed actual commercial marketing has
been reported.

In conclusion, many food irradiation processes seem to be promising from an economic point of view.

ASPECTS ECONOMIQUES DE L'IRRADIATION DES PRODUITS ALIMENTAIRES. Il existe actuellement
un matériel d'irradiation parfaitement sûr et, pour un industriel, la question de savoir s'il adoptera cette
technique dépend principalement de considérations d'ordre économique. Au Danemark, une entreprise
industrielle a maintenant jugé qu'il était rentable de construire une installation de taille industrielle à
fins multiples, équipée d'une machine américaine Linac, qui permettra de traiter des produits alimentaires.

Jusqu'ici présent, seules quelques entreprises dans le monde disposent de données concrètes sur les prix
de revient pour le traitement industriel des produits alimentaires, mais les chiffres concernant d'autres
domaines peuvent donner des indications. Pour les calculs pratiques, il est utile de classer les instal­
lations selon la caractéristique principale des opérations, par exemple: traitement des produits «en vrac»,
des articles «moyens», des articles «petits», et installations à «fins multiples»; les produits alimenta­
taires peuvent entrer sous n'importe laquelle de ces rubriques.

Le coût de l'irradiation dépend des propriétés du produit, du type d'installation, des quantités annuelles
et mensuelles traitées, des doses, des normes de contrôle, des exigences spéciales pour le réemballage
et autres opérations de manutention, etc. Dans chaque cas particulier on ne peut obtenir de chiffres sûrs que
par un calcul précis, mais pour une évaluation préliminaire l'industriel dispose de plusieurs gammes géné­
rales de prix et il est déjà évident, en ce qui concerne diverses opérations, que l'irradiation est économiquement
rentable.

Outre l'économie de l'installation, il serait bon que l'entrepreneur étudie certains problèmes commer­
ciaux généraux, tels que la préférence du consommateur et la structure du marché pour la denrée en question.
Le plus souvent, le meilleur moyen à cette fin consiste à commercialiser une production pilote avant de
décider d'investir de grosses sommes dans le matériel très spécialisé. Pour certains produits, des essais
fructueux ont déjà été faits sur le marché par des organismes de recherche ou par des industriels et l'on a
signalé des essais de commercialisation effective.

En conclusion, beaucoup de procédés d'irradiation des aliments semblent prometteurs du point de vue
économique.

ВОПРОСЫ ЭКОНОМИЧНОСТИ ОБРАБОТКИ ПРОДУКТОВ ПИТАНИЯ ПОСРЕДСТВОМ
ОБЛУЧЕНИЯ. В настоящее время имеется очень надежное оборудование для облучения, а
для предпринимателя главным является соображение экономичности, когда он решает вопрос о применении приемлемой для него в других отношениях обработки посредством облучения. В Дании один промышленный концерн нашел экономически оправданным построить многоцелевую промышленную установку, оборудованную американским линейным ускорителем, и эта установка сможет обрабатывать продукты питания.

До сих пор немного предприятий в мире сообщали о действительно расходах на обработку продуктов питания, однако цифры расходов из других областей могут служить в качестве руководства. При практических расчетах удобно разделять работу на определенные типичные группы, например, на установки "крупные", "средние", "тонкие" и "многоцелевые", однако продукты питания могут попадать в любой из этих разделов.

Стоимость облучения зависит от свойств продукта, вида установки, годовых и месячных количеств обрабатываемых продуктов, доз, контрольных норм, специальных требований к переупаковке и другой дополнительной обработке и т.д. Определенные цифры для конкретного случая должны основываться на точных расчетах, однако для предварительного суждения в распоряжении предпринимателя имеется много общих указаний относительно диапазона цен, и для многих целей уже очевидно, что обработка облучением экономически оправдана.

Независимо от экономичности установки предпринимателю рекомендуется изучить также некоторые коммерческие проблемы общего характера, такие как потребитель и рыночная структура для соответствующего товара. Часто это может быть сделано наилучшим образом путем сбыта опытной партии определенного размера, прежде чем принимать окончательное решение относительно главных вложений в узкоспециализированное оборудование.

Для некоторых продуктов проверка на сбыт, давшая хорошие результаты, уже проводилась с помощью существующих исследовательских или производящих установок, и сообщалось о действительно реальном коммерческом сбыте.

В заключение говорится, что многие процессы обработки продуктов питания представляют собой перспективными с точки зрения экономичности.

INTRODUCTION

For an industrialist, it is to-day largely an economic question whether to adopt irradiation processing. Many kinds of very reliable irradiation equipment are available, and a manufacturer need not refrain from starting irradiation processing because of fear of insoluble maintenance problems. Therefore, where necessary permits have been
obtained, this new type of processing may be judged by him in the same way as any other production method, i.e. that the product must be acceptable to the market and to himself, the price and quality being in satisfactory balance. Based on a study for industrial purposes, this paper describes how such judgment turned out in a practical case.

A DANISH INDUSTRIAL PLANT

A study has been carried out, mainly by the author, for an industrial concern which has, in consequence, decided to establish a multi-purpose irradiation plant in Denmark. The plant will be equipped with an American Linac and will be able to process food. Although many permit questions are still pending, it was considered essential to provide an irradiation plant because agricultural production is one of the largest factors in the Danish economy. It is interesting that the industrial concern took the decision to enter the irradiation field on purely economic grounds, in consideration of the development work which had already been done with very tangible practical results by the Danish Atomic Energy Commission (DAEC).

FOUR TYPES OF WORK

To date, few plants in the world have recorded actual cost experiences for industrial food processing but, in principle, there will be little difference between estimates of procedures for food, and those for other productions of generally comparable goods, except that control problems assume a character very different from, for example, polymerization work.

In basic practical calculations the following four headings are convenient:

(a) Bulk (or heavy-weight) goods
(b) Medium goods
(c) Thin goods
(d) Multi-purpose production

"Bulk (or heavy-weight) goods" may, for organic materials, be taken as those treated in thicknesses of about 4 cm and upwards. In practical terms, this group includes most processes for potatoes, other vegetables, grain, and in certain circumstances, even canned meat and fish, eggs, chicken, etc.

"Medium goods" are, for organic materials, taken as those treated in thicknesses of between 3 and 4 cm; the group comprises a large variety of products, e.g. all goods for surface pasteurization, sliced meat, some types of canned meat and fish, and, in certain circumstances, grain and other items of small-particle size.

The group "thin goods", covers all products less than 3 cm thick which, presumably, does not comprise many food items, but is dominated by technical products, such as polyethylene film and certain other plastic products. Technically, grain, rice, etc., might very well come under this heading, and indeed only a particular case study can ascertain whether such a classification would be economically justified. So far, the major part of industrial irradiation experience gained has been within
this sector, and some of the plants operating for these purposes are among the most routinely run processing facilities.

"Multi-purpose production" is a concept that will come in whenever a new market with somewhat unknown prospects is to be opened, and great variations in the types of work must be anticipated. In this situation it is not possible to reach the high degree of plant specialization that may be obtained where, from the outset, products are known to come under one of the first three groups. The Danish plant was planned for this concept ultimately; consequently it also formed the main basis for the present study. To meet multi-purpose requirements, a very flexible type of machinery was selected.

Evidently, many types of work may, depending on circumstances, come under more than one of the four headings. No existing plant presents the cheapest solution for all types of work, but many designs have a high degree of flexibility, so that good compromise solutions can be achieved.

Rock-bottom prices can only be reached where a plant can run continuously for a high percentage of hours in the year on products with a uniform, high utilization of the beam effect. In practical cases, these ideal conditions have no doubt been approached in the processing of plastic cable insulations, pipes, film and perhaps other products, and the same is probably true in certain plants for the sterilization of medical utensils.

However, in the study of these possibilities, a number of industrialists must have found a less profitable situation. Some doubted whether they could reach a satisfactory number of annual beam hours; others found it necessary to make up with processes of low utilization degrees, and again, others found that production must be concentrated mainly within a few months of the year.

PRICES DEPEND ON CIRCUMSTANCES

Economic considerations often have the effect of making industrialists conservative, with the result that a completely new industrial field will not be taken up readily, unless it shows considerable promise for the not too distant future. Industrial interest in irradiation will grow if and when prices obtainable leave a reasonable margin of profit.

Specimen calculations will invariably indicate that investment weighs more heavily for an irradiation plant than for most other industries, whereas variable and semi-variable expenses are comparatively lower. Assessment of depreciation percentages and periods is therefore one of the most important decisions for the calculator to make.

Until now, a great number of industries have traditionally written off their plant over ten years, and it has been very common that plant investment approximately equalled the annual turnover. This is a very rough statement, with important exceptions, but nevertheless gives as a reasonable, general indication for many products, that the sales price has to include about 10% for depreciation of plant.

It appears doubtful whether that low level could ever be reached by any irradiation industry. On the contrary, it will be easy to find examples where depreciations count for more than all other expenses together. It should be realized, therefore, that a decision regarding the period of total writing-off is of the greatest importance. In the author's opinion, this
period should not be more than five years, considering that this is an industry in very rapid development, but there have been a number of carefully specified calculations, made by outstanding experts, where 7, 10 or even 15 yr have been advocated.

With depreciation there is one other factor of the highest importance, namely, sales prognosis. This judgement is somewhat simplified in cases where, for example, a cable factory, a medical instruments factory, or a canning industry, intend to establish an irradiation plant for their own purposes. In many such cases the sales prognosis must be closely tied to market planning, already run routinely by the industry concerned. Evidently, in the case of an independent establishment intending to supply an irradiation service for other firms, the market prognosis depends on less controllable factors; it is particularly unlikely that production would be in full swing at once and continue for a number of years at maximum level.

If a plant must accept some kind of normal sales development, with an annual growth of a certain percentage, the average utilization over a number of years will inevitably be much less than 100%. This may be more clearly explained by an example. Consider a plant model, starting not at zero turnover, but at a minimum of some realistic magnitude, say, 1000, and anticipate that the turnover, as reached in the fifth year represents the maximum capacity of the plant; the typical turnover development can be seen in Table I.

Thus the maximum obtainable turnover is 55% only of the theoretical maximum turnover. As rule of thumb, the author recommends that normal preparatory economic calculations be made on a maximum of 13–16 h run per day, provided that a run of 24 h is reached by the end of the calculation period.

Roughly, all irradiation prices will be proportional to the dose actually given, and therefore more or less proportional to the minimum dose prescribed. If dose tolerances have to be particularly narrow for some reason, this will cost extra in control and a possibly lowered output.

Where production quantities show very marked variations throughout the year, this will inevitably influence prices. Special control measures can

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<td>2</td>
<td>2000</td>
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<tr>
<td>3</td>
<td>3000</td>
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<td>4</td>
<td>4500</td>
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<tr>
<td>5</td>
<td>6000</td>
</tr>
</tbody>
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Average for 5 yr: 3300

Total for 5 yr: 16 500
cost more or less heavily, and the economy will be particularly influenced if necessary control procedures tend to reduce production quantities.

Product properties may have other influences which are not generally predictable, and all such problems will have to be considered one by one and judged on their own merits.

Naturally, the type of plant selected is a most important factor when working out the economic calculations. It must be realized that whatever kind of accelerator or isotope source is studied, it will not prove equally ideal for all purposes, though some equipment is well suited for a wide range of processes.

Over and above the radiation source, the investment comprises considerable amounts for items like land, buildings, protection and conveyors, designing and preparatory expenses, running-in-period expenses, training of staff, interest on capital layout until returns begin, fees of all kinds, etc. In many cases laboratory facilities will not be included in the irradiation plant investment if it is felt that the new sector may draw as much as required on existing laboratory services, but strictly speaking this gives no correct economic picture, because requirements may be quite disproportionate, compared to sectors much more routinely run.

INVESTMENT CALCULATION EXAMPLE

Every project has its own problems and characteristics; it is useful therefore to illustrate the principles for setting up estimates; it is of less general value to go into the details of any particular establishment.

Assume that the type and capacity of equipment has been decided upon, and that the total investment is found to be $750 000. Before this stage is reached, of course, a number of similar calculations will have been made for various types of plant to provide the necessary basis for the final choice. With an accelerator plant as illustration, a realistic breakdown of an investment account may then be as follows. The percentages apply to medium-powered plants only and must be corrected as and when machinery with much higher output is developed.

In the case of a cobalt facility, the specification details will be somewhat different; especially the source investment may be timed according to actual requirement but, on the whole, the investment estimate will follow a very similar pattern.

SALES PROGNOSIS

However difficult, the best possible sales prognosis for a number of years must be set up, and its inherent factors and assumptions analysed and judged as carefully as possible. Close scrutiny often leads to considerable adjustments of first expectations.

It should be specified clearly which products are expected to become of major importance, whether the production capacity within geographical reach is sufficiently high; whether there is, within commercial reach, a sufficient buying capacity for the finished products, how much effort must be put into sales promotion, etc. Especially the latter point may often be underestimated.
TABLE II. INVESTMENT ITEMS

<table>
<thead>
<tr>
<th>Item</th>
<th>Percentage of total investment (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>I. Accelerator with attachments</td>
<td>45 - 55</td>
</tr>
<tr>
<td>Including:</td>
<td></td>
</tr>
<tr>
<td>Purchase price</td>
<td></td>
</tr>
<tr>
<td>Freight, packaging, insurance, local transport</td>
<td></td>
</tr>
<tr>
<td>Erection staff (local and other); outfit and expenses</td>
<td></td>
</tr>
<tr>
<td>Stock of spare parts</td>
<td></td>
</tr>
<tr>
<td>II. Land and site work</td>
<td>5 - 10</td>
</tr>
<tr>
<td>Including:</td>
<td></td>
</tr>
<tr>
<td>Land purchase</td>
<td></td>
</tr>
<tr>
<td>Connections to roads and utilities</td>
<td></td>
</tr>
<tr>
<td>Drainage, sewage, roads and earthwork</td>
<td></td>
</tr>
<tr>
<td>Fencing, green areas</td>
<td></td>
</tr>
<tr>
<td>III. Buildings and shielding</td>
<td>10 - 15</td>
</tr>
<tr>
<td>Including:</td>
<td></td>
</tr>
<tr>
<td>Structures and other civil engineering work</td>
<td></td>
</tr>
<tr>
<td>Heating, sanitary and light installations</td>
<td></td>
</tr>
<tr>
<td>Exhaunts with stacks and cooling plant, with decalcination</td>
<td></td>
</tr>
<tr>
<td>Steel doors and other shielding accessories</td>
<td></td>
</tr>
<tr>
<td>IV. Equipment</td>
<td>10 - 15</td>
</tr>
<tr>
<td>Including:</td>
<td></td>
</tr>
<tr>
<td>Conveyors, cranes, trucks, racks</td>
<td></td>
</tr>
<tr>
<td>Power supply</td>
<td></td>
</tr>
<tr>
<td>Instruments for dosimetry, supervision, recording, etc.</td>
<td></td>
</tr>
<tr>
<td>V. Sundry expenses</td>
<td>20 - 25</td>
</tr>
<tr>
<td>Including:</td>
<td></td>
</tr>
<tr>
<td>Laboratory and office furnishing</td>
<td></td>
</tr>
<tr>
<td>Architect, engineer and special consultants</td>
<td></td>
</tr>
<tr>
<td>General preparation and supervision, travelling, running-in</td>
<td></td>
</tr>
<tr>
<td>Legal, financial, Insurance and other overheads</td>
<td></td>
</tr>
<tr>
<td>Non-specified expenses</td>
<td></td>
</tr>
</tbody>
</table>

Regarding food products, it may safely be said that the quantities marketed are quite beyond comparison with all other products that might possibly be radiation-processed. However, in actual practice, market prospects for food depend in particular upon a number of widely different and so far more or less uncontrollable factors. Because of these
problems, food irradiation will, in many cases, probably be started as a side issue, at plants which have been erected primarily for other purposes. In the industrial economy calculations, food must then be handled in line with other products. Later, with specially designed and dimensioned plants working three shifts a day, calculations will be different, and minimum processing costs will be reached.

COMMERCIAL STRUCTURE OF THE MARKET

If a manufacturer intends to start an irradiation facility for processing his own products, he will probably have few or no new problems in respect to the commercial structure of the market. The position becomes quite different in the case of a multi-purpose service facility.

In many countries a large proportion of the trade in, for example, meat and many vegetables, is concentrated in a number of large undertakings; thus, few contacts cover a turnover of large quantities. For low-priced bulk commodities, like potatoes, transport is a heavy price factor. For grain disinfection, there seem to be indications that irradiation treatment must be given at the site of the silo as soon as the scale of laboratory experiment is passed.

The pasteurization of low-priced fresh fish presents an interesting structural problem, because this trade has very definitely concentrated on developing the quickest possible handling of product from ship to consumer; the introduction of a new phase in this carefully detailed process involves changes at many points.

Certain products are traditionally made and/or marketed through a large number of firms many of which are comparatively small. Examples in Denmark are dairy and bakery products for which there is approximately one firm per one thousand inhabitants. It is obvious that, to get an industrial plant going successfully, commercial considerations are certainly as decisive as many technical or scientific ones.

RUNNING BUDGET

Below, the author gives a more or less typical calculation example, and then shows how variations in various assumptions can influence cost figures. It is essential that any practical case should be budgeted on its own merits, because several factors may cause the ultimate cost prices to be higher or lower than those indicated here as a general type.

