FOOD IRRADIATION PROCESSING
FOOD IRRADIATION PROCESSING

PROCEEDINGS OF AN INTERNATIONAL SYMPOSIUM ON FOOD IRRADIATION PROCESSING JOINTLY ORGANIZED BY THE INTERNATIONAL ATOMIC ENERGY AGENCY AND THE FOOD AND AGRICULTURE ORGANIZATION OF THE UNITED NATIONS AND HELD IN WASHINGTON, D.C., 4–8 MARCH 1985

INTERNATIONAL ATOMIC ENERGY AGENCY VIENNA, 1985
The recommendation by the Joint FAO/IAEA/WHO Expert Committee on the Wholesomeness of Irradiated Foods in 1980 regarding the acceptability of food irradiated up to an overall average dose of 10 kGy, and the adoption of the Codex General Standard for Irradiated Foods by the Codex Alimentarius Commission in 1983 have contributed greatly to a wider acceptance of food irradiation. At present, the national public health authorities of 26 countries have granted some 140 unconditional or provisional clearances covering many different food products. While approvals and national legislation are of primary importance to the commercialization of food irradiation, the current disharmony of existing and proposed national legislation constitutes a significant obstacle to the economic introduction of the food irradiation process and makes trade of irradiated foods between countries almost impossible.

In the light of such a situation, it appeared timely to hold an international symposium on food irradiation processing dealing with issues which affect the commercial introduction of the food irradiation process.

The symposium, which attracted close to 300 participants, was planned to interest not only scientists and food technologists, but also representatives of government agencies, the food industry, trade associations and consumer organizations.

The symposium included a discussion of the technological and economic feasibility of applying ionizing energy for the preservation of food, and focused on the specific needs of developing countries.

It is rewarding for all the participants and those reading the proceedings of this symposium to see that two essential prerequisites to the introduction of the food irradiation process have been met, i.e. the demonstration of its technological efficacy and the acquisition of unequivocal evidence of the wholesomeness of irradiated food. The following tasks requiring further attention were identified: demonstrating the economic feasibility and the benefits accruing from the practical application of the food irradiation process; establishing an adequate legislative framework in member countries based on the provisions of the Codex Standard; promoting the acceptance of the concept of food irradiation by the consumer.

The sponsoring organizations hope that the proceedings will serve as a guide and valuable book for all those engaged in food irradiation and carrying responsibility for the adoption of this beneficial technology.

Sincere appreciation is expressed to the Government of the United States of America for hosting this symposium, and providing excellent facilities that helped greatly toward the success of the meeting.
EDITORIAL NOTE

The papers and discussions have been edited by the editorial staff of the International Atomic Energy Agency to the extent considered necessary for the reader's assistance. The views expressed and the general style adopted remain, however, the responsibility of the named authors or participants. In addition, the views are not necessarily those of the governments of the nominating Member States or of the nominating organizations.

Where papers have been incorporated into these Proceedings without resetting by the Agency, this has been done with the knowledge of the authors and their government authorities, and their cooperation is gratefully acknowledged. The Proceedings have been printed by composition typing and photo-offset lithography. Within the limitations imposed by this method, every effort has been made to maintain a high editorial standard, in particular to achieve, wherever practicable, consistency of units and symbols and conformity to the standards recommended by competent international bodies.

The use in these Proceedings of particular designations of countries or territories does not imply any judgement by the publisher, the IAEA, as to the legal status of such countries or territories, of their authorities and institutions or of the delimitation of their boundaries.

The mention of specific companies or of their products or brand names does not imply any endorsement or recommendation on the part of the IAEA.

Authors are themselves responsible for obtaining the necessary permission to reproduce copyright material from other sources.
CONTENTS

FEASIBILITY OF FOOD IRRADIATION APPLICATIONS (Sessions I and II)

Effects of gamma irradiation as a quarantine treatment on the
development of codling moth larvae (IAEA-SM-271/52) ...................... 3
   A.K. Burditt, Jr., H.R. Moffitt, F.P. Hungate

Le traitement ionisant des produits secs et deshydrates: Cas des plantes
médicinales à infusion (IAEA-SM-271/12) ........................................... 9
   L. Saint-Lèbe, Y. Henon, V. Thery

Pilot-scale studies on irradiation and storage of onions (IAEA-SM-271/4) ... 17
   M.A. Matin, M.M. Hossain, M.R. Amin, S. Rahman, B. Rokeya,
   M.A. Malek, A.K. Siddiqui, M.A. Hossain

Irradiation of onions, spices and enzyme solutions in the
German Democratic Republic (IAEA-SM-271/16) ................................... 35
   K. Wetzel, G. Huebner, M. Baer

Economic evaluation of radiation inhibition of potato sprouting
in Egypt (IAEA-SM-271/6) ........................................................................ 47
   A.A. Mahmoud, H.M. Roushdy

Efecto de la radiación gamma en manzanas “delicias” almacenadas
al medio ambiente y en refrigeración (IAEA-SM-271/36) ..................... 55
   H.J. Lastarria-Tapia, N. Sequeiros

Prospects and problems of irradiating papaya — A case study in Hawaii
(IAEA-SM-271/65) ...................................................................................... 61
   J.H. Moy

Radiation decontamination of dry chamomile flowers and
chamomile extract (IAEA-SM-271/75) ..................................................... 69
   B. Katušín-Ražem, D. Ražem, I. Dvorník, S. Matič, V. Mihočovič

Technological and irradiation conditions for radappertization
of chicken products used in the United States Army Raltech
toxicology study (IAEA-SM-271/73) ....................................................... 79
   E. Wierbicki

Preservation of potatoes by irradiation and economic considerations
(IAEA-SM-271/37) ...................................................................................... 101
   W. Fiszer, J. Zabielski, J. Mróz

Introduction of irradiation technology into the Hungarian
food industry (IAEA-SM-271/21) ............................................................. 109
   B. Kálmán, E. Kékessi, R. Sánta

Feed radicidation in Israel — An update (IAEA-SM-271/32) ................... 117
   Y. Klinger, M. Lapidot, I. Ross
Economic prospects of food irradiation in Zambia (IAEA-SM-271/76) .......................... 127

B.E. Chishya, K.D. Chalwe

Commercial experience in introducing radurized foods to the
South African market (IAEA-SM-271/42) ......................................................... 137

H.J. van der Linde, H.T. Brodrick

PILOT-SCALE FEASIBILITY STUDIES (Poster Session I)

Disinfestation of commercially packed dry dates by
combination treatments (IAEA-SM-271/100P) .................................................. 151

M.S.H. Ahmed, A.A. Hameed, A.A. Kadhum

Semi-commercial trials on radiation preservation of potatoes
under tropical conditions (IAEA-SM-271/95P) .................................................. 152

I. Khan, A. Sattar, M. Wahid, M. Jan

Effect of low dose irradiation and calcium treatment on the
microstructure and the shelf-life extension of fruits
(IAEA-SM-271/19P) ......................................................................................... 154

E. Kovács, A. Keresztes, J. Kovács

Garlic irradiation for sprout prevention in Israel (IAEA-SM-271/30P) .................. 155

M. Lapidot, M. Molco, R. Padova, K. Rosenberg, I. Ross

Feasibility of extending shelf-life of mature strawberry fruit
by ionizing radiation (IAEA-SM-271/7P) ......................................................... 156

A.A. Mahmoud, H.M. Roushdy, M.A. Hussein, R.A. Hegazy, M.B. Doma

Optimizing irradiation processing and packaging of papayas
(IAEA-SM-271/64P) ......................................................................................... 157

J.H. Moy, J.G. Parker, E. O'Sullivan, G. Parker

Radicidation of pre-cooked frozen tropical shrimp: A microbial
ecological study (IAEA-SM-271/47P) ............................................................... 159

N. Wongchinda, Y. Prachasitthisakdi, H. Stegeman, J. Farkas,
D.A.A. Mossel

Preservation of sausage by $^{60}$Co gamma irradiation (IAEA-SM-271/88P) ........ 160

Renli Yang, Shupei Liu, Qixun Chon, Yongzhi Wang,
Huachuan Deng

Multipurpose picowave processing plant (M 4 p) (IAEA-SM-271/116P) ........ 161

J.N. Goebel

Effect of oxygen-free packing and irradiation on the keeping quality
of dried anchovies (Engraulis anchoita) (IAEA-SM-271/111P) ......................... 162

M. Maha, D. Mustafa

Insect disinfestation of pulses, oil seeds and tobacco leaves
by irradiation in Bangladesh (IAEA-SM-271/101P) ........................................ 163

A.D. Bhuiya, M. Ahmed, R. Rezaur, G. Nahar, S.M.S. Huda,
S.A. K.M. Hossain
Irradiation disinfestation of pulses (broad bean, cowpea, etc.) during storage in Egypt (IAEA-SM-271/102P) .......................................................... 164

E.A. El-Kady

Disinfestation of wheat germ and bran by irradiation and marketing (IAEA-SM-271/103P) ................................................................................ 165

E. Kovács, I. Kiss, M. Horváth-Mosonyi, Cs. Farkas, Ny. Horváth, Gy. Jáksó

Disinfestation of copra, desiccated coconut and coffee beans by gamma radiation (IAEA-SM-271/104P) .................................................. 167

E.C. Manoto, L.R. Blanco, A.B. Mendoza, S.S. Resilva

Disinfestation of medfly in oranges by combining gamma radiation and cold treatments (IAEA-SM-271/105P) ........................................ 168


Irradiation disinfestation of apples (IAEA-SM-271/107P) .................................................. 169

C.J. Rigney, B. Sudatis, M. Izard

Radiation disinfestation of tobacco bales and coffee beans (IAEA-SM-271/108P) ................................................................................. 170

M.H. Soemartaputra, R.S. Haryadi, A. Rahayu, S. Kardha, Z.I. Purwanto, R. Chosdu

Distribution of microorganisms in spices and their decontamination by gamma irradiation (IAEA-SM-271/110P) ........................................... 171

H. Ito, H. Watanabe, S. Bagiawati, L.J. Muhamad, N. Tamura

REPORTS ON FOOD IRRADIATION DEVELOPMENTS IN SOME REGIONS OF THE WORLD (Session III)

Asian Regional Co-operative Project on Food Irradiation (RPFI) (IAEA-SM-271/90) .......................................................... 175

P. Loaharanu

Food irradiation development in Africa (IAEA-SM-271/91) .................................................. 185

B. Chinsman

Food irradiation activities in Latin American countries (IAEA-SM-271/92) .......................................................... 203

T. Rubio

Recent developments in food irradiation in Europe and the Middle East (IAEA-SM-271/93) .......................................................... 215

J. Farkas

CHEMICAL AND MICROBIOLOGICAL CHANGES IN IRRADIATED FOOD (Poster Session II)

Effect of radiation pasteurization of chicken carcasses on the taste quality of the cooked meat (IAEA-SM-271/28P) .................................................. 233