Assume that, as our basic estimate assumptions, the facility in question is processing 1800 kg/h, with a dose of 1 Mrad (whatever the purpose of the irradiation may be), and that this production runs for five consecutive years, in periods of 1000, 2000, 3000, 4500, and 6000 h. Thus, the "average calculation year" amounts to 3300 h. The investment, excluding land and buildings, is to be written off by 100% during this five-year period, in accordance with very common practice for highly advanced equipment in industry. The annual expenses can be assessed as shown in Table III.
TABLE III. BUDGET OF ANNUAL EXPENSES

<table>
<thead>
<tr>
<th>Expense items</th>
<th>Amount ($)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>I. Financial</strong></td>
<td></td>
</tr>
<tr>
<td>Including:</td>
<td></td>
</tr>
<tr>
<td>Depreciation by 20% p.a. on $650,000:</td>
<td>$130,000</td>
</tr>
<tr>
<td>Interest, 8% p.a. on average investment of $490,000:</td>
<td>Approx: $40,000</td>
</tr>
<tr>
<td></td>
<td>$170,000</td>
</tr>
<tr>
<td><strong>II. Other fixed</strong></td>
<td></td>
</tr>
<tr>
<td>Including:</td>
<td></td>
</tr>
<tr>
<td>Technical staff</td>
<td>80,000</td>
</tr>
<tr>
<td>Office staff, and other</td>
<td></td>
</tr>
<tr>
<td>Property maintenance, and other</td>
<td></td>
</tr>
<tr>
<td>Insurance and other overheads</td>
<td></td>
</tr>
<tr>
<td></td>
<td>80,000</td>
</tr>
<tr>
<td><strong>III. Variable</strong></td>
<td></td>
</tr>
<tr>
<td>Including:</td>
<td></td>
</tr>
<tr>
<td>Workers' wages (gross)</td>
<td></td>
</tr>
<tr>
<td>Maintenance and spare parts</td>
<td></td>
</tr>
<tr>
<td>Auxiliary materials</td>
<td></td>
</tr>
<tr>
<td>Laboratory materials</td>
<td></td>
</tr>
<tr>
<td>Utilities</td>
<td></td>
</tr>
<tr>
<td>Specialist assistance</td>
<td></td>
</tr>
<tr>
<td></td>
<td>150,000</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>$400,000</td>
</tr>
</tbody>
</table>

a) This gives an approximate cost of $120/h and €6½/kg.

PRODUCTIVITY

Actual productivity is decided by factors like scanning accuracy and homogeneity, penetration loss, variations in product weight and flow, equipment stability, reprocessing percentage and many others.

Typical figures of utilization for production in well-planned plants are 35-60% for accelerators and 15-25% for isotope facilities. In extreme cases, utilization may be considerably higher, or, which occurs more often, much lower.

Productivity variations

Variations in productivity, in utilization and throughput at the same plant will influence the running expenses per hour very little, resulting in probable considerable unit-rate differences. In Table IV various utilization percentages are compared.

Productivity tends to be low for many experiment productions and for other processes with special requirements.
### TABLE IV. PRODUCTIVITY VARIATIONS

<table>
<thead>
<tr>
<th>Utilization (%)</th>
<th>Production (kg/h)</th>
<th>Cost/kg at 1 Mrad dose ((£))</th>
</tr>
</thead>
<tbody>
<tr>
<td>35</td>
<td>1300</td>
<td>9-10</td>
</tr>
<tr>
<td>50</td>
<td>1800</td>
<td>6(\frac{1}{2}) a)</td>
</tr>
<tr>
<td>60</td>
<td>2200</td>
<td>5-6</td>
</tr>
</tbody>
</table>

\(\text{a)}\) As in Table III.

Costs at different dose levels

With good accuracy processing with higher or lower doses costs proportionately, although extremes must be judged separately. Typical figures, for ready reference, are shown in Table V.

### TABLE V. DOSE VARIATIONS

<table>
<thead>
<tr>
<th>Dose (Mrad)</th>
<th>Cost ((£/kg)) at 50% utilization</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.1</td>
<td>1 - 1</td>
</tr>
<tr>
<td>0.5</td>
<td>3 - 4</td>
</tr>
<tr>
<td>1.0</td>
<td>6(\frac{1}{2}) a)</td>
</tr>
<tr>
<td>2.5</td>
<td>16 - 17</td>
</tr>
<tr>
<td>4.5</td>
<td>30</td>
</tr>
</tbody>
</table>

\(\text{a)}\) As shown in Table III.

Continuous maximum utilization

Compared with other industrial calculations, irradiation plants show rather low variable expenses and exceptionally high fixed ones. The economy will therefore be tangibly improved if a plant can be utilized at 6000 h top capacity from the very beginning. In Table VI can be seen an abridged budget, using a dose of 1 Mrad, with an output of 1800 kg/h.

Prolonged depreciation period

In Table VII are shown calculations for a plant operating at 6000 h/yr with depreciation extended to 10 yr.

It should be realized that the situation described, a full three-shift production, running from starting date, and with few changes throughout...
TABLE VI. CONTINUOUS MAXIMAL UTILIZATION

<table>
<thead>
<tr>
<th>Expense items</th>
<th>Amount ($)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Financial</td>
<td>170 000</td>
</tr>
<tr>
<td>Other fixed (slightly increased)</td>
<td>90 000</td>
</tr>
<tr>
<td>Variable (more or less proportional)</td>
<td>170 000 - 270 000</td>
</tr>
<tr>
<td><strong>Total a) (for 6000 h)</strong></td>
<td>430 000 - 530 000</td>
</tr>
</tbody>
</table>

a) This gives an approximate cost of $72 - 88/h, or £ 4-5/kg at 1 Mtrad.

TABLE VII. LONG DEPRECIATION PERIOD

<table>
<thead>
<tr>
<th>Expense items</th>
<th>Amount ($)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Financial</td>
<td>100 000</td>
</tr>
<tr>
<td>Other, fixed</td>
<td>90 000</td>
</tr>
<tr>
<td>Variable a)</td>
<td>170 000 - 270 000</td>
</tr>
<tr>
<td><strong>Total b) (for 6000)</strong></td>
<td>360 000 - 460 000</td>
</tr>
</tbody>
</table>

a) As shown in Table VI.
b) This gives an approximate cost of $60-77/h or £ 3½ - 4/kg.

10 calendar years is, perhaps, not very characteristic of a normal industrial case. Under better conditions regarding utilization, annual hours, etc., figures can be lower.

AN OPTIMAL MARKET

This paper is mainly based upon the multi-purpose plant in Denmark, the author being of the opinion that, on the whole, similar conditions elsewhere will naturally lead to like reasoning and hence to the same economic calculations, a highly flexible plant being preferable to a very specialized one having specific properties for one article.

However, as mentioned, for large-scale uniform production, a highly-specialized facility is preferable. Presumably, then, general business assumptions will be different also from those of a multi-purpose concept, and this may be as important as technical considerations.
Many experts have made cost-rate budgets based on a combination of remarkably advantageous assumptions, and have then arrived at cost-rates much lower than those previously indicated in this paper. Such ultra-low-cost calculations will nevertheless prove correct in some cases; they outline a programme well worth working for in the irradiation industry.

Below is an example typical of an optimal market case. The figures are drawn mainly from studies made by the company supplying the accelerator for the Danish establishment.

The machine is assumed to be a 50-kW accelerator with energy in the 5-10-MeV region, this energy level being decided not on economic grounds, but on the actual permit situation, and the products to be a type suited for treatment by an unconverted electron beam, that is, not "heavy-weight" but "medium" goods. Take 6000 annual production hours as a basis for calculation, not the theoretical year's total of 8766 h, but assuming a three-shift production to run continuously from the beginning.

If the dose is 1 Mrad and utilization 50%, there will be an annual turnover of 55 million kg (or, comparatively, 550 million kg with a 0.1 Mrad dose).

A machine of this capacity is not expected to cost very much more than machines of lower capacity. For mass production, as suggested here, goods will be no doubt uniform, and handling and conveyors will be arranged as a direct extension of other production-line handling. With a standardized production, laboratory and management expenses will be quite low. Here, then, high flexibility has been replaced by high specialization, contrary to the position in Denmark.

The investment budget is estimated to be somewhat higher than the sum of $750,000 mentioned as an investment calculation example, but it is still under $1 million. It is emphasized that a 5-yr amortization period is maintained in any case.

The total running expenses for the year would naturally be higher than those for a plant of medium effect but the cost price per kilowatt of beam effect would be low. It is estimated that the cost rate would drop to $1.17/Mrad kg, a reduction that means a multiplication of fields of application.

CONCLUSIONS

Until permits are issued more freely, it is probable that pilot processing of foodstuffs must be done in multi-purpose irradiation plants, or plants directly intended for purposes other than food. This, however, does not present particular difficulties, because the processing of food products can, in many cases, be performed according to similar routines and economic calculations as other irradiation processes.

Each project must be carefully judged on its own merits, the estimates drawn according to normal industrial methods, and combined with a detailed sales prognosis. Unless an irradiation facility is intended to work mainly for an industrialist's own purposes, attention must be given to the structure and peculiarities of the expected market. As with other very advanced industrial techniques, the investment should be written off over a fairly short range of years.
It will probably be simpler to start first of all with low-dose processes, as permits appear more easy to obtain, chemical problems are minimized, and the cost price per kilogramme is naturally lower than that in sterilization processes.

The author is of the opinion that a good beginning can soon be made, at least on a pilot-process scale, thus enabling industry to judge where efforts to introduce the new technique on a large scale should be most profitably concentrated. The new Danish industrial irradiation company is hopeful of providing for a number of different industrial productions, including food-processing.
LEGISLATION AND CLEARANCES OF IRRADIATED FOOD

(Session IX)
SIMPLIFIED PROCEDURES FOR OBTAINING CLEARANCES OF FOODS PRESERVED BY IONIZING ENERGY

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UNITED STATES ARMY NATICK LABORATORIES, NATICK, MASS., UNITED STATES OF AMERICA

Abstract — Résumé — Аннотация — Resumen

SIMPLIFIED PROCEDURES FOR OBTAINING CLEARANCES OF FOODS PRESERVED BY IONIZING ENERGY. After thirteen years of intensive research, using high doses of ionizing energy, highly acceptable wholesome shelf-stable bacon, ham, pork, beef, chicken and shrimp can be produced in the laboratory. Using doses below 1 Mrad, the shelf life of highly acceptable wholesome fish, wheat and wheat products, oranges, and white potatoes can be extended. Before production in the United States can be scaled up to commercial quantities for the broad consumer market, approvals are required from the United States Food and Drug Administration (USFDA) and, for meats from mammals and birds, from the United States Department of Agriculture (USDA). These agencies have approved bacon, wheat and wheat products, and white potatoes, following receipt and evaluation of petitions containing all pertinent information including description of the process to be used and the food-package combination to be cleared, the proposed radiation source, the dose range, dosimetry methods, wholesomeness and nutritional data, positive proof of microbiological safety, absence of measurable induced radioactivity, acceptance data from taste panelists, and storage and shipping data where applicable.

Collecting the data required for successful petitions has proved to be both time-consuming and expensive. To improve this situation, the whole process of data collection and of writing the petitions is being re-examined in the interest of streamlining and expediting the process. Recommendations are offered relative to some of the means helpful in achieving this end.

PROCéDURES SIMPLIFIEES POUR OBTENIR L'AUTORISATION DE PRODUIRE DES DENREES ALIMENTAIRES CONSERVÉES PAR LES RAYONNEMENTS IONISANTS. Après treize ans de recherches intensives au moyen de fortes doses de rayonnements ionisants, il est maintenant possible de produire en laboratoire des denrées – lard, jambon, viande de porc et de boeuf, poulet, crevettes – se conservant bien et de comestibilité tout à fait satisfaisante. En utilisant des doses inférieures à 1 Mrad, il est possible de prolonger la durée de conservation du poisson, du blé et dérivés, des oranges et des pommes de terre à chair blanche, la comestibilité de ces denrées étant tout à fait satisfaisante. Aux États-Unis, pour développer la production de ces denrées dans des proportions suffisantes pour alimenter le marché, il est nécessaire d'obtenir l'autorisation du Service de contrôle des produits alimentaires et pharmaceutiques et, pour les viandes de mammifères et de volatiles, celle du Département de l'agriculture. Ces institutions ont approuvé la mise sur le marché de lard, de blé et dérivés et de pommes de terre à chair blanche, après réception et examen de demandes contenant tous les renseignements pertinents, notamment la description du procédé d'irradiation et de conditionnement à faire accepter, la source de rayonnements proposée, la dose, les méthodes de dosimétrie, les données relatives à la comestibilité et à la valeur nutritive, la preuve positive de l'innocuité microbiologique, l'absence de radioactivité induite mesurable, le certificat d'acceptation d'un groupe de dégustateurs et, s'il y a lieu, les données relatives à l'emmagasinage et à l'expédition.

Le rassemblement des données nécessaires aux demandes d'autorisation s'est révélé à l'usage long et coûteux. Pour remédier à cet inconvénient, on étudie actuellement les moyens de simplifier et d'accélérer le rassemblement des données et la rédaction des demandes. L'auteur présente des recommandations touchant certaines des méthodes qui permettraient d'arriver à ce résultat.

УПРОШЕННАЯ ПРОЦЕДУРА ПОЛУЧЕНИЯ РАЗРЕШЕНИЙ НА ПРОДАЖУ ОБЛУЧЕННЫХ ПИЩЕВЫХ ПРОДУКТОВ. После тринадцати лет интенсивных исследований с применением больших доз ионизирующей энергии в настоящее время в лаборатории можно получить следующие продукты высокого качества, не портящиеся при длительных сроках хранения: бекон, ветчину, свинину, куры и креветки. Используя дозы меньше 1 Мрад, можно значительно увеличить сроки хранения таких продуктов, как рыба, пшеница, мучные продукты, апельсины и белый картофель, без ущерба для их качества и пригодности употребления в пищу.
того, чтобы начать производство таких облученных продуктов в США в широких коммерческих масштабах потребуются специальные разрешения от Управления по пищевым продуктам и медикаментам США, а в случае мяса млекопитающихся и птицы — от Министерства сельского хозяйства США. Эти учреждения уже разрешили продажу облученного бекона, пшеницы, мучных продуктов и белого картофеля после получения и рассмотрения ходатайств, содержащих все необходимые сведения, включая описание процесса обработки, тары и упаковки, предлагаемых источников излучения, диапазон доз, методы азиметрии, данные о пригодности употребления в пищу и о содержании питательных веществ, доказательства микробиологической безопасности, отсутствие заметной наведенной радиоактивности, утверждение дегустаторами, а также, в случае необходимости, данные по хранению и транспортировке.

Сбор подобных данных, необходимых для принятия ходатайств, требует длительного времени и больших затрат. В целях облегчения и ускорения этой работы пересматривается весь процесс сбора данных и составления ходатайств. Дается соответствующие рекомендации.

SIMPLIFICACION DE LOS PROCEDIMIENTOS PARA LA OBTENCIÓN DE AUTORIZACIONES DE VENTA DE ALIMENTOS CONSERVADOS MEDIANTE RADIACIONES IONIZANTES. Después de trece años de investigaciones intensivas con aplicación de elevadas dosis de radiaciones ionizantes se ha logrado prolongar considerablemente en laboratorio el período de conservación de productos tales como el tocino, el jamón, la carne de cerdo, los pollos y los mariscos, sin que pierdan su comestibilidad. Aplicando dosis inferiores a 1 Mrad puede prolongarse el período de conservación del pescado, del trigo y sus derivados, de las naranjas y de las patatas blancas en condiciones de comestibilidad plenamente satisfactorias. En los Estados Unidos, antes de pasar a la producción en escala comercial para lanzar el producto al mercado, es preciso obtener la aprobación de la United States Food and Drug Administration (USFDA) y, en lo que se refiere a las carnes de mamíferos y de aves, del United States Department of Agriculture (USDA). Estos organismos han dado su aprobación para productos como el tocino, el trigo y sus derivados, y las patatas blancas, después de recibir y examinar peticiones acompañadas de toda la información pertinente: procedimiento que se aplicará, descripción del conjunto alimento-envase objeto de la petición, fuente radiactiva que se va a emplear, orden de magnitud de la dosis, métodos de dosimetría, datos sobre comestibilidad y valor nutritivo, pruebas positivas de seguridad microbiológica, ausencia de radiactividad inducida detectable, datos de aceptación obtenidos por grupos de catadores y, cuando proceda, datos referentes al almacenamiento y transporte.

La reunión de todos los datos necesarios para que se apruebe la petición exige mucho tiempo y resulta costosa. Para remediar esta situación se está revisando todo el proceso de acopio de datos y de presentación de peticiones a fin de hacerlo más expedito. En la memoria formulan sugerencias sobre los medios más apropiados para lograr este fin.

After fourteen years of intensive research using high doses of ionizing energy, highly acceptable, wholesome, shelf stable bacon, ham, pork, beef, chicken, and shrimp can be produced in the laboratory (1). By using doses below 1 megard, the storage life of highly acceptable, wholesome onions (2), fish (3), wheat and wheat products (4), white potatoes (5), strawberries (6), and other fruits and vegetables can be extended (2). Before production in the United States can be scaled up to commercial quantities for the broad consumer market, approvals are required by the U. S. Food and Drug Administration (FDA) and, in addition, for meats and meat products from cattle, sheep, swine, goats, horses, reindeer, poultry and domestic rabbits, by the U. S. Department of Agriculture (USDA).

Although considerable reliance for maintaining high safety and sanitary standards for foods is placed upon voluntary self-policing by the food processing industry, U. S. Government control of foods processed by ionizing energy is based upon the following three statutes:

1. The Federal Food, Drug and Cosmetic Act, administered by FDA of the U. S. Department of Health, Education and Welfare (HEW). This act applies to all food products entering into interstate commerce including those derived from wild animals, fish, and game (7). The
Food Additives Amendment of 1958 to the Federal Food, Drug, and Cosmetic Act (b) "includes regulation of any source of radiation intended for treatment of foods and deems intentionally irradiated foods to be adulterated unless such use of radiation has been cleared for safety by regulation or unless an exemption has been granted for research purposes." Specifically, the amendment to the law defines "food additives" to mean "*** any substance the intended use of which results or may reasonably be expected to result, directly or indirectly, in its becoming a component or otherwise affecting the characteristics of any food (including any substance intended for use in production, manufacturing, packing, processing, preparing, treating, packaging, transporting, or holding food; and including any source of radiation intended for any such use) ***".

The statute sets up procedures for petitioning FDA to issue regulations permitting under specified conditions the use of food additives such as ionizing energy. Title 21, U. S. Code Section 348 states: "(b) (1) Any person may, with respect to any intended use of a food additive, file with the Secretary (of HEW) a petition proposing the issuance of a regulation prescribing the conditions under which such an additive may be safely used. (2) Such petition shall, in addition to any exploratory or supporting data, contain:

A. The name and all pertinent information concerning such food additive, including where available its chemical identity and composition;

B. A statement of the conditions of the proposed use of such additive, including all directions, recommendations and suggestions proposed for the use of such additive, and including specimens of its proposed labeling;

C. All relevant data bearing on the physical or the technical effect such additive is intended to produce, and the quantity of such additive required to produce such effect;

D. A description of practicable methods for determining the quantity of such additive in or on food, and any substance formed in or on food, because of its use; and

E. Full reports of investigations made with respect to the safety for use of such additive, including full information as to the methods and controls used in conducting such investigations."