D. Basker, Y. Klinger, M. Lapidot, E. Eisenberg
Safety evaluation of irradiated food in China (IAEA-SM-271/89P) .......... 234

Yin Dai

Effects of gamma radiation on the sweet potato weevil

Callosobruchus chinensis (L.) (IAEA-SM-271/155P) ...................... 235

M.A. Dawes, M.A. Mullen, J.H. Brower, R.S. Saini, P.A. Lorentz

Radiation deactivation of bacterial flora in some Egyptian

poultry feed (IAEA-SM-271/9P) ...................................................... 236

Y.A. El-Zawahry, Y.A. Youssef, H.M. Roushdy, N.H. Aziz

Meat Irradiation Technology Center (MITC) for research in the

irradiation processing of meat (IAEA-SM-271/58P) ........................... 237

N. Ferrell, D.P. Sloan

Observations on the use of gamma irradiation to control

nitrosamine formation in bacon (IAEA-SM-271/59P) ...................... 238

W. Fiddler, J.W. Pensabene, R.A. Gates, R.K. Jenkins, E. Wierbicki

The role of lactobacilli and other bacteria in radurized meat

(IAEA-SM-271/40P) ................................................................. 239

W.H. Holzapfel, J.G. Niemand

Depuration of bacterially contaminated live and shucked soft shell clams,

Mya arenaria, by gamma irradiation (IAEA-SM-271/61P) .................. 241

J.C. Mallett, J.D. Kaylor, J.J. Licciardello

Interaction phenomena in the radurization of meat (IAEA-SM-271/39P) ... 243

J.G. Niemand, H.J. van der Linde, W.H. Holzapfel

Sensory evaluation and some quality parameters of maize

combined-treated with heat and gamma irradiation

(IAEA-SM-271/17P) ................................................................. 244

G.T. Odamtdten, V. Appiah, D.I. Langerak

Microbiological quality and production of aflatoxin B1 by

Aspergillus flavus Link NRRL 5906 during storage of artificially

inoculated maize grains treated by a combination of heat and

gamma radiation (IAEA-SM-271/18P) ........................................... 245

G.T. Odamtdten, V. Appiah, D.I. Langerak

Determination of irradiation D-values for Aeromonas hydrophila

in growth medium, buffer and fish (IAEA-SM-271/74P) ..................... 246


IRRADIATION FOR FOOD SAFETY (Session IV)

Irradiation: An effective mode of processing food for safety

(IAEA-SM-271/80) ................................................................. 251

D.A.A. Mossel

The interest of the pork industry in the United States of America

in irradiation (IAEA-SM-271/72) .................................................. 281

C.D. Van Houweling, D. Meisinger
LEGISLATION AND ACCEPTANCE OF IRRADIATED FOOD
(Session V)

The regulatory involvement of the food safety and inspection service in food irradiation (IAEA-SM-271/56) .................................................... 297
R.E. Engel

Etat actuel du développement des traitements ionisants en France (IAEA-SM-271/11) ..................................................................................... 311
Y. Henon

Status of commercial development of food irradiation in Iraq (IAEA-SM-271/27) ..................................................................................... 317
H. Auda

The South African food irradiation programme. Role of Government institutions (IAEA-SM-271/41) .................................................... 323
W.J. de Wet

DOSIMETRY AND ACCEPTANCE OF IRRADIATED FOOD
(Poster Session III)

The Cesium-137 Agricultural Commodities Irradiator (CACI) (IAEA-SM-271/84P) ..................................................... ............................ 335
G. Subbaraman, H. Farrar IV, S.B. Ahlstrom

Transportable Cesium Irradiator (TPCI) for on-site food irradiation research (IAEA-SM-271/57P) .................................................... 336
N. Ferrell, R. Andersen

Scientific considerations for the use of 10 MeV X-radiation in food processing (IAEA-SM-271/82P) .................................................... 337
M.C. Lagunas-Solar, S.M. Matthews, D.R. Slaughter

Dose ratios in pallet-size food packages as a function of radiation sources (IAEA-SM-271/83P) .................................................... 338
M.C. Lagunas-Solar, O.F. Carvacho, L.J. Harris, S.M. Matthews, D.R. Slaughter

Petitions and clearances in Israel – An update (IAEA-SM-271/31P) ........ 339
M. Lapidot

French programme in reference dosimetry for ionizing radiation processing of food (IAEA-SM-271/10P) .................................................... 340
D. Mosse, M. Cance, J.P. Simoen

Radurized foods — A challenge to marketing (IAEA-SM-271/38P) .............. 341
T.A. du Plessis, J.G. Niemand

An automated system for measuring the dose provided to irradiated food (IAEA-SM-271/66P) ........................................................ 342
T. Prusik, T. Wallace
Free radicals formation and decay in irradiated spices
(IAEA-SM-271/67P) ................................................................. 343
J.J. Shieh, E. Wierbicki

Electron and gamma dosimetry by glutamine lyoluminescence
(IAEA-SM-271/109P) ................................................................. 347
A. Miller, Liqing Xie

The suitability of chemoluminescence as a means of identifying
radiation processed spices (IAEA-SM-271/13P) ................................. 348
D.A.E. Ehlermann, H. Delincée, W. Kalus, T. Grünewald

Radiation dose distribution in spices radiation processed in a
vibrating conveyor measured by means of a new
semiconductor dosimeter (IAEA-SM-271/14P) .................................. 349
D.A.E. Ehlermann, M. Rudolf, T. Grünewald