The data in the petition should serve as convincing evidence that the food treated with ionizing energy is safe for human consumption, the desired effect of radiation is accomplished, the irradiation dose used is not higher than reasonably needed, no measurable induced radioactivity (above background level) is present in the food when it enters distribution channels, and the process is safe and efficacious under reasonably simulated commercial conditions without significant deleterious effects in flavor, odor, texture, or appearance of the product.

2. The Federal Meat Inspection Act (9), administered by the Consumer and Marketing Service, USDA, is "for the purpose of preventing the use in interstate or foreign commerce ...... of meat and meat food products which are unsound, unhealthful, unwholesome, or otherwise unfit for human food ......". The statute applies to cattle, sheep, swine and goats and edible products derived from them. The USDA's responsi-
bility begins with approval of plans to construct a new meat processing plant or remodelling an existing plant. The USDA inspectors supervise each stage of meat processing from the live animals in holding pens to the finished product. If ionizing energy is contemplated in processing meats for interstate or foreign commerce, its use must be approved by USDA. The list of animals covered in the basic statute has been extended by the Horse Meat Act of 1919 to horses and the Agricultural Marketing Act of 1946 to reindeer. Based upon requests sufficiently supported by scientific back-up data, the USDA will issue regulations approving the use of ionizing energy for meat processing. The evidence contained in the request for approvals must include data pertaining to wholesomeness, microbiological safety, absence of toxicity, nutritional adequacy, control of the processing, labeling and benefits.

3. Poultry Products Inspection Act of 1957, administered by the Consumer and Marketing Service of USDA "requires inspection for wholesomeness of all poultry processed at plants shipping any of their product in interstate or foreign commerce" (10). Poultry is defined in the Poultry Products Inspection Act of 1957 as "any live or slaughtered domesticated bird", including, but not being limited to chickens, turkeys, ducks, geese and guineas. The USDA is also responsible for inspection and grading of shell eggs, egg products and domestic rabbits (11). Use of ionizing energy in processing plants coming under the jurisdiction of the Poultry Products Inspection Act is permitted through issuance of regulations by USDA. The authority of USDA extends to the approval of floor plans for the processing plant, suspension of operations if alterations of buildings, facilities, and equipment have not been approved and to control of all operations and procedures involved in preparation, storage, or handling of any product to assure conformity to standards of cleanliness and sanitation. Labeling approved by USDA is also required for poultry products which have been treated with compounds to retard spoilage (12).

It is apparent that the petitioner has a formidable task in satisfying the many stringent requirements written into the statutes to obtain approval of the use of ionizing energy for preserving foods. Yet the task is not insuperable as attested by the fact that ionizing energy has been approved in the Soviet Union, Canada and the United States to inhibit sprouting of white potatoes, in Canada to inhibit sprouting of onions, and in the United States to deinfest wheat and wheat products and to produce shelf stable canned bacon.

It can be argued on purely scientific grounds that the use of ionizing energy to preserve food requires no special legislation. The reality of the situation is that a considerable segment of the population -- call it public opinion -- supports such legislation, and would effectively oppose eliminating such statutes from the books. Raising such a controversial issue could make the public apprehensive when it hears conflicting views expressed in testimony by the experts. The result of this controversy could adversely affect the market for irradiated foods. Instead of fighting the problem, the recommended approach is to complete the collection of the scientific evidence in support of petitions to clear a wide variety of foods. As more and more foods processed by ionizing energy receive approval, fewer and fewer foods will remain banned by the specialized legislation. Ultimately, no major foods or classes of foods amenable to preservation by ionizing energy will remain restricted under the special legislation. Also, as commercial experience with the processing of foods by ionizing energy becomes more and more widespread, the confidence of consumers, legis-
How can the petitioning process be simplified and streamlined?

In those countries where legislation pertaining to foods preserved by ionizing energy is not yet on the books, it is recommended that authority be vested in a single agency to administer laws on this subject. This defines clearly for the petitioner where the authority lies and minimizes the time, effort, and possible confusion if he is required to deal with several independent governmental agencies. I hasten to add that in the United States petitioners such as the Army, after some trial and error, have finally learned how to cope with the dual responsibility of FDA and USDA. We have ascertained that the supporting data required by these agencies is essentially the same since both have the same objective to protect the consumer. Therefore, in the case of future requests for clearances, we will submit the same petition to both agencies.

Since the data embodied in petitions requires years of research and significant expenditure in money and manpower, it is recommended that the regulatory agency establish as clearly as possible at the outset reasonable requirements for the breadth and depth of the scientific data it will require in petitions. This may be difficult to achieve initially when there is no precedent and where the irradiation process is so new that there is little in the way of prior experience to serve as guidance. In the United States, FDA at the request of the Army and Atomic Energy Commission has set general guidelines for animal feeding experiments to determine wholesomeness, for inoculated pack studies to determine microbiological safety, and for extractive studies to assess the suitability of flexible packaging. These guidelines serve as the basis for preparing detailed experimental protocols which in many instances, particularly with inoculated pack studies, are coordinated informally with responsible officials of FDA and USDA before commencing research. In this way the petitioner is able to see a finite end to the research needed to attain his objectives and can allocate his money, personnel, and time accordingly. FDA approved guidelines and research protocols used in the Army's program can be made available to the International Atomic Energy Agency/Food and Agriculture Organization of the United Nations (IAEA/FAO) for distribution to regulatory bodies of member countries.

Since the application of ionizing energy to preserve foods is still in its infancy, it is recommended that government regulating bodies adopt a flexible attitude toward their requirements for data in petitions as circumstances change. This flexibility can work either in the direction of tightening or loosening requirements. For example, if a food or packaging material can be cleared, the regulating agency could require fewer supporting data for a closely related food or material, or waive requirements altogether for further testing and grant a blanket clearance by class. On the other hand, if unexplained anomalies occur, the regulating agency may require more exhaustive testing than originally anticipated. Only under extenuating circumstances should regulating agencies change requirements or impose new ones in midstream.

Upon request the regulating agency should be willing to advise the petitioner during the process of data gathering. During the years of laborious accumulation of data, common sense or good judgment may lead the petitioner to modify his experimental protocols, or give greater or lesser emphasis to one or more facets of his research effort. He could also encounter seemingly insurmountable roadblocks; objectives may
change as circumstances change. In such cases, the regulatory agency should be amenable to giving advice informally to the petitioner. This advice could materially foreshorten the data gathering cycle. As a corollary to assistance during the data gathering cycle, the regulating agency should also be willing, upon request, to advise the petitioner in the preparation of the petition. In the United States, officials of FDA and USDA have always responded willingly and given unstintingly of their time to requests by the Army for advice and guidance during the period of data gathering and petition preparation.

The U. S. Army Medical Service has completed animal feeding studies on 21 foods representing the major food classes consumed in the United States. As a result of these monumental studies begun in 1955, the Army Medical Service has concluded that "foods irradiated up to absorbed doses of 5.6 megarads with a cobalt 60 source of gamma radiation or with electrons with energies up to 10 million electron volts have been found to be wholesome; i.e. safe, and nutritionally adequate (13)." The U. S. Atomic Energy Commission's animal feeding studies on fish, shellfish, fruits and vegetables have not uncovered a single deleterious finding in any animal which can be attributed to consumption of a food preserved with ionizing energy (14). As far as can be foreseen at present, there will be only minimal needs in the future for further wholesomeness testing by the Army (15). Because of the overwhelming cumulative evidence from animal feeding studies on the wholesomeness of foods treated with ionizing energy it is recommended that, except for irradiating fresh fruits and vegetables prior to maturation (e.g. bananas), regulating agencies require only absolutely essential additional feeding experiments. An annotated bibliography of all the previous feeding studies has been published (16).

The question of standards of safety from a microbiological standpoint of foods preserved by ionizing energy is still unresolved. Where the objective is to achieve shelf stable food products, the organism of primary concern is Clostridium botulinum. For want of a better standard, we use the 12-D concept - to reduce a Clostridium botulinum spore population by a factor of 10 to the 12th power (10^{12}). As knowledge increases on the natural occurrence of botulinal organisms in raw foods, and their susceptibility to irradiation, it may be possible to modify this standard. To this end, a special task group has been formed under the auspices of the National Academy of Sciences -- National Research Council (NAS-NRC) to recommend standards for microbiological safety for foods made shelf stable by ionizing energy. It is recommended that IAEA/PAO serve as a focal point for compilation of world-wide data of the natural occurrence of Clostridium botulinum in raw foods, and its susceptibility to irradiation. These data will serve as valuable inputs to the study under way by the NAS-NRC task group and could streamline the effort and reduce costs in experiments to determine the minimum required radiation doses for individual shelf stable foods.

The petition cycle can be simplified and shortened if regulating agencies establish timetables to which they will adhere for review of petitions and rendering decisions. In the United States, FDA's timetable is normally to decide within two weeks from the date of receipt of a petition either to accept it for filing or to return it to the petitioner. FDA's timetable calls for ninety days from the date of acceptance of a petition for filing to rendering a decision. If ninety days are insufficient, FDA has the option of extending the examination period an additional 90 days. When FDA requires additional information from a petitioner, this information at the option of FDA can be considered an.
amendment to the petition. In such cases the countdown can either be suspended until the additional information is received or it reverts back to day number 1 on the 90 or 180 day cycle. The newly appointed commissioner of FDA has publicly stated in response to a question concerning alterations in procedures to evaluate petitions or in enforcement activities that he is studying this matter and expects "to speed up action, and will take whatever measures are required to achieve this" (17).

Since evaluation of petitions often requires study by individuals in the several fields of science, action could become bogged down as the petition passes from group to group and office to office. It is suggested that regulating agencies consider the project manager system which has worked so well in the Department of Defense and assign a project officer for each petition. It would be the responsibility of the project officer to see that the petition is evaluated and a regulation issued at the earliest date following its receipt.

There is much that the petitioner can do to assist in streamlining and shortening the petition process.

First, the petitioner has an obligation to keep the regulating bodies informed of the status of his research. The ability of a regulating body dealing with the new field of preserving foods by ionizing energy to perform its statutory duties is influenced by the knowledge it has in this field. Since the regulating agency does not generally conduct extensive research in the area it must regulate, it depends upon and learns from the research findings of potential petitioners. It behoves petitioners in their own self-interest to keep open the channels of communication with officials of governmental regulating bodies, invite them to participate in meetings, conferences, and symposia, give them the opportunity to taste-test candidate foods for clearances, keep them abreast of research timetables and anticipated dates to submit petitions, and make them aware of both progress and temporary setbacks. By such actions the prospective petitioner can understand the requirements as well as the thinking of the officials of regulating agencies and can respond intelligently.

Secondly, the petitioner should apprise regulating officials of major findings and other data as they unfold. These actions alert the regulating agencies and condition them to respond favorably and more rapidly when petitions are officially submitted. Often a number of diverse groups, based upon varying scientific disciplines required to evaluate data in a petition, are involved in passing on a petition. Their reaction times will be reduced to the extent they are brought abreast of the most recent significant findings. It is incumbent upon the petitioner to take the initiative in preparing and seeking advice and informal concurrence of officials of regulating agencies a priori in proposed protocols for major time consuming and costly experiments. It is certainly recommended that he prepare drafts of his proposed protocols and discuss them with the very officials who will later pass judgment on his petition. We have found this to be one of the most important facets in planning ahead in areas requiring major research.

In the process of coordinating research protocols with officials of regulating agencies and keeping them informed, the petitioner should use discretion lest he burden these officials unnecessarily. He should use good judgment to avoid consuming the time of these officials with the less important aspects of his problems. He should refrain from making
repetitive requests to reconsider, review, or reopen matters (such as proposed research protocols) which have previously been decided.

Most important of all the duties and obligations of the petitioner is to earn the confidence of regulating agencies in his scientific competency and integrity. In this new method for food preservation, the petitioner may be much more knowledgeable about the application of ionizing energy than those who will sit in judgment. If the petitioner has earned the confidence of members of regulating bodies, they will be more receptive to his requests, proposals and to the ultimate petition. There is no substitute for competency and integrity on the part of the petitioner! There is no better way to get a petition approved faster than to have the work done by the most competent and honorable investigators.

There is a final recommendation I can make to this international audience — that the IAEA/FAO serve as a clearing house for all petitions approved by regulating bodies of any nation. This would involve a massive job in reproduction for members of the United Nations. I believe, however, that the benefits to all mankind far transcend the burden I would like to see IAEA/FAO assume. By bringing to the attention of the scientific community all the information contained in these petitions, much time and money can be saved and needless duplication in research can be minimized, thus materially shortening the lead time and streamlining the entire petitioning process.

The salient points can be summarized as follows:

1. The scientific feasibility of the process to preserve foods with ionizing energy has been demonstrated.

2. To establish this process on a commercial basis will require approvals by governmental regulatory bodies of petitions, supported by adequate evidence, requesting exemptions to legal prohibitions where they may exist to the use of ionizing energy to preserve foods.

3. For countries which are considering enacting statutes for the control of irradiation of food and food products for human consumption, it is recommended that authority to administer these statutes be vested in a single agency.

4. The time-consuming expensive process of data collecting, writing, and evaluating petitions can be streamlined and expedited if the regulatory agency:

   a. Establishes clearly in advance reasonable requirements for the breadth and depth of the required scientific evidence.

   b. Adopts a flexible attitude as circumstances change, yet not arbitrarily change requirements or impose new ones in midstream.

   c. Is willing, upon request, to advise the petitioner during the course of data gathering.

   d. Is willing, upon request, to assist the petitioner in preparation of the petition.

   e. Establishes and adheres to a finite timetable for passing on petitions and issuing regulations.
f. Considers using the project officer system or similar procedure to expedite handling of petitions from time of receipt to issuance of regulations.

g. Considers granting approvals for groups of foods, food products, and packaging materials once experience has been gained from initial approvals on an individual basis.

h. Places minimal requirements for further animal feeding studies in light of the overwhelming evidence from the U. S. Army's and AEC's studies indicating that irradiated foods are wholesome at doses up to 5.6 Mrads and at electron energies below 10 MeV.

5. The petitioner can simplify the petition process if he:

a. Keeps the regulatory agency informed of the status of his research.

b. Apprises the regulatory agency of major research findings and other evidence as they unfold.

c. Prepares and seeks advice and concurrence of the regulatory agency a priori in proposed protocols involving major time-consuming and costly experiments.

d. Refrains from unnecessarily overburdening officials of regulating agencies with the less important aspects of his problems and with repetitive requests to reconsider, review, or reopen matters previously decided.

e. Earns the confidence of the regulatory agency in his scientific competency and integrity.

6. To expedite the flow of information among member countries, avoid duplication of effort, and simplify and shorten the petition cycle, it is recommended that the IAEA/FAO of the United Nations serve as a clearing house for all petitions approved by regulatory bodies of any nation and accompanying implementing regulations.

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(4) Petition to FDA for clearance of wheat and wheat products treated with ionizing radiation for deinfestation, (approved) 21 Code of Federal Regulations 121.3003.

(5) Petition to FDA for clearance of white potatoes treated with ionizing radiation to inhibit sprouting, (approved) 21 Code of Federal Regulations 121.3003.
DISCUSSION

J. VERGРАGT: I should like to suggest that a deputy project officer be appointed to assist the project officer assigned for each petition.

E.S. JOSEPHSON: Thank you for your suggestion. I agree that it would be helpful for the project officer to be assisted by an assistant or deputy, who would be responsible for the processing of the petition in the absence of his superior. I shall pass this suggestion on to the regulatory bodies in the United States.

A. LAFONTAINE: I feel that the World Health Organization as well as the International Atomic Energy Agency and the Food and Agriculture Organization of the United Nations should take part in a world-wide survey of the incidence of Clostridium botulinum.

E.S. JOSEPHSON: Yes indeed; WHO could also assist the task group of the National Academy of Sciences-National Research Council in formulating recommendations for microbiological standards of safety for radappertized foods.
ISSUING OF REGULATIONS ON THE CLEARANCE OF IRRADIATED FOOD PRODUCTS ON THE BASIS OF FOREIGN PETITIONS

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Abstract — Résumé — Аннотация — Resumen

ISSUING OF REGULATIONS ON THE CLEARANCE OF IRRADIATED FOOD PRODUCTS ON THE BASIS OF FOREIGN PETITIONS. Since the beginning of 1965, Israel has been interested in legal problems on the clearance of irradiated food and in the installation of a food irradiator.

Supervision and control of the irradiation, and distribution of the irradiated products, the applications of relevant laws, or their enactment where none exist, are some points of special importance among those dealt with.

Most legislation now requires that the wholesomeness of irradiated food be proven unequivocably before irradiation and consumption of the food are authorized. Such proof, however, is beyond the means of small, and of developing countries, the very ones which could most benefit from the introduction of irradiation techniques on an industrial scale, since this would increase both the availability of local foods for internal consumption and also export possibilities.

As a test case, on 24 February 1966, a petition was submitted to the Israel Ministry of Health for permission to use, for human consumption, white potatoes which had been irradiated to prevent sprouting. The petition was based not on local work, but on that published abroad, with the request that the wholesomeness tests approved by other governments be accepted as sufficient proof. Another similar petition on the use of irradiated onions will be submitted shortly.

If successful, this procedure could be adopted by other countries and might facilitate international trade agreements. It could be instrumental in the rapid development of the application of irradiation for food preservation in places where it could prove of useful economic value.

PROMULGATION D’UN REGLEMENT REGISSANT L’AUTORISATION DE COMMERCIALISER DES DENRES ALIMENTAIRES IRRADIEES, SUR LA BASE DE DEMANDES FONDEES SUR DES DONNEES ELABOREES A L’ETRANGER. Depuis le début de 1965, Israël s’intéresse aux problèmes juridiques que pose l’autorisation de vendre des aliments irradiés et à l’installation d’un irradiateur.

Parmi les points les plus importants qui font l’objet d’une étude, il convient de citer le contrôle de l’irradiation et de la distribution des produits irradiés, l’application des lois pertinentes et, le cas échéant, la promulgation de dispositions nouvelles.

La plupart des dispositions législatives applicables à l’heure actuelle prévoient que la comestibilité des aliments irradiés doit être démontrée de façon incontestable avant que les autorités puissent permettre l’irradiation et la consommation de ces denrées. Toutefois, une telle démonstration dépasse les moyens des petits pays et des pays en voie de développement, alors que ce sont eux, précisément, qui pourraient tirer les plus grands avantages de l’application des méthodes d’irradiation à l’échelle industrielle, puisqu’elle leur permettrait d’augmenter l’approvisionnement de leur marché intérieur en produits locaux et d’accroître leurs possibilités d’exportation.