COMMERCIAL DEVELOPMENTS: IRRADIATION SOURCES
AND ASPECTS OF THE IMPLEMENTATION OF FOOD IRRADIATION
(Session VI)

Design considerations for food irradiators in developing countries
(IAEA-SM-271/24) ......................................................................... 353
K. Krishnamurthy, D.R. Bongirwar

The multi-purpose food irradiation plant in Thailand (IAEA-SM-271/44) 365
C. Banditsing, V. Prinksulka, S. Piadang, M. Sutantawong,
K. Noochapramool, Y. Prachasitisakdi

Evaluación económica del proceso de irradiación para una
planta multipropósito (IAEA-SM-271/49) ........................................... 379
V.J. Martin, A. Montalban, S. Curbelo

Electrons versus gamma rays—Alternative sources for irradiation
processes (IAEA-SM-271/54) ...................................................... 397
M.R. Cleland, G.M. Pageau

Economies of scale in single-purpose food irradiators
(IAEA-SM-271/63) ....................................................................... 407
R.M. Morrison

Commercial feasibility of irradiating seafood in the United States
of America (IAEA-SM-271/60) .................................................. 429
J.D. Kaylor, J.W. Slavin, R.J. Learson

Commercial risks and benefits of investments in food irradiation
on an industrial scale (IAEA-SM-271/15) ...................................... 437
L. Wiesner

An industrial view of commercial food irradiation (IAEA-SM-271/51) 451
G.G. Giddings
COMMERCIAL DEVELOPMENTS: PROGRAMMING AND FINANCING
(Session VII)

Irradiation of dried fruits and nuts (IAEA-SM-271/70) ..................................... 469
  R.K. Switzer
Research and development of food irradiation in Shanghai, China
  (IAEA-SM-271/87) ..................................................................................... 475
  Zhicheng Xu
Applicability of food irradiation techniques to food preservation in
developing countries (IAEA-SM-271/34) .................................................... 479
  A.O. Olorunda
Guidelines for assessing food irradiation technology (IAEA-SM-271/68) ...... 487
  N. Ferrell, J.S. Sivinski
Caribbean Area Food Irradiation Feasibility Study (IAEA-SM-271/62) ...... 493
  R.F. Morris
New considerations for radiation-technology transfer programmes
  for developing countries (IAEA-SM-271/85) ........................................... 499
  M.C. Lagunas-Solar
Significant milestones of progress to date in food irradiation and
  identification of areas of future advances (IAEA-SM-271/114) .............. 509
  W.M. Urbain

EXPERT PANEL REPORTING (Session VIII)

  Panel: Implementation of the Food Irradiation Process ......................... 521

  Chairmen of Sessions and Secretariat of the Symposium ......................... 527
  List of Participants ............................................................................. 529
  Author Index ........................................................................................ 551
  Index of Papers and Posters by Number ............................................. 553
FEASIBILITY OF FOOD IRRADIATION APPLICATIONS
(Sessions I and II)

Chairmen
J. FARKAS
Hungary
H.M. ROUSHDY
Egypt
EFFECTS OF GAMMA IRRADIATION AS A QUARANTINE TREATMENT ON THE DEVELOPMENT OF CODLING MOTH LARVAE

A.K. BURDITT, Jr., H.R. MOFFITT
United States Department of Agriculture, Agricultural Research Service,
Yakima Agricultural Research Laboratory, Yakima, Washington

F.P. HUNGATE
Battelle Pacific Northwest Laboratories, Richland, Washington

United States of America

Abstract

EFFECTS OF GAMMA IRRADIATION AS A QUARANTINE TREATMENT ON THE DEVELOPMENT OF CODLING MOTH LARVAE.

Codling moth, Cydia pomonella (L.), larvae reared on thinning apples at ca. 24°C, 80% r.h. and 16:8 hours light:dark cycle were divided into three groups according to age. Young (1–3 instar) or older (3–5 instar) larvae in apples or mature non-diapausing codling moth larvae in cocoons were exposed to gamma radiation at doses up to 160 Gy. Following irradiation the larvae were held to permit further development, pupation and adult emergence. The number of adults emerging as well as mature larvae and pupae present that did not produce adults was determined. Two deformed adults developed and emerged from the young larvae exposed to 100 Gy. Six deformed adults developed and emerged from older larvae exposed to 120 Gy and one from 140 Gy. Of the mature larvae treated at 120, 140 and 160 Gy, 14, 3 and 2 adults emerged, respectively. One of those from each of the 120 and 140 Gy treatments appeared to be normal in external appearance. At lower doses (40, 60 or 80 Gy) adult emergence was reduced and many of those that did emerge were physically deformed. At 60 Gy, and above, adult emergence was restricted to mostly males. Examination of the dead puparia showed that many of the females were unable to complete their development to the adult. Data from these studies will be used to predict doses of gamma irradiation required as a quarantine treatment to prevent emergence of codling moth adults from fruit infested by larvae.

Introduction

Larvae of the codling moth, Cydia pomonella (L.), infest apples, pears, and many other deciduous fruit crops. The codling moth is found throughout most of the temperate world, with the exception of some areas of Asia, including Japan, Korea and Taiwan. These three countries have established quarantines that prevent or restrict importation of fruit that may serve as
hosts for this pest. Taiwan permits importation following inspection and certification that fruit is not infested. Japan and Korea prohibit import of host fruit unless it has been treated to eliminate codling moth eggs or larvae that may be present.