A titre d’essai, on a présenté le 24 février 1966 au Ministère israélien de la santé une requête demandant d’autoriser la consommation humaine de pommes de terre à chair blanche préalablement irradiées pour arrêter leur germination. La demande ne se fondait pas sur des études faites en Israël mais sur des recherches publiées à l’étranger; on précisait que les critères de comestibilité approuvés par les gouvernements d’autres États devraient être admis par les autorités israéliennes comme suffisants.

Une autre demande analogue relative aux oignons irradiés sera présentée sous peu.

Si cette procédure réussit, elle pourrait être adoptée par d’autres pays, ce qui faciliterait sans doute la conclusion d’accords commerciaux internationaux. Elle devrait contribuer à une généralisation rapide de l’irradiation pour la conservation des aliments dans les régions où ce procédé peut présenter un intérêt économique.
ПРОЦЕДУРА ПОЛУЧЕНИЯ РАЗРЕШЕНИЙ НА ПРОДАЖУ ОБЛУЧЕННЫХ ПИЩЕВЫХ ПРОДУКТОВ НА БАЗЕ ИНОСТРАННЫХ ХОДАТАЙСТВ. Юридические проблемы, связанные с получением разрешений на продажу облученных пищевых продуктов, стали интересовать Израиль с начала 1965 года, т. е. с момента установки по облучению пищевых продуктов.

Одним из важнейших вопросов, с которыми приходилось сталкиваться, было: наблюдение и контроль за процессом облучения и распределения облученных продуктов, применение соответствующих законов или разработка новых в случае их отсутствия.

Большая часть законодательства, существующего в настоящее время, требует абсолютно подтверждения пригодности употребления тех или иных пищевых продуктов в пищу, прежде чем будет получено разрешение на их облучение и сбыт. Однако такое доказательство пригодности пищевых продуктов не по средствам малым и развивающимся странам, т. е. тем странам, которые могли бы получить наибольшую выгоду от внедрения методов облучения в промышленных масштабах, так как это увеличивало бы количество местных пищевых продуктов для внутреннего потребления и экспорта.

В качестве эксперимента в Министерство здравоохранения Израиля было направлено 24 февраля 1966 года ходатайство о разрешении выпустить на рынок белый картофель, облученный с целью предотвращения прорастания. Ходатайство было составлено не на основании исследовательских работ в Израиле, а на основании данных, опубликованных за границей. В нем содержалась просьба принять в качестве доказательств опыты, одобренные другими правительствами.

Вскоре будет представлено аналогичное ходатайство относительно сбыта облученного лука.

В случае успеха, эта процедура может быть использована и другими странами, что облегчило бы подписание международных торговых соглашений. Это способствовало бы быстрейшему внедрению методов облучения для сохранения пищевых продуктов в тех странах, где это может принести экономическую выгоду.

1. INTRODUCTION

The use of food which has been subjected to irradiation to prolong its conservation is only possible if the legal problems concerning control of irradiation plants and supervision and distribution of the Irradiated products, are solved. At present no laws exist on this subject in most countries [1, 2]. If, therefore, an international agreement is the objective of in-
interested governments and international organizations (FAO, IAEA, WHO),
a way should be found to ensure the adoption of appropriate national regu-
lations which will not differ on important points in the various countries.

Since 1958 legal problems arising from the use of irradiated food have
been discussed at regional meetings, such as the Food and Agriculture
Organization (FAO) European Meeting on the use of Ionizing Radiation for
Food Preservation held at Harwell in November 1958 [1], and at world-
wide meetings, such as the International Conference on Radiation Preser-
vation of Foods, held in Boston, Mass., United States of America, from
27 to 30 Sept. 1964 [3].

In the summary report of the FAO European Meeting at Harwell the
following statement appears: "Indeed, in the absence of sufficient in-
formation on radiation effects on foods, prohibitive legislation against the
use of irradiated foods has been introduced in some countries"

Such a negative attitude, justified at that time, still persists today,
even though much useful information has been published; the attitude of
many governments, however, has taken a more positive trend.

The action of the United Kingdom Ministry of Health in nominating a
Committee on Medical and Nutritional Aspects of Food Policy led to the
appointment, in 1962, of a Working Party "to review the medical and
scientific information available about the effect of irradiation upon food,
including any changes in its nutritive value and the possible hazards to
man that might thereby arise, and to report to the Committee whether this
indicates a need for control, and possibly, the principles which should
govern any official control"

The Report of the Working Party [4] is probably the most complete
review available on the subject and, because of its recommendations, is
a very important contribution to the resolution of legal problems, not only
in the United Kingdom, but also in many other countries.

This complex problem has been discussed for several years – at
Brussels in 1962, at Rome in 1964 – and the discussion is still continuing
[5]. So far, there have been few concrete steps taken to implement inter-
national recognition of irradiated foods authorized by one country, or even
bilateral recognition of authorizations issued in one country which would
permit consumption of the irradiated food in another, importing country.

The authors propose the adoption of a technique the first stage of
which is being tested in Israel: licences for irradiated food granted by one
country would be accepted by other countries on the basis of wholesome-
ness data approved by the first country. If this principle is established it
is hoped that the second stage will be that licences for the wholesomeness
of irradiated foods, issued by the producing country, would be acceptable
by importing countries on the basis of a radiation-sanitary certificate
similar to the phytosanitary certificates now used for international trade
in plants and fresh fruits and vegetables.

2. LEGISLATION IN ISRAEL AND SMALL COUNTRIES

In Israel, interest in these problems became intensified in 1965 with
the development of a wide research programme on food irradiation.

A prerequisite to any legislation on the use of irradiated foods is that
their wholesomeness must be proved in an unequivocal way to independent
Public Health experts of the legislative authorities.
Obviously, such wholesomeness tests require large amounts of money [5], time, and scientific manpower, which are beyond the means of a small country such as Israel, and probably of most countries which lack the necessary facilities and/or experienced personnel.

However, many of the small, and developing, countries are the ones which could benefit most from the introduction of irradiation techniques on an industrial scale. The use of irradiation would (a) increase the availability of locally produced food for internal consumption by preventing spoilage due to inadequate storage transport facilities, climatic conditions and insect damage, and (b) increase export possibilities. Most developing countries, Israel included, are situated in the tropical and subtropical regions of the world, which are favoured by a fairly good climate for crop growing, but which are distant from their export markets. Thus there is a high rate of spoilage during the long trips unless the produce is shipped under refrigeration.

It is at this point that suitable co-ordinated legislation allowing the use and export-import of irradiated food becomes important for the successful commercial development of irradiation techniques.

At present no legislation exists in Israel, or in many other countries, for regulating the use and consumption of irradiated food. The present work is the prototype of a procedure which will be followed in Israel for all subsequent petitions. Therefore importance is attached to the preliminary work for formulation of the problem prior to submission of the petition.

As a test case, it was decided to submit a petition to the Israel Ministry of Health for permission to use, for human consumption, white potatoes which had been irradiated by gamma rays from a cobalt-60 source to prevent sprouting. The petition was not based on wholesomeness work done in Israel, but on that already published abroad, mainly in the United States, Canada, and USSR, with the request that the tests approved by the authorities of these countries be accepted as sufficient proof of wholesomeness.

It was felt that, for any given foodstuff, or group of foodstuffs, wholesomeness data based on fully-documented results in any country suitably equipped to carry out such tests, and accepted as adequate by an independent Public Health Authority of that country, should be sufficiently convincing to be accepted by other national Public Health Authorities; this with the proviso that all the original experimental results obtained in the first country be made available as required by the second country wishing to issue authorization for the particular irradiated foodstuff. In this way, should the health authority of the second country doubt the clarity of some portion of the original data, it could decide that this portion only need be repeated and clarified in its own country before granting authorization.

It was also felt that experimental, or pilot-plant scale tests on the locally grown varieties were necessary to prove that these varieties gave an attractive irradiated product, and that there was sufficient local interest in this irradiated foodstuff to justify examining and approving such a petition.

The petition was officially submitted to the Israel Ministry of Health by the Department of Industrial Applications of the Soreq Nuclear Research Centre on 24 February 1966 [6].

The petition, some of the paragraphs of which were included at the request of the Ministry of Health, contained the following:
(1) Introduction.
(2) General principles of ionizing radiation.
(3) Scope of irradiation.
(4) Description of the process, including particulars on the equipment used.
(5) Dosimetry method.
(6) Influence of gamma radiation on potatoes.
(7) Health aspects of the consumption of irradiated potatoes (wholesomeness). The material in this chapter was presented with an appendix of copies of the corresponding chapters in the petitions presented to the Food and Drug Administration in the United States, to the Food and Drug Directorate in Canada, and to the Central Inspectorate of Public Health in the Soviet Union.
(8) Packing methods and marking of irradiated potatoes.
(9) Extensive bibliography on all published information on irradiated potatoes with special attention to the wholesomeness problem.

Simultaneous to the preparation of the wholesomeness petition, an extensive economic evaluation [7] was made for the Israel economy on the advantage of using irradiation versus cold storage, or chemical additives, to prevent losses of potatoes and onions due to sprouting and spoilage.

The petition was accompanied by the results of experiments made on the locally grown crop. Large-scale irradiation, of the order of many tons of potatoes, was made to implement the available data with direct information on the response of locally grown potatoes to irradiation treatment.

The competent authority, in this case the Israel Ministry of Health, has already appointed a special committee to discuss the petition and to advise on the steps necessary for its approval.

The attitude of the Ministry of Health is to consider irradiated products under the category of food additives and to legislate the use of irradiated foods by regulations. Furthermore, other regulations on the safety of operation of commercial irradiation facilities will be issued.

Another similar petition on the use of irradiation to prevent sprouting in onions is now being prepared and will be submitted shortly.

Should the procedure suggested by the authors lead to an early authorization, it could also be adopted by other countries, particularly by developing countries.

This procedure could become instrumental in the rapid development of the application of the irradiation technique in those countries where it could be of great usefulness and economic value.

REFERENCES


ASPECTS OF LEGISLATION ON IRRADIATED FOODS IN EUROPEAN COUNTRIES

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Abstract — Résumé — Аннотация — Resumen

ASPECTS OF LEGISLATION ON IRRADIATED FOODS IN EUROPEAN COUNTRIES. Clearance for the general distribution of irradiated foods, as well as for the technological procedures to be used, requires legislation. Legislation on food irradiation is still in progress in Europe. A short survey of the present situation is given. General lines of approach are emerging today and can already be distinguished in some national legislations.

For the international exchange of irradiated foodstuffs, a coherent system for the control of these products is of primary importance. Useful guidelines aiming at harmonization of the national regulations to be established have already been issued by international organizations working on this subject.

Lack of practical methods for detection and estimation of the amount of ionizing radiation supplied to irradiated foods makes it, for the time being, necessary to rely on a government licensing system to ensure the safety for consumption of these items. Bilateral or multilateral agreements between the interested governments on the mutual acceptance of their licensed products seem inevitable as long as there exists no international organization to assume responsibility for the safety of irradiated foods and enforcement of the requirements to be met by these products at the international level.

The clearance for consumption and distribution of irradiated food has to be based on solid evidence on the nutritional, toxicological and microbiological safety of the food items under consideration. A free flow of information, and the use of common standards for the testing and evaluation of the evidence collected, as one of the most essential requirements for the establishment of an international circulation of irradiated foods, is stipulated.
все еще находится в стадии разработки. Дается краткий обзор существующего положения вещей. В настоящее время начинают вырисовываться общие линии подхода к данной проблеме, и их можно уже определить в некоторых национальных законодательствах.

Для международного обмена облученными продуктами питания первостепенное значение имеет четкая система контроля за этими продуктами. Полезные руководящие принципы, имеющие целью гармонизацию создаваемых национальных правил, уже были опубликованы международными организациями, работающими в данной области.

Недостаток практических методов обнаружения и оценки количества ионизирующего излучения, переданного облученным продуктом питания, обуславливает на некоторое время необходимость опираться на систему правительственного лицензирования для обеспечения безопасности потребления данных товаров. Двухсторонние или многосторонние соглашения, заключенные между заинтересованными правительствами на основе взаимного принятия ими их лицензированных продуктов, представляются неизбежными до тех пор, пока не будет создана международная организация, которая приняла бы на себя ответственность в международном масштабе за безопасность облученных продуктов питания и за обязательное выполнение требований, которым должны отвечать эти продукты.

Одобрение потребления и распространения облученных продуктов питания должно основываться на твердой очевидности пищевой, токсикологической и микробиологической безопасности рассматриваемых продуктов питания. В качестве специального условия оговаривается свободное движение информации и использование общих стандартов испытания и оценки накопленного опыта в качестве одного из наиболее существенных требований для учреждения международного обмена облученными продуктами питания.

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INTRODUCTION

This survey is limited to the European Member States of the International Atomic Energy Agency (IAEA), namely, Austria, Belgium, Byelorussian Soviet Socialist Republic, Czechoslovak Socialist Republic, Denmark, Finland, France, Federal Republic of Germany, Greece, Hungary, Iceland, Italy, Luxembourg, Netherlands, Norway, Poland, Portugal, Spain, Sweden, Switzerland, Turkey, Ukrainian Soviet Socialist Republic, Union of Soviet Socialist Republics, United Kingdom of Great Britain and Northern Ireland, and Yugoslavia (Fig.1).

Irradiation refers to treatment with ionizing radiation. Treatment of food by infra-red or ultra-violet radiation is not considered.
FIG. 1. Countries in Europe members of the International Atomic Energy Agency.
1 - Austria; 2 - Belgium; 3 - Byelorussian Soviet Socialist Republic; 4 - Czechoslovak Socialist Republic;
5 - Denmark; 6 - Finland; 7 - France; 8 - Federal Republic of Germany; 9 - Greece; 10 - Hungary;
11 - Iceland; 12 - Italy; 13 - Luxembourg; 14 - Netherlands; 15 - Norway; 16 - Poland; 17 - Portugal;
18 - Spain; 19 - Sweden; 20 - Switzerland; 21 - Turkey; 22 - Ukrainian Soviet Socialist Republic;
23 - Union of Soviet Socialist Republics; 24 - United Kingdom of Great Britain and Northern Ireland;
25 - Yugoslavia

Since at present the use of radiation for the treatment of food is confined to the use of gamma radiation, X-radiation and fast electrons, the question must be considered whether or not a licensing system exists for the use of radiation sources in general. The word "licensing" has been taken in a broad sense and means every legal system under which the user of a radiation source is under the obligation to have official approval prior to the use of a radiation source. This approval may be given after compliance of the user with certain conditions already fixed before, or the licence may include the necessary regulations for the activities to be approved.

A special subject covered in this paper relates to the question whether or not special regulations exist concerning food irradiation, or the import and trade of irradiated foods. The indication "no data", does not necessarily mean that no regulations exist. In that case, however, the subject has not been mentioned in the available documents or literature. The
licensing and controlling authorities have been indicated, in so far as these could be extracted from the available data.

Since the rapid development in the technology of the use of radiation is followed by a comparable expansion of the accompanying legislation, it is possible that some data in this survey are already out-dated. Corrective remarks are invited and will be gladly accepted.

I. GENERAL POSITION OF RADIATION LEGISLATION IN EUROPE

(a) The advent of nuclear energy, and its attendant widespread use of radioisotopes, has given rise to many problems of legislation. The methods adopted to cope with these problems are various. In some countries the necessary regulations were inserted in the existing legislation; in others, new legislation covering the whole field of radiation and radiation protection came into being. The inserting of regulations into existing legislation indicates clearly that the new regulations form part of a greater system, such as health protection and labour protection regulations. It has the disadvantage that the interdependence of different radiation protection rules is easily overlooked. Earlier legislation furthermore has been made with other problems in mind, and therefore often lacks the scope and background necessary for the very specialized radiation legislation.

(b) In all European IAEA Member States studied, a licensing system for the use of radioisotopes exists. The legal forms for obtaining and granting official approval vary, however, from country to country. It is remarkable that the licensing of X-ray apparatus and other non-radioactive radiation sources is less common practice than the licensing of radioactive substances.

Legislation on the licensing of these devices, which in their development are much older, is, with the exception of the Scandinavian countries and Finland, contemporary with, or even of later date than, the licensing regulations for the use of radioisotopes.

(c) A basic difference in the legal approach is given by two diametrically opposed attitudes. In some countries a line has been followed to keep the legislation to a minimum, because detailed legislation would inevitably become out of date in a very short time. A good example of this attitude can be found in the Norwegian legislation. The opposing attitude, as exemplified by the legislation in Belgium, Switzerland and the USSR, consists of giving very detailed rules and regulations. In these cases, however, care has been taken that the status of these regulations does not interfere too much with the possibility of making the necessary changes and adjustments. In Denmark a solution to that end has been sought by including in the legislation a provision for the automatic application of the Recommendations of the International Commission on Radiological Protection (ICRP), whenever these are modified.

(d) As the use of radiation is not confined to one single kind of activity, but has a wide range of uses, it is understandable that there are differences in the designation of the authority (or the authorities) responsible for the safe use of radiation.
In some countries the main responsibility rests with the Public Health authorities. For instance, this is the case in Czechoslovakia. In other countries, inter alia the United Kingdom, this responsibility is shared by several Ministries (Labour, Power, Housing and Local Government, Agriculture, Fisheries and Food).

Sometimes, as for instance in France, a national agency is created that next to an advisory task towards the Government, has received governmental responsibilities by delegation.

(e) A further important aspect of Radiation legislation is the frequency with which changes caused by scientific developments are needed. Compared with other types of legislation for the protection of the public, radiation legislation is quite new in most European countries. Nevertheless, several adaptations and revisions have already been made over a short period of time. It can be safely assumed that legislation on the use of radiation for technological, agricultural and medical purposes is still in a stage of transition, and will remain so for a considerable time.

II. GENERAL PRINCIPLES FOR LEGISLATION ON IRRADIATED FOODS

The concept of food legislation includes the wholesomeness of foods in general distribution being safeguarded for the benefit of the consumer, who is not in a position to protect himself from the long- and short-term effects of microbiological, chemical, and physical noxious agents in the food, or to evaluate the qualities of that food for the maintainance and restoration of his personal vitality. National authorities, acting for the benefit of the consumer, have to be satisfied that marketed foods meet the necessary requirements. Whereas irradiation of the food under consideration cannot yet be determined in the finished food item itself, prophylactic supervision and inspection by the authorities of production methods and materials at different stages of food processing will be inevitable.