In the Northwestern USA the codling moth usually has two generations. It overwinters as diapausing larvae in cocoons, pupates in the early spring and emerges as an adult moth. Eggs are laid, hatch and produce larvae that usually pupate and produce adults in midsummer. These moths lay eggs that produce a second generation of larvae. Such larvae usually mature in late summer and leave the fruit in search of a suitable site in which they can spin a cocoon to overwinter.

Fumigation using methyl bromide has been accepted by Japan and Korea as a treatment to eliminate any codling moth infestation that may be present in cherries [1,2]. However, thus far we have not been successful in developing such a treatment for apples or pears. Since gamma irradiation had shown promise as an alternative treatment for fruit subject to infestation by fruit flies of the family Tephritidae [3], we decided to undertake research to determine if it could be used for fruit infested by codling moth larvae. Our initial research predicted that the dose required to prevent emergence of adult codling moths irradiated as non-diapausing larvae in fruit was 206.5 Gy and as diapausing larvae in fiberboard strips was 225.3 Gy [4]. The following research was undertaken to determine effects of irradiation on young, older and mature non-diapausing codling moth larvae.

Materials and Methods

Codling moth larvae used in this research were reared on thinning apples as in our previous experiments [4,5]. On May 24, 1984 codling moth eggs were placed on thinning apples, in trays, in a controlled environment room at ca. 24°C, 80% r.h. and 16:8 hours light:dark cycle. A total of 36 fiberboard trays, each containing ca. 380 infested thinning apples were set up for this study.

On May 30, ten of the trays of infested apples were selected at random. Ten fruit from each of these trays were placed in each of 33 1-gallon (17 cm diameter x 18 cm high) paperboard cartons. Fluted fiberboard strips were placed in each carton to provide a suitable site in which mature larvae would be able to spin cocoons and subsequently pupate. The strips were replaced 3 times at weekly intervals. On May 31, the 100 fruit in 1 carton were cut to determine the stages of
development of larvae present. The remaining cartons, each containing 100 infested fruit, were irradiated using the AECL-650 unit at Battelle Pacific Northwest Laboratories. Cartons were treated at nominal doses of 0, 10, 20, 40, 60, 80, 100 or 120 Gy.

On June 7, ten more of these trays of infested apples were selected and the above procedure was repeated. On June 8, the cartons of infested fruit were treated at nominal doses of 0, 20, 40, 60, 80, 100, 120 or 140 Gy.

Fiberboard strips were placed on the infested apples in the remaining 16 trays to collect mature larvae. On June 11, the strips were collected and placed in 32 paperboard cylinders 4 cm diameter x 11.4 cm long. These were treated on June 12 at nominal doses of 0, 40, 60, 80, 100, 120, 140 or 160 Gy.

The fiberboard strips from each treatment were collected weekly and held in 1-quart cartons to permit mature larvae to form pupae and adults to emerge. Adult emergence was determined daily from June 21 until July 18. The strips were held until August 8 to ensure that emergence was complete. Subsequently, the strips were opened to determine the number and stage of development of any insects remaining in the strips. Finally, the infested apples were cut to determine the number and stage of development of insects remaining in the fruit.

Samples were exposed to gamma radiation supplied by an AECL Gammabeam-650® irradiator having an initial (1971) loading of 50000 Ci of cobalt-60. The unit has 12 vertical tubes into which the cobalt is raised and held in place pneumatically during the timed exposure period. The twelve source tubes are adjustable to a closed position (7 cm diameter space between the tubes) or an open position (80 cm diameter space) or any intermediate position. The tubes had an initial sequential loading of 8, 4, 0.5, 8, 4, 0.5, 8, 4, 0.5, 8, 4, 0.5 Ci; i.e., the loading was symmetric but not uniform. Since any one or group of tubes can be raised, this gives dose rate flexibility. The dose rate can also be adjusted by placing material outside the array of tubes. The room housing the source is 7.3 x 7.3 meters with the source in the center.

The gallon cartons containing infested apples or the paperboard cylinders containing strips, were placed on a Nordic Micro-Go-Round® No. 62304 food rotator which rotated at approximately 0.5 rev/min. Two cartons were placed one on top of the other on the Go-Round which was in the center of the open tubes; i.e., 80 cm diameter spacing. Four cylinders, held together by a rubber band, were placed on the Go-Round for treatment.
For the present exposures (the source tubes in their open position), a series of measurements made with direct NBS-traceability indicated the mid-point dose rate was 9.4 Gy/min. Measurements with the apples in place with both a Victoreen thimble and with TLD chips (LiF) indicated the mean dose at the center of the carton was 8.9 Gy/min. The 5% difference is accounted for by the dose absorbed by the apples. There was up to a 15% dose variation with position of the apples in the two stacked cartons; i.e., the mid-point was highest with lower doses above and below the mid-point during the May 31 and June 8 exposures. The fiberboard strips exposed on June 12 were in 4 cylinders held together by a rubber band and exposed together so that the dose rate delivered to the cocooned larvae was uniformly close to 9.4 Gy/min. Exposure times were: May 31 - 1.1, 2.2, 4.4, 6.6, 8.8, 11, and 13.2 minutes; June 8 - 2.2, 4.4, 6.6, 8.8, 11, 13.2 and 15.5 minutes; June 12 - 4.4, 6.6, 8.8, 11, 13.2, 15.5, and 17.7 minutes.

Results

Examination of a sample of the infested apples that was irradiated on May 31 showed that 54.6% of the young larvae present were 1st instar, 40.5% were 2nd instar and 4.9% were 3rd instar at the time of treatment. Examination of those that were irradiated on June 8 showed that 17.6% of the older larvae were 3rd instar, 17.6% were 4th instar and 64.8% were 5th instar. Examination of a sample of strips handled in a manner similar to strips irradiated on June 12 showed that 12% of the mature cocooned larvae had transformed to pupae.

Data on the number of insects surviving exposure to gamma radiation as larvae and their subsequent development are summarized in Table I. Data for the control treatments (0 Gy) were analyzed to determine if there were significant differences in the number of larvae in the initial population tested. These analyses showed that there was no significant difference in the total number of insects recovered from the populations tested on May 31 and June 8. However, the population of larvae tested on June 12 was significantly lower than the others since this population contained only the larvae that had matured, left the fruit and entered the strips by June 11 when they were removed for treatment.

Based on the stage of development of larvae at the time of treatment, we suggest that those larvae that were in the 2nd and 3rd instar when irradiated on May 31 apparently were able to continue their development and emerge as adults following exposure to 40 Gy. However, only the 3rd instar larvae were able to emerge as adults following exposure to 80 Gy and 89% of
Table I. Development of codling moth larvae following irradiation

<table>
<thead>
<tr>
<th>Date</th>
<th>Dose (Gy)</th>
<th>Mean number of surviving insects and stage of development completed</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Irradiated</td>
<td>Mature Larvae</td>
</tr>
<tr>
<td>May 31, 1984</td>
<td>0</td>
<td>2.7 ab</td>
</tr>
<tr>
<td></td>
<td>10</td>
<td>6.0 abc</td>
</tr>
<tr>
<td></td>
<td>20</td>
<td>2.0 a</td>
</tr>
<tr>
<td></td>
<td>40</td>
<td>2.2 ab</td>
</tr>
<tr>
<td></td>
<td>60</td>
<td>6.5 abc</td>
</tr>
<tr>
<td></td>
<td>80</td>
<td>11.2 c</td>
</tr>
<tr>
<td></td>
<td>100</td>
<td>7.7 bc</td>
</tr>
<tr>
<td></td>
<td>120</td>
<td>5.5 ab</td>
</tr>
<tr>
<td>June 8, 1984</td>
<td>0</td>
<td>1.5 a</td>
</tr>
<tr>
<td></td>
<td>20</td>
<td>2.7 a</td>
</tr>
<tr>
<td></td>
<td>40</td>
<td>4.7 a</td>
</tr>
<tr>
<td></td>
<td>60</td>
<td>5.2 a</td>
</tr>
<tr>
<td></td>
<td>80</td>
<td>20.7 b</td>
</tr>
<tr>
<td></td>
<td>100</td>
<td>60.0 c</td>
</tr>
<tr>
<td></td>
<td>120</td>
<td>108.2 d</td>
</tr>
<tr>
<td></td>
<td>140</td>
<td>120.5 e</td>
</tr>
<tr>
<td>June 12, 1984</td>
<td>0</td>
<td>2.2 a</td>
</tr>
<tr>
<td></td>
<td>40</td>
<td>1.7 a</td>
</tr>
<tr>
<td></td>
<td>60</td>
<td>2.7 a</td>
</tr>
<tr>
<td></td>
<td>80</td>
<td>2.2 a</td>
</tr>
<tr>
<td></td>
<td>100</td>
<td>2.7 a</td>
</tr>
<tr>
<td></td>
<td>120</td>
<td>20.0 b</td>
</tr>
<tr>
<td></td>
<td>140</td>
<td>24.7 b</td>
</tr>
<tr>
<td></td>
<td>160</td>
<td>26.5 b</td>
</tr>
</tbody>
</table>

Means within each date and column followed by the same letter are not significantly different at P = 0.05, using Duncan's new multiple range test.

Those were obviously abnormal in appearance, having malformed wings or abdomens. At an exposure of 100 Gy some of the 2nd and most of the 3rd instar larvae were able to form pupae. Larvae in the 1st instar at the time of treatment apparently were not able to mature and form cocoons following exposure to 60 Gy, although they were able to continue development and emerge as adults following exposure to 20 Gy. First instar larvae that died before reaching maturity apparently decomposed and could not be accounted for when the fruit or strips were examined (Table I).

Based on the stage of development of larvae treated on June 8, we suggest that those larvae that were in the 3rd instar were
not able to form pupae following exposure to 60 Gy, and most were unable to become mature larvae following exposure to 80 Gy. The groups of 3rd instar larvae that had been treated on May 31 developed to this stage twice as rapidly as those treated on June 8. Further research is needed to confirm our above suggestions. This research would require detailed research on the effects of irradiation on further development of larvae treated in various stages of development and time required to reach a specific instar. Exposure on June 8 of older larvae to 80 Gy resulted in less adult emergence than expected, based on development when treated. However, the larvae were able to form pupae. Those larvae destined to become female moths were more susceptible to irradiation than the males, and terminated development as pupae.

Analyses of the dosage-mortality data for larvae irradiated on May 31 showed that quarantine security based on probit 9 (99.9968%) mortality could be achieved by an exposure to 133 Gy based on adult emergence. Exposure to 442 Gy would be required to prevent any 1st, 2nd or 3rd instar larvae reaching maturity and spinning cocoons. However, exposure to a dose of 133 Gy would eliminate 95% of the mature larvae.

Analyses of the dosage-mortality data for older or mature larvae (those irradiated on June 8 or 12) showed that the doses required to prevent adult emergence at the probit 9 security level were 177 and 230 Gy, respectively. Since many of the former larvae were in the 5th instar, it was not possible to prevent larvae reaching maturity.