It will obviously be advantageous for international co-operation and trade when general principles formulated for food legislation, and for the establishment of safety for consumption, lead to a common approach in the various countries. This is especially important when legislation is still in the process of formation, as in the case of irradiated foods. In the meeting of the Joint FAO/WHO/IAEA Expert Committee on the Technical Basis for Legislation on Irradiated Foods held in Rome from 21-28 April 1964, such an endeavour was made, resulting in the enumeration of the following basic principles:

(a) Governments should establish legislation to control the production, importation, exportation, and distribution of irradiated foods;
(b) In such legislation, requirements for establishing safety for consumption should be laid down;
(c) Legal control should be based on the principle of a "positive list" of individually permitted foods and their radiation treatments;
(d) Distribution of an irradiated food item should be permitted only after acceptance by the appropriate government authority of the evidence that the food is safe for consumption ("wholesome").

A general remark about the difficult word "wholesome", on which the author already commented on an earlier occasion\(^2\), must be made here. At the first intergovernmental meeting on the Wholesomeness of Irradiated Foods sponsored by FAO, WHO, and IAEA and held at Brussels in October 1961, difficulties were already encountered with the translation of the word "wholesomeness". This word, attractive as it may be for its shortness, covers so many aspects of health, safety, and reliability, that it is practically impossible to find truly equivalent terms in foreign languages. The term "safety for consumption" is therefore preferable in documents for international distribution. It should be understood that "safety for consumption" in a broad sense refers to three categories:

**Toxicological safety** – evaluation of the formation or introduction of harmful substances.

**Nutritional safety** – evaluation of the degradation of nutrients of essential importance in the diet.

**Microbiological safety** – evaluation of the presence of harmful microorganisms and of toxins of microbiological origin.

The first of these criteria is relevant for all irradiated foods, irrespective of their part in the diet of the consumer. This criterion involves an adequate testing programme for the possible presence of toxic substances, carcinogens, and radioactive substances.

The second criterion, although related to a specific food item and its radiation treatment, varies in significance depending on local or regional circumstances. The greater the contribution of the food under consideration to the diet of a population, or of a group (such as children) in that population, the heavier the weight of this factor against the clearance of that irradiated food item for general distribution.

The third criterion is the most difficult one, for it has to be considered in several relationships:

(i) In relation to the food as a medium for microbiological activities;
(ii) In relation to the microorganisms, either as a concomitant of the origin of the food, or as a contaminant introduced at any stage of the long and intricate chain from food source to consumer; and
(iii) In relation to the radiation-preservation process itself, which might be satisfactory from toxicological and nutritional standpoints, but still unreliable with regard to the bacteriological safety of the irradiated food item.

A very interesting part of the international trade in irradiated foods is to be found in the necessity for an appropriate government authority at the national level to be satisfied with the evidence that the proposed irradiated food is safe for consumption.

Applications for a licence for the distribution of irradiated food have to be supported by circumstantial reports of tests that demonstrate the lack of toxicity, the nutritional adequacy, the lack of carcinogenicity, and the lack of microbiological hazards, with special reference to the possible presence of Clostridium botulinum and its toxins, and of other microorganisms responsible for the more common food poisonings.

The load of evidence to be collected (at great cost and over a consider-

able period of time) can hardly be prepared each time, anew, for each application to every national government authority issuing licences for production and importation, according to its existing national rules and regulations. No national authority, with respect to its national laws, can, however, without discussion, recognize the licences issued by foreign governments. Such national authority might, of course, request applicants to submit again the evidence supplied to the governments that have already licensed their procedures. The same national authority would undoubtedly like to learn from its opposite government body abroad the reasons for its favourable decision and its weighing of the pros and cons of this new method for food preservation.

Furthermore, the authority dealing with an application will also be interested to know what measures the licensing government has taken for the supervision of the irradiation process and the control of the product under consideration, in order to ensure that the licensed food is consistently safe for consumption.

For the sake of the development of the radiation preservation of foods as a new and promising method, national legislation should facilitate international co-operation between the appropriate national bodies and their specialists; international trade makes this collaboration all the more imperative, with a view to the use of common standards for the testing and evaluation of the safety for consumption, and for the harmonization of the procedures to be applied for the free circulation of irradiated foods.

III. EXISTING LEGISLATION ON RADIATION IN THE EUROPEAN MEMBER STATES OF IAEA IN 1965, WITH SPECIAL REFERENCE TO IRRADIATED FOOD

Generally speaking, the same attitudes mentioned for radiation legislation as a special subject can be noted in the legislation on the irradiation of foods and feeds and their trade, although only a few countries have, as yet, specific regulations already in force, or in preparation (see Table I). Some of them (Switzerland, Federal Republic of Germany) have regulations which form a part of the much wider field of food legislation. Others (Belgium) have rules which are integrated in the radiation legislation.

A third approach, with some practical advantages, may be found in the form of a compromise. It seems possible to regulate the characteristics of the irradiation of foodstuffs by means of the legislation dealing with the use of radiation sources, on the one hand, and to regulate the trade in irradiated food (inclusive of importation) as a subject in the field of legislation on foodstuffs, on the other hand.

This approach is preferred, though not yet definitely regulated, in the legislation under preparation in the Netherlands.

Some regulations for food irradiation are highly detailed (Switzerland). Other regulations do not give much more than a basis for ad hoc decisions when the occasion arises (Italy).

When, at this stage, generally acceptable basic principles for the legislative rules on food irradiation could be agreed upon, legislation on this important subject in Europe could be harmonized to a very great extent with, nevertheless, full acknowledgement of the responsibilities of the governments of each European country to elaborate the necessary
### TABLE 1. RADIATION LEGISLATION IN EUROPE

<table>
<thead>
<tr>
<th>Country</th>
<th>Licence required for radioactive substances</th>
<th>Licence required for other radiation sources</th>
<th>Specific regulations on food irradiation</th>
<th>Specific regulations on importation or trade</th>
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Radiation legislation for radioactive substances and/or radiation sources in force
 Regulations on food irradiation or trading of irradiated food in force

1 - Austria; 2 - Belgium; 3 - Byelorussian Soviet Socialist Republic; 4 - Czechoslovak Socialist Republic; 5 - Denmark; 6 - Finland; 7 - France; 8 - Federal Republic of Germany; 9 - Greece; 10 - Hungary; 11 - Iceland; 12 - Italy; 13 - Luxembourg; 14 - Netherlands; 15 - Norway; 16 - Poland; 17 - Portugal; 18 - Spain; 19 - Sweden; 20 - Switzerland; 21 - Turkey; 22 - Ukrainian Soviet Socialist Republic; 23 - Union of Soviet Socialist Republics; 24 - United Kingdom of Great Britain and Northern Ireland; 25 - Yugoslavia

details relevant to their specific situations. These details should, preferably, be limited at first, so that the effects of new developments in science and technology could be easily absorbed in the national regulations.

In the Annex to this paper detailed information on 25 European countries is presented, with references to the sources from which it has been abstracted.

Table I summarizes the actual situation (1965) in these countries, with reference to the state of the legislation: in preparation (O), in force (+) (or both: ©), not in force (Θ), and no data available (-).

A licensing system for radioactive substances is already in force in 20, and for radiation sources in 18, out of 25 European IAEA Member State countries (Fig. 2).

Specific regulations on food irradiation, and on importation and trade in irradiated food, are in force in only 4 out of 25 European countries (Fig. 2).
The conclusion drawn from this survey is that an excellent opportunity for timely international harmonization of this highly specific feature of radiation legislation exists, which may be stimulating for the international agencies concerned - FAO, WHO and IAEA - to continue to pave the way to the important goal to be achieved by the competent national authorities in this field.

ACKNOWLEDGEMENT

The author expresses his sincere thanks to J. Ch. Cornelis, Deputy Chief of the Division of Nuclear Energy and Radiation Protection, Ministry of Social Affairs and Public Health, The Hague, for his collaboration in preparing and collecting the data on legislation for this survey.

ANNEX

1. AUSTRIA

The legislation of this country requires official approval, prior to use, for all kinds of radiation sources. The legal base is partly the German Order of 7 February 1941 and partly the "Gewerbe Ordnung" (Industrial Code). A few other regulations cover special aspects of radiation protection.

New legislation, to bring the existing regulations up to date, is in course of preparation.

No regulations were found on food irradiation.


2. BELGIUM

The Belgian Royal Decree of 28 February 1963 institutes a licensing system for the use of radioactive substances, as well as for the use of apparatus emitting ionizing radiation, such as X-ray apparatus and accelerators.

Section 64.1 of this Royal Decree prohibits the irradiation of food. Section 64.2, however, makes irradiation of food for research purposes possible, subject to a licence from the Minister of Public Health and the Minister of Labour.

Section 64.2 prohibits, without the possibility of a licence, the import of irradiated food, the possession of such food, and its transport.


3. BYELORUSSIAN SOVIET SOCIALIST REPUBLIC

The regulations, mentioned under the Union of Soviet Socialist Republics, are in force for the whole territory of the Soviet Union. No data were found on special regulations in the Byelorussian Republic.
4. CZECHOSLOVAK SOCIALIST REPUBLIC

A licence, granted by the Provincial Hygienist, is required for the acquisition and storage of radioelements, and for the use of radiation sources; the Chief Hygienist can extend the validity of such a licence, to cover several provinces, or the whole country. (Regulation on Radiation Protection of 1963.)

The addition of radioactive substances to food is prohibited.

No regulations on the irradiation of food were found.


5. DENMARK

Control of X-ray apparatus is based on Law No. 147 of 1930 and the control of radioactive substances on Law No. 94 of 1953. Both laws have been implemented by several regulations. At present, supervision is carried out by the Radiation Hygiene Laboratory.

No data on food irradiation were found.


6. FINLAND

A licensing system for X-ray apparatus has been in force since 1932. In 1957 a licensing system for other radiation sources was introduced.

The licensing authority is the Minister of Trade and Industry. For medical uses, however, it is the Minister of the Interior, who has delegated this power to the State Medical Board.

Supervision is carried out by the Institute of Radiophysics.

No special regulations on food irradiation were found.


7. FRANCE

In France a licensing system for the use of radioactive substances exists. Apparatus capable of emitting ionizing radiations needs official approval, prior to use.

As several Ministries handle different aspects of the use of ionizing radiation, the legislation is somewhat complicated.

In general, supervision is centralized in the Central Service for Protection against Ionizing Radiations (instituted by Decree of 16 August 1960).

French legislation has no specific rules on the irradiation of food. Lacking these, Section R 5235 of the Cure of Public Health is applicable.

A licence must be asked from the Commission interministérielle des radioéléments artificiels for the use of a radioactive source. This commission, however, (in the case of an application for a licence for the irradiation of food) cannot take a decision, but must ask advice from the Council for Public Health, which council gives its advice in collaboration with the Academy of Medicine.
For each separate food, a separate application must be made. Details must be given on:

(a) The irradiation technique envisaged, and the way in which irradiation will take place;
(b) Proofs of the wholesomeness of the food after irradiation, based on a sufficient period of experiments under strict scientific control; and
(c) The economical and technical aspects.

If this information is not given the application will not be considered.

(Up till now only one application for a licence has been made. A decision has not yet been taken, pending further experiments.)

A detailed survey of the questionnaire which has to be answered is given as Appendix XV of the Report of the Meeting on the Wholesomeness of Irradiated Foods, Brussels (1961), FAO, Rome (1962).

For importation and trading purposes, irradiated food is considered to be food with radioactive additives. Importation is prohibited.


8. FEDERAL REPUBLIC OF GERMANY

A licensing system for the use of all kinds of radiation sources exists. In some cases a formal licence is needed, in other cases official inspection before the installation is put into use suffices. The federal structure of the Republic entails a decision of authority between the control (Bundes) authorities and the state (Landes) authorities.

Treatment of food with ionizing radiation is possible, provided that authorization is obtained from the (Federal) Minister of Public Health, which authorization must be given in agreement with other competent Ministers. The authorization is subject to approval by the Bundesrat (Section 4c of the Food Act of 17 January 1936).

There is a regulation on the irradiation of food, dated 19 December 1959, which regulation makes it possible, under certain conditions, to irradiate food with electro-magnetic rays, gamma-rays, and X-rays, for purposes of control and measurement.

Section 21 of the Food Act prohibits the importation of irradiated food.


9. GREECE

No regulations on food irradiation exist.


10. HUNGARY

No data available.
11. ICELAND

Dating from 1962, a Law exists on protection measures against ionizing radiation from radioactive substances, or apparatus producing radiations; a licensing system for radiation sources exists.

No data on food irradiation were found.


12. ITALY

Legislation or radiation protection is covered by a large number of laws, decrees, circulars, etc. New, comprehensive legislation is in the course of preparation.

It will be based on Law No. 1860, of 31 December 1962, on the peaceful uses of nuclear energy.

In general, a licence is required for the use of radioactive substances. For other radiation sources, a system of notification and registration exists.

Act No. 283 of 30 April 1962 and the Decree of the President, No. 185, of 18 February 1964 (Sections 1, 2), cover the irradiation of food. Irradiation is possible, provided a licence has been obtained from the Minister of Public Health.

A regulation, giving rules on the way in which licences can be obtained, etc., is in course of preparation.

Section 7 of the Act states that the Minister of Public Health can, by decree, authorize trade in irradiated food.

Up till now no licences or authorizations have been given.


13. LUXEMBOURG

At present no legislation exists. However, regulations on the use of ionizing radiation are in preparation.

The future regulations will contain a licensing system for the use of radiation sources.

Section 5.1 will contain a provision that the irradiation of food is subject to authorization of the Minister of Public Health. This authorization is needed for each single food product.

An authorization will only be granted if the conditions put by the Minister are fulfilled. The same Minister will be empowered to grant licences for the importation of irradiated food and for offering this food for consumption.

Source: Euratom Document EUR/C/1720/1/65 (not published).

14. NETHERLANDS

Under the Radioactive Substances Decree of 1963, a licensing system exists for the use of radioactive substances.
For the use of X-ray apparatus and accelerators a licensing system exists, based on legislation for the protection of inhabitants of adjacent buildings against danger and damage. New legislation, however, covering all aspects of radiation protection is in preparation.

No specific regulations exist for the irradiation of food. If irradiation is to be done by the use of radioactive substances, the general licensing procedure applies.

No specific rules exist on the importation of and trade in irradiated food.

Regulations covering the irradiation, as well as trade in, irradiated food are in preparation.

An advisory commission has advised that a system be adopted requiring licences for the irradiation of food, as well as for the importation of irradiated food.

15. NORWAY

A system exists for the inspection of sources of ionizing radiation before operations are begun.

A very important role is being played by the State Health Physics Laboratory, which later became the State Institute of Radiation Hygiene, which has to approve installations and can also prohibit the use of such installations and apparatus.

The legislation is in very general terms.

The State Institute of Radiation Hygiene has always been careful not to lay down rigid rules, as it was felt that such rules would hinder development in this field.

No special rules on the irradiation of food were found.


16. POLAND

On the use of radiation sources in general, the Ordinance on Radiation Protection (1957) is applicable. (New legislation is in course of preparation.)

For the use of radiation substances, as well as for the use of X-ray apparatus, a "prior to use" approval by the State Sanitary Inspectorate and the Technical Labour Inspectorate must be obtained.


17. PORTUGAL

In 1961 a Decree Law on radiation protection was promulgated. By this Decree Law the control and granting of licences was entrusted to a Commission for Protection against Ionizing Radiations (CPCRI) which was established within the Nuclear Energy Board.

Authorization of the CPCRI is required prior to the importation, production, use, storage, transport and disposal of radioactive substances, as well as for the importation, production, installation and use of ap-
paratus producing ionizing radiations for scientific, medical or industrial purposes.
No data on food irradiation were found.

18. SPAIN

Since 1957 authorization is needed for the acquisition and use of radioactive substances. This authorization is given by the Nuclear Energy Board. Recently a law was enacted (April 1964) that applies to radioactive sources as well as to X-rays.
No data on food irradiation were found.

19. SWEDEN

Under Act No. 110 of 14 March 1958, the use of every kind of radiation source is subject to a licence.
General licences, however, for given professions, or for given groups of laboratories, etc., are possible. Authorization (licence) is given by the Radiation Protection Board. For medical use, advice is given by the Royal Medical Board.
No regulations on food irradiation were found.

20. SWITZERLAND

In general, a licence is needed for the use of all kinds of radiation sources. (Federal Law on the Peaceful Use of Atomic Energy and Radiation Protection, 23 December 1959.)
Section 11.1 of the Food Ordinance rules that irradiation of food must be authorized by the Federal Service of Public Hygiene (FSPH). This service must also authorize trade in irradiated food for human consumption (Sect. 4).

Authorization is only given if proof is provided by biological tests that the irradiation has no consequence for the wholesomeness of the food, and has not resulted in altering other qualities specified in the Ordinance (such as change in the nutritive value, forming of toxic substances, change of taste, etc.).
The proof must be certified by an independent research laboratory, approved by the FSPH, or by a university laboratory. The results of tests made by the applicant constitute no proof; the results of these tests are, however, taken into consideration.
If the biological tests have been made in another country, it is not necessary to do them again in Switzerland. The FSPH will give authorization for the irradiation of food if the data on the tests taken are judged to be sufficient from a scientific point of view.
It is necessary, however, that the tests made in another country are made by a University laboratory, a State laboratory, or a similar organi-
zation. It is also necessary that the competent Public Health Authorities in the other country have given permission for the trade of the food conserved in that country.

For the present separate authorization must be obtained for each separate food. The authorization gives only permission for the use of a specified source of irradiation. Conditions are given on the admissible dose; the packaging during irradiation is determined exactly; the same holds for the other circumstances pertaining during irradiation (e.g. surrounded by vacuum or inert gases).

The request for authorization should be addressed to the FSPH, and should be accompanied by all necessary documents, containing details about the envisaged irradiation and the tests that have been made. The FSPH will make the condition, in its authorization, that some of the irradiated foods (e.g. every 1000th unit) must be replaced by a "phantom" with a dosimeter. These "phantoms" must be conserved for two years.

Section 11 of the Ordinance institutes periodical tests on the safety of the procedure. Detailed rules are given in the authorization. If a method of irradiation is authorized by the FSPH, special labelling is not necessary.

Importation of irradiated food, too, is subject to authorization by the FSPH. The request for authorization should be accompanied by all documents which are needed to obtain authorization for irradiation of the food in question. A copy of the authorization given by the authorities in another country only is not enough.


21. TURKEY

All radiation sources are owned by the Government.

Food irradiation is carried out only for purposes of research by the Agricultural Faculty of the University of Ankara.

Source: Embassy of Turkey, The Hague, Netherlands.

22. UKRAINIAN SOVIET SOCIALIST REPUBLIC

The regulations mentioned under Union of Soviet Socialist Republics are in force for the whole territory of the USSR.

23. UNION OF SOVIET SOCIALIST REPUBLICS (USSR)

The legislation for the control of radiation sources is very detailed and of a technical character. It has been extensively revised. First legislation appeared in 1953. Replacement took place in 1957 and in 1960: "Health Rules for Work with Radioactive Substances and Sources of Ionizing Radiations" (Nos 333-60).

The regulations were issued by the Chief State Health Inspectorate of the Ministry of Public Health jointly with the State Committee of the Council of Ministers of the USSR for the Utilization of Atomic Energy.
These regulations are only applicable to radioactive substances as sources of radiation.

Plans for the construction or reconstruction of existing installations must be approved by the Health Inspection Authorities. Before such an installation can be put into operation it must be approved by a commission composed of representatives of the operating organization, the health inspection authorities, the police and the fire brigade. This approval stipulates the purpose for which the installation is intended.


24. UNITED KINGDOM OF GREAT BRITAIN AND NORTHERN IRELAND

The use of radioactive substances is governed by the Radioactive Substances Act, 1960. The Ionizing Radiations (Sealed Sources) Regulations, 1961, are concerned also with apparatus intended to produce ionizing radiations of not less than 5 kV (except for medical use). Licensing and supervision are divided between several Ministers and between the Government and the Local Authorities.

Under the Foods and Drugs Act, 1955, and the corresponding Scottish Act of 1956, it is an offence to subject food, intended to be sold for human consumption, to any process or treatment that renders the food injurious to health. The probable cumulative effect of consuming the food in ordinary quantities is taken into account in considering whether or not the food is injurious to health. It can also be an offence to sell for human consumption food which is not of the nature, substance or quality demanded, or food which is unfit for human consumption unless notice is given to the purchaser that the food is not intended for human consumption. In every case brought under these Acts the onus is on the prosecution to prove to the satisfaction of the Court the allegation as to the harmfulness, unsatisfactory quality or unfitness for human consumption of the food in question. Whether or not the sale of irradiated food contravenes the provisions of the Acts is therefore a matter for the Court to decide when a prosecution is brought before it. At the present time, no food which has been irradiated to prolong its storage life is known to have been offered for sale for human consumption in Great Britain, and no proceedings have been taken in respect of such a sale under the English or Scottish Acts.

Part IV of the Ionizing Radiation (Sealed Sources) Regulations mentions the use of ionizing radiation in the irradiation of materials for the purpose of inducing chemical, physical, or biological changes.


25. YUGOSLAVIA

No data available.
F. C. LU: As representative of the World Health Organization (WHO), I would like to say a few words about its role in the field of food irradiation. WHO is interested in food irradiation because it believes that good health depends on, among other things, an adequate supply of wholesome food, and irradiation may be useful in the preservation of foodstuffs; WHO is also interested in the safety of irradiated food for human consumption. In this connection, may I point out that WHO co-sponsored, with the Food and Agriculture Organization of the United Nations and the International Atomic Energy Agency, an intergovernmental meeting on the wholesomeness of irradiated food which was held in Brussels in 1961. In 1964 it co-sponsored an expert committee on the technical basis for legislation on food irradiation.

At the World Health Assembly, in May, some delegates stressed the role of WHO in relation to the health aspects of food irradiation, and preliminary steps have been taken to provide funds for convening, early in 1969, a further expert committee to consider the international clearance of individual irradiated foodstuffs. It is reasonable to expect that certain irradiated foodstuffs treated under specific conditions will then be considered acceptable for general human consumption. A recommendation to that effect, addressed to governments, might contribute to the promulgation of appropriate legislation to allow the production of such foodstuffs and to facilitate their free international circulation.

I would also mention that WHO is prepared to undertake the collection and dissemination of information relating to the health aspects of irradiated food.

M. INGRAM (Chairman): Mr. Spaander referred to two broad difficulties: first, that of convincing governments of the necessity to legislate for food irradiation, and second, that of framing the legislation suitably. Granted the usefulness of an irradiation process, the first difficulty should be easily overcome, for the dangers of non-uniform procedures in radiation processing are obviously even greater than those associated with heat-processing. But the second difficulty seems to me formidable, on an international plane. I am not, however, now referring to the kind of difficulty we have been discussing at this Symposium; I think it will be relatively easy to reach agreement on technical points, such as requirements for toxicity testing. On the other hand, far-reaching difficulties seem likely to arise, for example, because radiation is regarded as an additive in the United States law, whereas it is not in Britain; because the British suggestion is to include animal feeds but not tobacco, whereas other countries include the latter but not the former; or because, as Dr. Josephson has said, there are two government departments involved in the United States, and they are not likely to correspond exactly to those involved in other countries. Such differences in basic principles seem to me much more likely than technical details to obstruct the international exchange of irradiated food; I think, therefore, that the international agencies should convene a meeting of legal administrators to consider, at a high level, the implications of such differences. There is, indeed, no time to be lost, as some of the new laws are already being drafted.

J. SPAANDER: I agree entirely. In my opinion these problems can be dealt with only at an intergovernmental level and it is essential that
governments be brought together as soon as possible to consider them. However, legislators are bound to ask whether it is necessary to introduce international legislation governing food irradiation when there is as yet no international trade in such commodities. I therefore support Mr. Kahan's suggestion, in his presentation of Paper SM-73/50, that countries should make a start by moving limited quantities of irradiated food across their frontiers in order to give legislators something on which to legislate.

D. MASSA: I should like to mention that the Italian Minister of Public Health has appointed an advisory committee on the wholesomeness of irradiated food.

M.H. BALASAYGUN: As representative of the Council of Europe, may I say that two main points of interest to the Council have emerged at this Symposium: first, there is a growing need, for countries which have not yet done so, to enact national legislation in relation to food irradiation; and second, there will then follow a need for harmonization of national legislation.

The Council of Europe has, up to now, sponsored over 50 international agreements, seven of them relating to public health, precisely in this field of harmonizing conflicting national legislation, and I would be interested to hear whether Mr. Spaander and Mr. Lu consider it timely for the Council to prepare, with the assistance and co-operation of the interested international organizations, an international instrument relating to food irradiation.

J. SPAANDER: Generally speaking, any instrument that can help in furthering the free international circulation of foodstuffs that have been cleared and accepted for human and animal consumption is to be welcomed.

F.C. LU: As I indicated earlier, WHO is keenly interested and actively engaged in the health aspects of irradiated foods. As to the aspects of food irradiation, my unofficial view is that it might be left to individual countries to work out appropriate national legislation and subsequently to conclude bilateral and multilateral agreements among themselves.
LEGISLATION AND IDENTIFICATION OF IRRADIATED FOODSTUFFS. Originally of purely military importance, the irradiation of food commodities is nowadays of increasing interest in the civilian sector, and commodities so treated will shortly be marketed. Protection of the health of the consumer should be the main element in arguments for and against this practice.

In view of the uncertainties which make it difficult to take up a definite attitude to the problem as a whole, Belgium has preferred to adopt the principle of prohibition, with the possibility of progressively departing from this principle as further knowledge becomes available.

Article 64.1 (b) and (c) of the Royal Decree of 28 February 1963 prohibits the addition of radioactive substances to foodstuffs and the treatment of foodstuffs by ionizing radiations.

Article 65 (a) and (b) actually already provides for rescindment of prohibition on condition that the addition or treatment is performed for research purposes and that a specific licence has been granted by the Ministry of Public Health.

The import, possession or transport of foodstuffs to which radioactive substances have been added or which have been treated by ionizing radiations are also prohibited under Article 64.2.

Similar prohibitions are applied in regard to two products of a somewhat similar nature to foodstuffs, i.e. medicaments and medical supplies which have been treated by ionizing radiations; with a view to progressive liberalization, however, considerable easing of the regulations is proposed as far as medical supplies are concerned.

In spite of the lack of conviction in certain scientific circles regarding the wholesomeness of irradiated foods, it is likely that a number of processes will shortly be accepted. A number of countries have already authorized consumption of various irradiated foods and it is to be assumed that national barriers will be overcome by commercial ties. At the same time, some control is essential to ensure that the authorized processes are not applied to foods for which they have not been specified and to check that the permissible doses are not exceeded. Identification of irradiated foods and, as appropriate, determination of the doses employed therefor, constitute a national and an international problem.

The problem can be approached in numerous ways, as shown by the following list of possible methods: measurement of the paramagnetic state of the atom, electrophoresis, measurement of redox potential, polarography, spectrophotometry, chromatography, colorimetry, microscopic examination of tissues, immunological changes, microbiology, changes in the packing material, and changes in organoleptic characteristics.

The most promising methods so far appear to be spectrophotometry, chromatography, electrophoresis, changes in redox potential and determination of various oxidation products. Considerable research remains to be done and this must take account of the following requirements:

- the method must be as specific as possible; it must be qualitative and if possible quantitative;
- results must be obtained from parallel tests on irradiated products, untreated products, and products preserved by other processes;
- the tests must be protracted, covering a period at least as long as that for which the foods are kept before consumption, in order to ascertain whether the changes observed persist, become more pronounced, or disappear.
- finally, the method must be capable of as near universal application as possible, account to be taken of the range of foods which can be irradiated, the types of irradiation and the doses employed.

REGLEMENTATION ET IDENTIFICATION DES DENREES IRRADIEES. D'un intérêt purement militaire au début, les recherches sur l'irradiation des denrées alimentaires ont progressivement intéressé le domaine civil et nous sommes au seuil de la commercialisation de tels produits: la protection de la santé du consommateur doit être l'élément principal du faisceau d'arguments pour ou contre une telle pratique.
En raison des incertitudes qui empêchent de formuler un jugement définitif sur l'ensemble du problème, la Belgique a préféré recourir au principe de l'interdiction, quitte à envisager des dérogations progressives en fonction du progrès des connaissances.

L'arrêté royal du 28 février 1963, en son article 64,1 alinéas b et c, interdit d'ajouter des substances radioactives aux denrées alimentaires ou de traiter celles-ci par les radiations ionisantes.

Déjà actuallement l'article 65, alinéas a et b, prévoit une dérogation à condition que l'incorporation ou le traitement soient effectués à des fins de recherches et qu'une autorisation spécifique ait été accordée par le Ministère de la Santé publique.

L'importation, la détention et le transport de denrées auxquelles des substances radioactives sont ajoutées ou traitées par des radiations ionisantes sont également interdits en vertu de l'article 64.2.

Des dispositions analogues d'interdiction sont prises à l'égard de deux produits proches des denrées, les médicaments et le matériel médical traités par les radiations ionisantes; toutefois, dans le sens d'une libéralisation progressive, un sérieux assouplissement est proposé en ce qui concerne le matériel médical.

Malgré les incertitudes qui continuent à régner dans certains milieux scientifiques quant à la salubrité des aliments irradiés, il est vraisemblable que certains procédés ont des chances d'être admis à plus ou moins brève échéance. Quelques pays ont d'ailleurs déjà autorisé la consommation de plusieurs aliments irradiés et il est à prévoir que le circuit commercial tendra à franchir les frontières nationales. Par ailleurs, il est indispensable de pouvoir s'assurer que les procédés autorisés n'ont pas été indûment appliqués à des denrées pour lesquelles elles n'étaient pas prévus et que les doses tolérées ont été respectées. Le problème de l'identification des produits irradiés et de la connaissance éventuelle de la dose utilisée pour l'irradiation se pose par conséquent sur le plan national et sur le plan international.

Un inventaire des méthodes qu'on peut envisager montre la multiplicité des modes d'approche de la question; mesure de l'état paramagnétique de l'atome, électrophorèse, mesure du potentiel d'oxydo-réduction, spectrophotométrie, chromatographie, colorimétrie, examen microscopique des tissus, modifications immunologiques, microbiologie, modification du matériau d'emballage et modification des caractères organoleptiques.

Jusqu'à présent, la spectrophotométrie, la chromatographie, l'électrophorèse, les modifications du potentiel d'oxydo-réduction et le dosage de certains produits d'oxydation paraissent les plus prometteurs.

Des recherches importantes restent nécessaires; elles doivent tenir compte de divers impératifs:
- la méthode doit être aussi spécifique que possible, qualitative et, si possible, quantitative;
- les résultats doivent provenir d'essais menés parallèlement sur des produits irradiés, sur des produits non traités et sur des produits conservés par d'autres procédés;
- les essais doivent être étendus dans le temps au moins aussi longtemps que dure la conservation habituelle des denrées avant leur consommation pour se rendre compte si les modifications éventuellement observées se maintiennent, s'accentuent ou disparaissent;
- enfin, la méthode doit être aussi universelle que possible, compte tenu de la gamme de denrées pouvant être irradiées, des modes d'irradiation et des doses utilisées.

ЗАКОНОДАТЕЛЬСТВО ПО ОБЛУЧЕННЫМ ПИЩЕВЫМ ПРОДУКТАМ И МЕТОДЫ ИХ ИДЕНТИФИКАЦИИ. Научные исследования в области облучения пищевых продуктов, представляющие сначала интерес с чисто военной точки зрения, постепенно охватывают и гражданскую область, и мы находимся накануне такого положения, когда эти продукты приобретут коммерческое значение. Охрана здоровья потребителя должна быть главным аргументом такой практики.

Ввиду имеющихся неясностей, мешающих составить окончательное мнение по проблеме в целом, Бельгия предпочитает прибегнуть к принципу запрещения, избегать постепенных отступлений в зависимости от прогресса познаний.

Королевским постановлением от 28 февраля 1963 года, статья 64,1 подпункты b и c, запрещается применять радиоактивные вещества к пищевым продуктам или обрабатывать их при помощи ионизирующих излучений.

Уже в настоящее время статья 65, подпункты a и b, предусматривает отступление от вышеуказанного правила при условии, что применение таких веществ или обработка ими будут осуществляться в исследовательских целях и при наличии специального разрешения Министерства здравоохранения.

Ввоз, хранение и перевозка пищевых продуктов, которые подвергались обработке радиоактивными веществами, также запрещены в силу статьи 64,2.

Аналогичные положения приняты в отношении медикаментов и медицинского оборудования, обрабатываемых при помощи ионизирующих излучений. Тем не менее в порядке постепенного предоставления большей свободы допускается определенная гибкость в отношении медицинского оборудования.
Несмотря на то, что некоторые научные круги продолжают сомневаться относительно безвредности облученных пищевых продуктов, представляется вероятным в недалеком будущем использовать некоторые методы. Некоторые страны к тому же уже дали разрешение на потребление некоторых видов облученных пищевых продуктов и можно предвидеть, что их продажа выйдет за рамки национальных границ. Кроме того, необходимо обеспечить такое положение, чтобы методы, которые были одобрены, не применялись к продуктам, для которых они не предусмотрены, и чтобы соблюдались допустимые дозы облучения. Таким образом, в национальном и международном плане возникает проблема идентификации облученных продуктов и возможного определения дозы облучения.

Рассмотрение перечня возможных методов указывает на множество способов подхода к решению этого вопроса: измерение парамагнитного состояния атома, электрофорез, измерение потенциала окислительно-восстановительного процесса, поларография, спектрофотометрия, хроматография, калориметрия, микроскопическое изучение тканей, иммунологические изменения, микробиология, изменение упаковочного материала и изменение органолептических свойств.

До настоящего времени спектрофотометрия, хроматография, электрофорез, измерение потенциала окислительно-восстановительного процесса и дозировка некоторых окислов, по-видимому, являются наиболее обещающими. Необходимо проведение важных исследований с учетом различных требований:
- метод должен быть по возможности специфическим, качественным и, если возможно, количественным;
- результаты должны вытекать из исследований, параллельно ведущихся с облученными продуктами, с необработанными продуктами и с продуктами, сохраняемыми другими способами;
- исследования должны проводиться в течение такого времени, которое возможно для обычного хранения пищевых продуктов до их потребления, с тем, чтобы выяснить, сохраняются, усиливаются или исчезают наблюдаемые в известных случаях модификации;
- наконец, метод должен быть по возможности универсальным, учитывая большое количество продуктов, которые могут быть облучены, способы облучения и используемые дозы.

LEGISLACION Y IDENTIFICACION DE LOS ALIMENTOS IRRADIADOS. Las investigaciones sobre irradiación de alimentos, que al principio tenían un interés puramente militar, han llegado a interesar al sector civil; pronto se procederá a la comercialización de esos productos irradiados: el principal elemento del conjunto de argumentos aducidos en pro o en contra de tal procedimiento debe ser la protección de la salud del consumidor.

En vista de las incógnitas que impiden formular un juicio definitivo sobre el problema considerado en su totalidad, Bélgica ha preferido adoptar el principio de la prohibición, sin perjuicio de derogaciones progresivas a medida que vayan progresando los conocimientos.

En los apartados b у с del artículo 64.1 del real decreto de 28 de febrero de 1963 se prohíbe añadir sustancias radiactivas a los productos alimenticios o tratarlos con radiaciones ionizantes.

Ya en la actualidad, el artículo 65 (apartados a y b) prevé una excepción siempre que la incorporación o el tratamiento se efectúen con fines de investigación y con una autorización explícita del Ministerio de Sanidad Pública.

El artículo 64.2 prohíbe también la importación, retención y transporte de productos alimenticios a los que se hayan añadido sustancias radiactivas o que hayan sido tratados con radiaciones ionizantes.

Se han adoptado disposiciones prohibitivas análogas con respecto a dos productos afines a los alimentos alimenticios: los medicamentos y los suministros médicos tratados con radiaciones ionizantes. No obstante, con miras a una liberalización progresiva, se propone una gran flexibilidad en lo que respecta a los suministros médicos.

Pese a la incertidumbre que continúa existiendo en ciertos medios científicos en cuanto a la salubridad de los alimentos irradiados, es probable que ciertos procedimientos sean admitidos en plazo más o menos breve. Algunos países han autorizado ya el consumo de diferentes alimentos irradiados y cabe prever que el circuito comercial tenderá a retrasar las fronteras nacionales. Por otra parte, es indispensable tener la posibilidad de verificar que los procedimientos autorizados no se aplican indebidamente a artículos para los que no han sido previstos y que se respetan las dosis establecidas. Es decir, se plantea, en el plano nacional y en el internacional, el problema de la identificación de los productos irradiados y, eventualmente, el de la comprobación de la dosis de radiación administrada.