References

LE TRAITEMENT IONISANT DES PRODUITS SECS ET DEHYDRATES

Cas des plantes médicinales à infusion

L. SAINT-LEBE, Y. HENON, V. THERY
Service de radioagronomie,
Département de biologie,
CEA, Centre d'études nucléaires de Cadarache,
Saint-Paul-lez-Durance, France

Abstract—Résumé

IONIZING RADIATION TREATMENT OF DRY AND DEHYDRATED PRODUCTS: CASE OF MEDICINAL PLANTS INTENDED FOR INFUSION.

Drying and dehydration are common methods of stabilizing foodstuffs. The removal of insects or bacteria from them has hitherto been carried out by chemical treatments the effectiveness of which is not fully satisfactory and which also raise the problem of residues. Treatment with ionizing radiation does not have these drawbacks and therefore offers a very attractive alternative. The application of such treatment to dry and dehydrated products is especially appropriate because their low water content limits the possible organoleptic changes. In France, authorization has been or is soon to be granted for several intermediate products — spices, aromatics, gum arabic, dehydrated vegetables and cereal flakes for dairy products. However, the treatment is also justifiable for products sold to the public which are often of inadequate microbiological quality. This is the case with medicinal plants intended for infusion, the market for which is growing dramatically. The risks are often further increased by the consumer himself making his infusion under poor conditions. Ionization treatment, carefully performed, considerably reduces the microbial load without affecting the principal chemical characteristics of these plants at the doses used. Numerous organoleptic tests have demonstrated the absence of significant change in taste as compared with control batches. A request for authorization has therefore been submitted wherein it is proposed that ionizing radiation treatment should be used only if the total microbial load is above $10^4$ but below $10^8$. An overall average maximum dose of 9 kGy will then be sufficient.
trouvent d’ailleurs souvent accrus par le consommateur lui-même qui réalise son infusion dans de mauvaises conditions. L’ionisation, utilisée avec discernement, permet une réduction considérable de la charge microbienne sans affecter, aux doses utilisées, les principales caractéristiques chimiques de ces plantes. Les nombreux tests organoleptiques effectués ont montré l’absence de modifications gustatives significatives par rapport à des lots témoins. Une demande d’autorisation vient donc d’être déposée où il est proposé de n’employer l’ionisation que si la charge microbienne totale est supérieure à $10^4$ sans toutefois excéder $10^8$. Une dose globale moyenne maximale de $9 \text{kGy}$ suffit alors.

INTRODUCTION

Les produits secs et déshydratés sont souvent utilisés dans les pays industrialisés comme des produits intermédiaires destinés aux industries agro-alimentaires alors qu’ils constituent pour les pays en voie de développement des aliments de base d’une importance primordiale. Les plantes médicinales à infusion échappent à cette règle.


La qualité des plantes médicinales à infusion s’apprécie à la fois par leurs caractéristiques intrinsèques (espèce, composition, origine, etc) [2—4] et leur degré de pollution organique (insectes, micro-organismes) [5] ou chimique (résidus de pesticides) [6—8]. Au cours de cinq dernières années, diverses revues d’unions de consommateurs européennes ont souligné l’excessive contamination microbienne d’un grand nombre de produits secs ou déshydratés parmi lesquels les plantes médicinales à infusion figuraient en bonne place [9—12]. Le traitement ionisant peut résoudre ce problème de façon satisfaisante.

1. ASPECTS MICROBIOLOGIQUES

Les plantes médicinales à infusion, comme la plupart des végétaux récoltés, sont contaminées par une microflore qui provient essentiellement du sol. Ainsi, la plus ou moins grande proximité du sol des parties récoltées a plus d’importance sur leur niveau de contamination que les conditions climatiques ou les pratiques agricoles. On a pu ainsi trouver un nombre de germes aérobies dont le nombre varie de $4 \times 10^2$ à $10^8$ pour de la camomille et de la menthe récoltées toutes deux dans de bonnes conditions hygiéniques.

Le séchage des plantes médicinales à infusion entraîne une nette diminution de la contamination et souvent la disparition d’espèces comme les streptocoques...
FIG. 1. Niveau de contamination de diverses plantes à infusion en vrac (prélevées chez le producteur ou chez le détaillant) ou en infusettes [5].

fécaux et les pseudomonas. Les opérations ultérieures de broyage, mélange et conditionnement augmentent de nouveau la contamination (figure 1):

L'infusion, c'est-à-dire la mise dans l'eau bouillante des plantes séchées, doit en principe conduire à une pasteurisation poussée du produit. Ce n'est pas toujours le cas, car le consommateur utilise fréquemment une eau qui n'est pas assez chaude (l'idéal serait que la température reste supérieure à 60°C pendant environ 10 minutes) et attend beaucoup trop longtemps pour consommer son infusion. Dans ces conditions, les bactéries sporulées, les bacilles anaérobies sulfito-réducteurs et quelquefois les spores d'Aspergillus résistent. De plus, sous l'influence de la chaleur, les spores peuvent germer. On aboutit donc à une réduction peu importante du nombre de micro-organismes, voire à une augmentation de celui-ci (figure 2).

Une pasteurisation des plantes médicinales à infusion est donc souhaitable. L'action de la chaleur ne peut être retenue car les essences dont sont riches la plupart de ces plantes sont thermosensibles.