El inventario de los métodos que se podrían aplicar muestra la variedad de las maneras de abordar la cuestión: medición del estado paramagnético del átomo, electroforesis, medición del potencial de
oxidorreducción, polarografía, espectrofotometría, cromatografía, colorimetria, examen microscópico de los tejidos, modificaciones inmunológicas, microbiología, modificación del material de embalaje y modificación de los caracteres organolépticos.

Hasta ahora, la espectrometría, la cromatografía, la electroforesis, las modificaciones del potencial de oxidorreducción y la valoración de ciertos productos de oxidación parecen los métodos más prometedores. Continúa siendo necesario efectuar algunas investigaciones importantes en las que se han de tener presentes diferentes imperativos:
- el método debe ser lo más específico posible - cualitativo, y, si es posible, cuantitativo;
- los resultados deben provenir de ensayos realizados paralelamente con productos irradiados, con productos no irradiados y con productos conservados por otros procedimientos;
- los ensayos deben extenderse a todo el tiempo que dure la conservación habitual de los productos antes de su consumo para poder comprobar si las modificaciones que eventualmente se observen se mantienen, se acentúan o desaparecen;
- por último, el método debe ser lo más universal posible, teniendo en cuenta la variedad de productos que pueden irradiarse, las modalidades de la irradiación y las dosis administradas.

1. REGLEMENTATION

D'un intérêt purement militaire au début, les recherches sur l'irradiation des denrées alimentaires ont progressivement passé au domaine civil et nous sommes au seuil de la commercialisation de produits irradiés. Certains pays ont déjà admis le procédé pour certaines denrées et dans certaines conditions, mais la persistance de certains doutes quant à leur innocuité et la nécessité de mieux connaître les exigences à fixer pour la mise en œuvre des techniques d'irradiation expliquent que certains pays aient adopté une attitude de prudence. C'est le cas de la Belgique, qui a estimé devoir recourir à l'interdiction de principe tout en envisageant des dérogations et une libéralisation progressive en fonction des progrès des connaissances. Une telle position permet mieux aux autorités de la Santé publique de suivre le problème en même temps qu'elle évite aux technologues des innovations qui risquent de déboucher sur une impossibilité pratique.

La réglementation belge apparaît dans l'arrêté royal du 28 février 1963, paru au Moniteur du 16 mai de la même année et portant règlement général de la protection de la population et des travailleurs contre le danger des radiations ionisantes. Cet arrêté, en son article 64.1 b) et c), interdit

«b) d'ajouter des substances radioactives aux denrées alimentaires, aux produits de beauté, aux cosmétiques, aux jouets et aux produits et objets à usage domestique;

c) de traiter des denrées alimentaires ou des médicaments à l'aide de radiations ionisantes.»

En son article 64.2, le même arrêté interdit l'importation, la détention et le transport de tels produits.

Toutefois, dès maintenant, en vertu de l'article 65, sont autorisés moyennant autorisation préalable du Ministère de la Santé publique:

«a) l'incorporation de substances radioactives aux denrées alimentaires à des fins de recherches;

b) le traitement des denrées alimentaires ou de médicaments à l'aide de radiations ionisantes à des fins de recherche.»
Cette disposition permet donc, dès à présent, les recherches indispensables sur les plans scientifique et technique, mais elle n’autorise pas, par exemple, d’essais expérimentaux de diffusion de denrées pour connaître les réactions du public et des consommateurs.

L’évolution des connaissances permettra vraisemblablement dans un avenir plus ou moins rapproché un assouplissement dans certains domaines spécifiques et pour certaines denrées déterminées, pour autant que soit respectée la condition essentielle qu’est la protection de la santé du consommateur et que le procédé de traitement et le produit irradié et livré à la consommation répondent aux prescriptions réglementaires concernant les denrées alimentaires.

La tendance est d’envisager parallèlement l’irradiation des denrées et celle des médicaments et du matériel médical: à ce propos, il y a lieu de signaler qu’une proposition est soumise aux instances responsables en vue d’autoriser la stérilisation par les radiations du matériel médical.

2. IDENTIFICATION

Il est évident qu’une libéralisation des procédés d’irradiation des denrées suppose une série de conditions sur le plan national et sur le plan international.

Il est indispensable d’établir des principes aussi normatifs que possible, qui devraient être admis internationalement, sur les techniques d’irradiation à utiliser, sur les associations éventuelles de l’irradiation avec d’autres méthodes conventionnelles de conservation, sur les conditions d’emballage des produits à irradier et sur les contrôles à appliquer aux denrées mêmes.

Il est par ailleurs nécessaire de pouvoir s’assurer que les procédés utilisés n’ont pas été indûment appliqués à des denrées pour lesquelles ils n’étaient pas autorisés et que les doses tolérées ont été respectées.

Sont posées par conséquent la question de l’identification des produits irradiés et celle de la connaissance de la dose utilisée pour l’irradiation.

Tant que des méthodes pratiques de détection de l’irradiation et d’estimation de la dose appliquée n’auront pas été établies et admises, la surveillance des denrées irradiées posera des problèmes délicats sur le plan national, et plus encore sur le plan international lorsque le circuit commercial s’étendra au-delà des frontières. S’il est vrai que, même en l’absence de méthodes valables, des accords restent possibles sur le plan réglementaire, il est certain que les possibilités d’identification et d’estimation des doses entraîneraient une diminution des réticences de la part des autorités sanitaires et, partant, favoriseraient indiscutablement l’extension des procédés d’irradiation. Toutefois, il faut reconnaître que le problème est difficile à résoudre, car
- les buts recherchés sont extrêmement variables suivant les denrées;
- les doses appliquées sont extrêmement variables en fonction du but recherché;
- les modifications apportées aux denrées par l’irradiation sont souvent loin d’être spécifiques.

Nous rappellerons que les principaux buts recherchés sont
- provoquer un effet microbicide pour aboutir, soit à une stérilisation de la denrée analogue à celle obtenue par des procédés thermiques, soit à une pasteurisation visant à une diminution du nombre total de germes
avec prolongation de la conservation dans des conditions plus aisément réalisables ou la destruction de certains germes pathogènes relativement radiosensibles;
- modifier les caractéristiques physico-chimiques et enzymatiques de certains fruits et légumes en vue d’en améliorer la conservation ou d’en modifier la maturation;
- désinfecter les denrées contaminées par des insectes ou des parasites;
- inhiber les phénomènes de germination et de croissance.

Les denrées envisagées sont très variées et les doses utilisées s’étagent entre 8 krad et 6 Mrad suivant le but recherché: on comprend aisément que les modifications puissent être plus ou moins importantes.

Par ailleurs, tout en reconnaissant qu’aucun procédé de conservation n’est exempt d’effets secondaires désagréables, voire regrettables, il faut reconnaître que certains inconvénients seraient plus particulièrement à redouter après irradiation:
- une altération des caractéristiques organoleptiques dont les conséquences sont plus économiques que sanitaires;
- une modification de la situation microbiologique de l’aliment:
  a) la résistance sélective de certains micro-organismes toxigènes, comme Clostridium botulinum, oblige à un contrôle particulièrement strict pour en écarter le danger;
  b) la sélection par radiorésistance relative de certaines espèces bactériennes ou fungiques peut, après irradiation, poser des problèmes de comestibilité d’une part et de conservation subséquente d’autre part;
  c) l’induction éventuelle de mutants dont l’action pathogène ou biochimique est imprévisible;
- une altération de la qualité nutritionnelle par destruction ou altération de certains nutriments essentiels;
- l’apparition possible de substances toxiques cancérigènes ou mutagènes: les multiples expériences réalisées jusqu’à présent, bien qu’en général favorables, ne permettent pas encore de tirer des conclusions formelles et des doutes subsistent qui justifient une attitude réservée dans le cas de nombreux produits et de nouvelles recherches sur les mécanismes de défense éventuellement mis en œuvre par les organismes supérieurs pour parer aux agressions potentielles;
- l’apparition d’une radioactivité induite si le produit a été indûment traité par des rayonnements d’énergie trop élevée; un tel risque n’existe pas pour les procédés préconisés utilisant les rayonnements gamma du cobalt ou des électrons accélérés à une énergie inférieure à 10 MeV.

Pour exercer la surveillance des procédures d’irradiation, contrôler les inconvénients éventuels des denrées pour lesquelles l’irradiation est admise, écarter l’emploi de l’irradiation de denrées pour lesquelles elle n’est pas acceptée, éviter l’irradiation intempestivement répétée d’une même denrée, vérifier si les denrées irradiées sont conservées dans les conditions appropriées, il est nécessaire que les autorités compétentes puissent identifier les denrées irradiées et connaître le procédé utilisé ainsi que la dose administrée.

On peut naturellement imaginer un système d’étiquetage approprié indiquant que le produit a été irradié, la qualité du rayonnement utilisé et la dose administrée. Ces informations peuvent être complétées par
L'introduction de témoins d'irradiation dont les modifications sont relativement spécifiques et dans certaines limites en relation avec la dose.

Néanmoins, un tel étiquetage n'est valable que si la loyauté commerciale est indiscutable. De plus un tel étiquetage peut être pratiquement impossible à appliquer dans le cas de certaines denrées, par exemple des grains irradiés en vrac pour la destruction des prédateurs. L'étiquetage peut être également critiqué pour des raisons psychologiques. Par ailleurs, il peut ne pas être exigé pour certaines denrées loyalement traitées dans le pays de production mais exportées vers d'autres pays où l'irradiation est interdite. Enfin, des raisons nettement frauduleuses peuvent amener certains producteurs peu scrupuleux à irradier sans discrimination une série de produits qu'ils auront soin de ne pas étiqueter.

Ces divers arguments suffisent à expliquer l'intérêt, voire la nécessité de techniques qui permettraient d'identifier l'irradiation antérieure d'une denrée, de distinguer, si possible, la denrée irradiée de la même denrée conservée par d'autres procédés et de déterminer la dose d'irradiation délivrée à la denrée.

De telles techniques doivent autant que possible être applicables à la denrée elle-même, surtout si elle est présentée en vrac. Il est pourtant certain qu'une méthode non négligeable d'approche du problème est celle qui vise à se servir de l'emballage de la denrée comme indicateur (par exemple l'incorporation d'indicateurs colorés à la matière de l'emballage ou l'étude des modifications structurales de certains polymères). Encore faut-il, pour qu'une telle méthode soit valable, que les techniques d'emballage soient réglementées et normalisées sur le plan international et, encore une fois, qu'il n'y ait pas de fraude.

Nous citerons d'abord, parmi les méthodes portant sur la denrée elle-même, certaines techniques très élaborées, généralement difficiles à mettre en pratique, même si elles sont suffisamment spécifiques et permettent d'évaluer la dose, par exemple l'établissement des proportions entre les divers constituants de la population microbiologique ou l'étude des modifications structurales de certains polymères. Encore faut-il, pour qu'une telle méthode soit valable, que les techniques d'emballage soient réglementées et normalisées sur le plan international et, encore une fois, qu'il n'y ait pas de fraude.

Nous énumérons ci-après les méthodes qui permettent certains espoirs (voir tableau I):

a) Les technologues signalent pour de nombreux produits des modifications caractéristiques des propriétés organo-nectiques; de telles modifications pourraient être utilisées surtout si elles peuvent être objectivées par des techniques physico-chimiques comme la distillation fractionnée à basse pression, la chromatographie en phase gazeuse, etc.

b) Les modifications du potentiel d'oxydo-réduction pourraient être appliquées au poisson et à la viande. Si la relation entre le potentiel redox et la dose n'est pas encore suffisamment établie, il est indiscutable que, pour la dose de 3 Mrad, les courbes permettent une distinction indiscutable entre viande et poisson irradiés ou non. Cette méthode pourrait éventuellement être étendue à d'autres denrées suffisamment riches en protéines: si elle n'est pas spécifique et si elle est influencée par certains facteurs enzymatiques ou microbiologiques, elle est aisée et rapide.
### TABLEAU I. MÉTHODES ENVISAGEES

<table>
<thead>
<tr>
<th>Doses (Mrad)</th>
<th>Denrées</th>
<th>But recherché</th>
<th>Technique applicable</th>
</tr>
</thead>
<tbody>
<tr>
<td>4 à 6</td>
<td>Viandes, poissons</td>
<td>Stérilisation</td>
<td>Chromatographie, Electrophorèse, Immunoélectrophorèse, Colorimétrie, Altération de texture, Spectrophotométrie, Modification de l'état paramagnétique (?), Modifications organoleptiques (?)</td>
</tr>
<tr>
<td></td>
<td>Autres denrées hautement périssables</td>
<td></td>
<td></td>
</tr>
<tr>
<td>0,3 à 1</td>
<td>Œufs liquides et en poudre</td>
<td>Pasteurisation</td>
<td>Modification du potentiel redox, Spectrophotométrie, Electrophorèse (?), Chromatographie, Modification de l'état paramagnétique (?), Modifications organoleptiques (?)</td>
</tr>
<tr>
<td></td>
<td>Viandes congelées, volailles</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Aliments susceptibles d'être contaminés par des pathogènes</td>
<td></td>
<td></td>
</tr>
<tr>
<td>0,08 à 0,3</td>
<td>Viandes parasitées</td>
<td>Désinsectisation</td>
<td>Technique histologique (?), Modification de certains processus enzymatiques (?)</td>
</tr>
<tr>
<td></td>
<td>Céréales, farines, fruits frais et desséchés contaminés par les insectes</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Tubercules et bulbes</td>
<td>Inhibition de la germination</td>
<td></td>
</tr>
</tbody>
</table>
c) Pour les jus de fruits et éventuellement pour la viande, une technique spectrophotométrique est éventuellement utilisable; elle est fondée sur le fait qu'il se produit, notamment au niveau des jus, des modifications optiques apparentement spécifiques liées aux altérations relatives des sucres présents. L'application de cette méthode à la farine et aux poudres d'œufs irradiés est également encourageante, mais ces extractions préliminaires sont laborieuses et lentes et le procédé ne peut être appliqué qu'aux produits irradiés à doses élevées.

d) La polarographie est relativement simple et rapide mais les extractions et concentrations préalables sont longues, les produits dosés ne sont pas spécifiques et la technique exige un personnel spécialisé.

e) L'extraction fractionnée avec analyse chromatographique des fractions, sans être spécifique ni très sensible tout en étant laborieuse, peut être appliquée à de nombreux aliments comme technique complémentaire.

f) L'électrophorèse peut être utilisée pour les aliments riches en protéines mais les altérations décelées ne sont pas spécifiques et n'apparaissent que pour des doses de plus d'un Mrad.

g) Si les techniques microbiologiques et immunologiques ont donné des résultats décevants, il n'est pas impossible que l'immunoélectrophorèse soit utile; nous avons pu obtenir des résultats intéressants pour les viandes, permettant de distinguer un produit irradié d'un produit traité par la chaleur.

h) La colorimétrie, visant à apprécier l'apparition de produits carbonylés de courte chaîne, pourrait rendre des services comme technique accessoire.

j) Certaines techniques, comme la colorimétrie comparative et l'appréciation de la texture (coefficient d'exsudation, coefficient d'extrait liquideux par compression, tendreté, élasticité, viscosité, résistance à l'écrasement) pourraient être utiles pour la viande.

k) L'examen de la structure microscopique pourrait être utile pour les bulbes comme l'oignon; elle ne paraît pas utilisable pour la viande.

Aucune technique n'est actuellement au point, mais en combinant plusieurs d'entre elles, il est possible de conclure à la haute probabilité d'une irradiation, du moins pour les doses relativement élevées. Cette probabilité est grandement accrue si les mêmes méthodes peuvent être appliquées à la même denrée non traitée et traitée par des procédés conventionnels de conservation, aux fins de comparaison.

Pourtant, jusqu'à présent la plupart des essais n'ont pas pris en considération l'évolution des modifications décelables au cours de la conservation de la denrée; or il est évident qu'une méthode, pour être valable, doit être applicable à la denrée pendant le temps de conservation commercialement justifié.

Par ailleurs, les résultats prometteurs ne sont généralement obtenus que pour des doses d'irradiation élevées: pour les doses faibles d'irradi-
ation, comme celles utilisées pour inhiber la germination des pommes de terre ou pour désinsectiser les grains et même celles utilisées pour la maturation des fruits et légumes et pour la pasteurisation, les résultats sont beaucoup plus aléatoires.

Malgré l'insuffisance actuelle des résultats obtenus, il faut espérer qu'une ou des techniques puissent être élaborées qui permettraient de répondre aux critères suivants:
- simplicité et rapidité (en raison du nombre d'échantillons relativement élevé pouvant être soumis à l'analyse);
- réponse dans un délai raisonnable (en raison des délais d'utilisation de certains aliments et des difficultés d'entreposage pour certaines denrées) et persistance de la réponse dans le temps;
- prix de revient modéré et possibilité de mise en œuvre par un laboratoire doté d'un appareillage non hautement spécialisé et d'un personnel normalement qualifié;
- spécificité et si possible relation avec la dose;
- universalité aussi grande que possible pour être applicable à la plus grande gamme possible de denrées et de doses d'irradiation.

Les recherches actuellement conduites dans ce domaine doivent être menées en fonction de ces critères. Elles doivent de plus être appliquées parallèlement à des produits irradiés, à des produits non traités et à des produits conservés par d'autres procédés. Elles doivent en outre être étendues dans le temps au moins aussi longtemps que dure la conservation commerciale habituelle des denrées avant leur consommation, et cela afin de savoir si les modifications éventuellement constatées se maintiennent, s'accentuent ou disparaissent.

CONCLUSIONS

La réglementation belge est fondée sur une interdiction de principe: elle permet des dérogations à des fins de recherches. Cette position paraît sage parce qu'elle permet une libéralisation progressive en fonction du progrès des connaissances et des résultats des études toxicologiques et microbiologiques préalables établissant l'innocuité aussi bien que les avantages du procédé pour la ou les denrées considérées.

Une attitude plus libérale suppose, en outre, la possibilité de distinguer les denrées irradiées et de connaître la dose qui a été appliquée. À l'heure actuelle, aucune technique idéale et spécifique applicable à la denrée même n'a été élaborée, mais la combinaison de plusieurs techniques (surtout si l'on compare la même denrée non irradiée ou traitée par des procédés conventionnels de conservation) permet de conclure à une haute probabilité, au moins pour les doses d'irradiation élevées. Les recherches doivent être continuées en tenant compte des diverses denrées susceptibles d'être irradiées, des doses utilisées, de la durée de conservation du produit irradié.
J. VERGRAGT: In a field which is developing so rapidly, I should think that a system which empowers a minister to issue licences permitting food irradiation under certain conditions is less cumbersome than, and hence preferable to, the Belgian system of prohibition in principle, with the possibility of permitting exceptions.

A. LAFONTAINE: The system of prohibition with possible exceptions may be more or less cumbersome, depending on the legal system of the country. There are many ways of granting exceptions, but in all cases the public health authorities must be in a position to lay down specific conditions with regard to the processes to be used and the foodstuffs to be treated.
NEED FOR MICROBIOLOGICAL CONTROLS
IN LEGISLATION ON IRRADIATED FOOD

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Abstract — Résumé — Аннотация — Resumen

NEED FOR MICROBIOLOGICAL CONTROLS IN LEGISLATION ON IRRADIATED FOOD. One of the principal values of ionizing radiation for food preservation arises from the ability to destroy the microorganisms and insects which cause food spoilage and deterioration. The objectives of food preservation by radiation treatment can be divided into three categories: (a) destruction of spoilage and pathogenic microorganisms in the food (radappertization) so that microbial spoilage will not take place regardless of the storage conditions; (b) treatment of food to destroy viable non-spore-forming pathogenic microorganisms (radicidation); and (c) reduction of numbers of spoilage microorganisms sufficient to enhance the keeping quality of the food (radurization). In any legislation on the radiation treatment of food there is need for microbiological control to ensure that the objectives of the treatment have been met or that a public health hazard is not likely. If claims are made that a process accomplishes any of these objectives, there must exist microbiological methods and techniques with which to establish proof of attainment of that objective. This points to the need for standardized microbiological procedures to be incorporated into control legislation. Discussion on the various problems involved is presented.
NECESIDAD DE CONTROLES MICROBIOLOGICOS EN LA LEGISLACION RELATIVA A LOS ALIMENTOS IRRADIADOS. Una de las principales ventajas del empleo de las radiaciones ionizantes en la conservación de alimentos estriba en que permiten eliminar los microorganismos e insectos que los deterioran y descomponen. Los objetivos de la radioconservación de los alimentos pueden agruparse en tres categorías: a) Destrucción de los microorganismos patógenos que estropean los alimentos (radapertización) a fin de que no causen un deterioro independientemente de las condiciones de almacenamiento; b) tratamiento de los alimentos para destruir los microorganismos patógenos viables que no forman esporas (radicidación), y c) reducción suficiente del número de los microorganismos que causan el deterioro a fin de conservar la calidad de los alimentos (radurización). En las disposiciones relativas a la irradiación de los alimentos es necesario introducir el control microbiológico para cerciorarse de que se han alcanzado los objetivos del tratamiento o de que no se presentará ningún riesgo sanitario. Cuando se pretenda que un proceso cumpla estos requisitos, debe recurrirse a técnicas y métodos microbiológicos para demostrarlo. Por ello es necesario incorporar procedimientos microbiológicos normalizados en la legislación sobre el control de los alimentos. En la memoria se examinan diversos problemas relacionados con esta operación.

The purpose of any food preservation process is to control or limit the growth of agents likely to cause deterioration of food during storage or marketing. The degree to which the processing is required depends upon the type of preservation desired, and the circumstances under which the food is likely to be held. One of the principal values of ionizing radiation for food preservation is the ability to destroy, without the application of heat, microorganisms and insects which cause food spoilage and deterioration. The objectives of food preservation by ionizing radiation are divided into three categories:

(a) The destruction of spoilage and pathogenic microorganisms in the food to such a degree that microbial spoilage does not occur regardless of storage conditions;
(b) Treatment of food to destroy viable non-spore-forming pathogenic microorganisms so that there is no potential health hazard; and
(c) Reduction in the number of spoilage microorganisms in a sufficient amount to enhance the keeping quality of the food.

These objectives are clearly described by Ingram et al. in these Proceedings [1, 2] and are discussed as Radappertization, Radicidation and Radurization, respectively.

In the Report of a joint FAO/WHO/IAEA1 Expert Committee which met in Rome in 1964 [3] it is stated that the manufacture, storage, and distribution of irradiated food should be controlled by national legislation. Such legislation should incorporate certain requirements believed to be necessary to accomplish the purposes of the irradiation process, and to protect the health of the people.

Josephson, in his paper in these Proceedings [4], discusses the need for and the means of obtaining clearance for the human consumption of irradiated food in compliance with one type of national legislation. The author describes the need for microbiological controls in legislation, to assure that the aims of the various types of treatment are attained, or

1 Food and Agriculture Organization of the United Nations/World Health Organization/International Atomic Energy Agency
that any claims made for a certain process are fulfilled. As an example, if a process is designed to rid a food product of organisms of public health significance, and this is not achieved, the product could become a potential public health hazard. Legislation on irradiated food should incorporate safeguards to ensure that a particular process achieves its purpose. The three categories of irradiation treatment are described below in regard to possible differences in legislative requirements.

RADAPPERTIZATION

Ingram and Roberts [1] defined this treatment as being one "...to produce an indefinitely stable article, by destroying most, or ideally all, of the microorganisms in the food". If this occurs, there is no microbial problem. If, however, for some reason the microorganisms are not destroyed, then a problem exists, and legislative controls should be available to prevent the occurrence of such a problem. In the thermal processing of food, inadequate treatment generally manifests itself by spoilage and swelling of the food containers; there is usually little likelihood that toxin is formed in containers not exhibiting such defects. In radiation-processed food a different situation is possible. For example, the spores of *Clostridium botulinum* are known to be more radioresistant than any other spore-forming spoilage microorganism and it is therefore conceivable that, in an under-processed product, toxin may have been formed by this type of organism without spoilage being evident.

It is improbable that the conventional incubation of a statistically significant number of containers, as practised in the canning industry, will produce sufficient evidence of spoilage to be of value in irradiated food. The routine search for possible toxin production in containers of food, on a commercial scale, by animal testing would be prohibitive in cost of time, personnel, and the destructive sampling of the product, and would prove of doubtful value. It seems logical, therefore, to place controls on the processing of food so as to guarantee an adequate process for the destruction of spores of *Clostridium botulinum*.

It has been shown that the amount of absorbed radiation necessary to destroy a certain organism differs, depending on the food and conditions of the organism in the environment. Since different foods present different conditions, it follows that the radiation-dose requirement is not the same for all foods. Thus, determination of the processing requirement must be made for each type of food.

One conventional way of determining the radiation dose necessary for a food is to determine the "D-value" for the organism in the particular food. The D-value is the radiation dose required to obtain a 90% reduction in the number of the specific microorganisms in the sample. By determining the D-values experimentally over as wide a range of killing as possible, a radiation process can be evolved. These determinations produce values from which the absorbed dose necessary to guarantee the destruction of the specific organism in the particular food can be calculated.

Legislative controls for the Radappertization of a food could be enacted by requiring the presentation of adequate scientific data establishing the destructive radiation dose range for the food. This radiation dose could then be made a requirement for that particular type of food. Proof of the
accuracy of the delivery of this dose could be established by the submission of automatically recorded data regarding the operation of the plant when each particular lot of food was processed. For example, if the necessary absorbed dose for a particular food had been established as 4.0 Mrad, evidence must be submitted that this dose was in fact delivered to the particular lot of food. A certificate could be used not only for proof of compliance within the country of origin, but may be useful also in international trade.

RADICATION

This radiation treatment is to destroy in food organisms of interest to public health. The foods involved may vary from dry foods of low-water activity to liquid foods, and may be raw, or processed foods of plant or animal origin. Since it is not possible to devise a single radiation treatment covering such a wide range of products, with different environmental conditions for the microorganisms, it would be necessary to control such a process on the basis of the individual products. Ingram and Roberts [1] describe variances in the radiation dose required to kill the same type of organism in different products and under different conditions.

If a food is treated by radiation to eliminate pathogens of possible hazard to health, such as those causing food poisoning, the treatment must accomplish this, or it is of little value. Microbiological controls are therefore needed to ensure adequacy of treatment for the purpose intended. Legislation should require proof of adequacy of the treatment proposed to control specific pathogens in a particular food. The radiation dose should be that necessary to control the highest population of the particular pathogens expected to occur in a food of acceptable quality. By determining the D-value for the specific pathogens in the food under consideration, and assuming a certain population value of the organisms to be controlled, calculation of the absorbed radiation dose required can be made. Ingram and Roberts [1] give an excellent example, in discussing Radicidation, of the manner in which they arrived at the radiation dose necessary to eliminate contamination by Salmonellae in frozen egg; the radiation treatment was established at seven times the experimental D-value for Salmonellae in frozen egg.

If the food is a perishable product, other precautions must be taken into consideration, such as the prevention of recontamination after treatment, and possibilities of the outgrowth at elevated temperatures of certain pathogens not killed by the treatment. For example, if normally the food product is refrigerated to prevent spoilage, there is no reason to expect that it will keep without refrigeration merely because it has received radiation treatment to kill certain pathogens. Also, a Radicidation treatment offers no safeguard against danger resulting from subsequent contamination with pathogens. Legislation should cover not only the requirements for the treatment, but the safeguards to be employed in handling the products after treatment.

RADURIZATION

This radiation treatment is to extend the normal shelf or market life of perishable food products by markedly reducing the number of spoilage
microorganisms in the food. Usually, this treatment would be given to products of moderate to high moisture content, such as fresh fruit and vegetables, fresh meats, fish and poultry, and certain compounded or pre-cooked foods.

Legislative controls are needed to ensure that the treatment has been used to accomplish the results intended, and not to cover up the inferiority of a product by reducing the microbial population. Radiation treatment should never be allowed to be used as a substitute for good-quality raw products, or for good sanitary practices in their handling. Also, a marked departure from the normal practices of handling and shipping of the product should not be permitted, such as substituting room temperature for refrigeration. The radiation treatment should be designed to reduce in number those organisms commonly causing spoilage under usual conditions of handling. With meat, fish and poultry, the normal spoilage flora consists mainly of cold-tolerant organisms, which can be markedly reduced in number by fairly low doses of ionizing radiation. If, after treatment, the product is no longer stored at refrigeration temperature, the spoilage flora that develops can be expected to be of a different type.

Since the purpose of Radurization treatment is to extend the shelf life, and not to kill pathogens possibly present, precautions must be taken to prevent conditions which may give rise to the outgrowth of pathogens. For example, cool temperatures normally retard the growth of pathogens, but if there is marked elevation in temperature, the outgrowth of certain pathogens could become a health hazard. Rhodes et al. [5] suggest 10 days to be considered as a safe storage life for packaged irradiated fish when stored at 4.4°C. No difficulty is foreseen if the storage temperature is 3.3°C, or lower.

Legislative controls should take into consideration the radiation dose permitted for the Radurization of food, and should guard against a possible assumption or claim that the product is pathogen-free because it has received radiation treatment. Controls should be exerted also over the quality of the raw product, the packaging, and the storage and handling conditions for products in this category. In certain cases, such as pre-cooked or compounded food, the problem of accidental contamination with pathogens must be avoided.

MICROBIOLOGICAL REQUIREMENTS AND METHODS

Any legislation dealing with microbiological requirements should also designate the particular conditions under which the microorganisms are to be identified and/or enumerated. This is necessary to establish a common ground for all parties concerned. There should be common understanding of the requirements, and of the methods used to enforce them. This would eliminate most of the misunderstandings likely to result from the rejection of a product.

There are many different types of microbiological methods and culture media in use in laboratories in the world, and these often vary from country to country, and between different laboratories. Since all the methods are not of equal sensitivity, or of equal productivity in bacterial growth, it is desirable to select those methods and culture media that will best meet the particular requirements for compliance with the regulations of the country.

This factor in the legislative controls of irradiated food was recognized by the joint FAO/WHO/IAEA Expert Committee [3], when they recommended that
"...The methods and standards used to ensure the microbiological safety of the irradiated product should, as a matter of urgency, be subject to review by competent international bodies in order that internationally acceptable methods and standards may be agreed upon".

This advice was put into action through the convening of a FAO/IAEA Panel of Experts in Vienna in June 1965 [6]. The Panel took into consideration the requirements for the three categories of radiation-treated foods and tried to simplify, as far as possible, the microbiological requirements in determining the effectiveness of the treatment. Wherever possible a single, reliable, simple and practicable method for identification of specific microorganisms, or estimation of their numbers, was recommended. The FAO/IAEA Report will be forwarded to Member States for their information, and possible voluntary use in the preparation of any contemplated legislation on irradiated food.

Legislative controls should be made as simple as possible in accordance with the aims. Methods of determining compliance should not be complicated or difficult to carry out. Laboratory determinations on samples of the product should be kept to a minimum, as lengthy and expensive procedures add markedly to the cost of conforming to the requirements of the regulations. Undue delays caused by lengthy procedures prevent rapid handling in industry and cause high costs in the movement of treated food products. It is preferable to establish controls that give confidence in the safety and wholesomeness of the food products and allow them to flow normally to the market-place, rather than cause each lot to be processed through a clearance procedure before being released. An orderly procedure, comprising periodic plant visits and tests of the products to determine the degree of compliance with the regulations, should be drawn up. A considerable part of the 'burden of proof' should be placed upon the producer by requiring the periodic completion of automatically recorded records of processing together with the results of certain routine tests performed in the laboratory of the company. Such procedures should be arrived at through mutual understanding. Periodic check sampling by the regulatory agency should give assurance that the radiation process is under adequate and effective control.

There is a definite need to establish such controls in a way which meets the needs of international trade in irradiated products. Marked differences in requirement from country to country may hinder the free flow of products due to difficulties in irradiating products to meet many different requirements. It is therefore recommended that an attempt be made to incorporate similar legislative requirements and similar methods of determining compliance into individual national regulations so as to facilitate the international exchange of irradiated products. Through discussions at international meetings, and the exchange of information between countries normally trading with each other, it should be possible to arrive at a common basis for agreement on the controls necessary in the manufacture, handling, export and import of irradiated food products.

REFERENCES


In closing this final session I have also the task of trying to distil, from a general impression of the proceedings, a brief conclusion as to the progress we have made since the last meeting of this kind was held in Europe, at Harwell nearly ten years ago. I do not find this easy, since so much has happened in the meantime and most of the important things have already been said.

In those early days many regarded irradiation as a universal panacea, although opinions ranged from inevitable pessimism to rash enthusiasm. The range of opinion was indeed so wide that it was hard to see where a proper judgement should lie. Since then, however, various things have in my opinion swung the balance in a definitely hopeful direction.

First, the range of conceivable uses has been considerably extended, and there is now a greater number of situations where irradiation offers the prospect of a unique means to attain a desired end. This is especially true of low-dose treatments, which received relatively little attention until the comparatively late arrival on the scene of the US Atomic Energy Commission (USAEC). I know, of course, that among the participants in this Symposium is a small band of investigators who, even in 1958, had for some time been trying low-dose treatments, but their resources were trifling compared with those of the Quartermaster sterilization programme, and it is only since the intervention of the USAEC that world effort has been directed predominantly at low-dose treatments.

Second, and more significant, we have made notable progress in dealing with some of our long-standing problems. For instance, they now know at Natick how to improve substantially the acceptability of their radappertized items. And, if you think their latest process too expensive to be practical, remember the history of radar and jet aircraft. Similarly, with Salmonella radicidation, there is now a much better understanding of the principles involved than there was a few years ago, and a rapidly growing appreciation by public health authorities of the help that such a process could give in some of their problems.

Third, it has become more widely realized that irradiation is in fact not a universal panacea, and that each process must be regarded in the light of economic possibilities and the structure of the relevant industry. In fact, several speakers at this Symposium have emphasized the need for such "feasibility studies", and Session 8 was devoted to some of the most important economic factors. What is more, we are beginning to gain experience in making feasibility studies; and though many of them may prove to be unfavourable or unnecessary, like that on sprout inhibition with potatoes in the United Kingdom, there are applications, such as Salmonella radicidation on frozen horse meat imported into the United Kingdom, where the outlook seems favourable. In some other countries the prospects are even better.

Fourth, it is certain that quality acceptable to the consumer can be achieved. In fact there are several less ambitious but potentially useful
applications where the irradiated product is unlikely to be distinguished from the normal product by the consumer. The doubtful factor is the consumer reaction to the description "irradiated", as Mr. Killam remarked.

Lastly, and perhaps most important, the conviction is growing that irradiated foods are not dangerous. This is the result of a test programme of unprecedented scope, the main results of which have shown that, with evident limitations, there is no danger from induced radioactivity; the foods are not grossly toxic, nor do they seem likely to be carcinogenic, and the nutritional changes are usually trifling and quite normal for food processing.

In only two respects would I myself have reservations. First, we do not seem well provided with evidence to refute recent insinuations, based on experience of debatable relevance with very different organisms, that irradiated food might cause reproductive abnormalities in man or his domestic animals. I am surprised that this topic has scarcely been mentioned at the Symposium.

Second, in non-sterilizing treatments with the highly perishable foods, we have failed to adjust ourselves to a number of microbiological problems; it is noteworthy that the Soviet health authorities were prompt to accept processes for fruits, where there are no such problems, but have not yet accepted proposals for fish, where such problems exist. Mr. Shea apparently shared this view when he suggested that the first successful civil application in the United States might well be for strawberries. We have not in the past concentrated on proposals most likely to avoid these difficulties.

It seems certain that the only thing which now prevents the application of irradiation to foods is the reluctance of health authorities to approve the process, doubtless for the kind of reason just mentioned. Ten years ago already, my own group wanted limited marketing tests based on our proposals for radurization of poultry, and there are certainly others present who have been in a similar situation. This was why, at the Brussels conference on wholesomeness in 1961, participants emphasized the desirability of making legal provision for this kind of trial under suitable supervision, in order to minimize the long delays inevitable in resolving the wholesomeness question. The apostles of free enterprise have evidently noticed with chagrin that our Russian counterparts have been the more effective in grappling with this crucial problem. The Canadian authorities were bold in deciding to embark on a low-dose treatment of potatoes without more ado. The Canadians were similarly bold in approving antibiotics as food preservatives. Those countries which are the first to arrive at such decisions will be first in these new fields, and I hope a hypersensitive attitude will not prevail in the countries whose need is greatest.
INTERNATIONAL SYMPOSIUM ON FOOD IRRADIATION
HELD AT KARLSRUHE, 6-10 JUNE 1966

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