La fumigation à l'oxyde d'éthylène est parfois pratiquée; peu efficace sur les levures et les moisissures, ce gaz a l'inconvénient de se fixer par chimisorption. Il peut aussi changer la structure de certains constituants et former des composés reconnus cancérogènes tels que le chloro-2-éthanol [5, 13]. Son usage est donc de plus en plus restreint.

FIG. 2. Nombre de micro-organismes aérobie mesophiles avant et après infusion [5].

<table>
<thead>
<tr>
<th>Contamination (germes totaux/g)</th>
<th>Traitement</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt;10⁴</td>
<td>Pas de traitement</td>
</tr>
<tr>
<td>10⁴ à 10⁶</td>
<td>7 kGy</td>
</tr>
<tr>
<td>10⁶ à 10⁸</td>
<td>9 kGy</td>
</tr>
<tr>
<td>&gt;10⁸</td>
<td>Pas de traitement, lot à éliminer</td>
</tr>
</tbody>
</table>

TABLEAU I. DOSES GLOBALES MOYENNES D'IONISATION (kGy) À APPLIQUER EN FONCTION DU DEGRÉ DE CONTAMINATION INITIALE POUR ABOUTIR À UNE POPULATION THÉORIQUE DE 10⁴ GERMES PAR GRAMME MAXIMUM.
contamination inférieure à $10^4$ ne justifie pas un traitement ionisant. Par contre si celle-ci dépassee $10^8$, le traitement ionisant est à exclure car les bonnes pratiques n'ont certainement pas été respectées. Il ne faut jamais prôner l'utilisation des traitements ionisants pour récupérer des produits dégradés.

2. PRINCIPALES CARACTERISTIQUES CHIMIQUES ET ORGANOLEPTIQUES

Les huiles essentielles [21, 22] ont plus particulièrement retenu l'attention des chercheurs. Toutes les analyses effectuées par chromatographie sur couche mince ou en phase gazeuse et par spectrométrie démontrent que la composition aromatique des plantes médicinales à infusion n'est pas modifiée aux doses utilisées pour les pasteuriser, c'est-à-dire à moins de 10 kGy [23—27]. On constate même, dans le cas de la menthe, qu'à une dose trois fois supérieure à celle qui sera couramment utilisée, il n'y a pas de différences significatives par rapport au témoin (tableau II).

Les tests sensoriels effectués ont souvent conclu à l'absence de modifications organoleptiques dans les infusions préparées à partir de plantes ionisées. Nous avons effectué un test triangulaire [20] avec deux échantillons de verveine non traitée et un échantillon de verveine traitée à 10 kGy (tableau III).

Pour que la différence puisse être considérée comme significative, il aurait fallu qu'au moins 15 personnes reconnaissent le produit différent ($0.02 < P < 0.05$). Il semble cependant y avoir une légère tendance à préférer la tisane de verveine ionisée qui a souvent été qualifiée comme « ayant plus d'arôme ». Des études similaires que nous menons avec d'autres produits aromatiques dégagent la même tendance. On peut avancer l'hypothèse que l'action du rayonnement ionisant sur la fraction inerte (essentiellement cellulosique), également dite fraction fixatrice, conduit à une dépolymérisation aboutissant à une plus grande facilité de libération des arômes; c'est à vérifier.

CONCLUSION

L'ionisation appliquée aux plantes médicinales à infusion permet d'offrir aux consommateurs des produits d'une qualité microbiologique supérieure à celle habituellement rencontrée, sans affecter les principes aromatiques. Si cette application de l'ionisation se révèle extrêmement utile dans le domaine de la préparation des produits pharmaceutiques, il n'est pas sûr qu'elle puisse être rapidement mise en œuvre pour les plantes médicinales à infusion commercialisées directement auprès des consommateurs. L'infusion est en effet l'un des produits les plus chargés de symboles. Les consommateurs et donc les vendeurs y associent
TABLEAU II. ÉTUDE DE L'EFFET DU TRAITEMENT IONISANT SUR LES COMPOSANTS DES PRINCIPALES HUILES ESSENTIELLES DE LA MENTHE DOSES PAR CHROMATOGRAPHIE EN PHASE GAZEUSE APRES ENTRAÎNEMENT PAR DE LA VAPEUR D'EAU

<table>
<thead>
<tr>
<th>Composant</th>
<th>ppm dans la plante</th>
<th>Témoin</th>
<th>10 kGy</th>
<th>25 kGy</th>
</tr>
</thead>
<tbody>
<tr>
<td>Menthol</td>
<td></td>
<td>7443</td>
<td>7366</td>
<td>7622</td>
</tr>
<tr>
<td>α-pinène</td>
<td></td>
<td>104</td>
<td>111</td>
<td>116</td>
</tr>
<tr>
<td>β-pinène</td>
<td></td>
<td>178</td>
<td>182</td>
<td>187</td>
</tr>
<tr>
<td>Myrcène</td>
<td></td>
<td>31</td>
<td>31</td>
<td>30</td>
</tr>
<tr>
<td>α-terpinène</td>
<td></td>
<td>41</td>
<td>40</td>
<td>37</td>
</tr>
<tr>
<td>Limonène</td>
<td></td>
<td>172</td>
<td>174</td>
<td>170</td>
</tr>
<tr>
<td>1–8 cinéole</td>
<td></td>
<td>1043</td>
<td>1006</td>
<td>959</td>
</tr>
<tr>
<td>Ocimène</td>
<td></td>
<td>41</td>
<td>42</td>
<td>42</td>
</tr>
<tr>
<td>γ-terpinène</td>
<td></td>
<td>62</td>
<td>59</td>
<td>60</td>
</tr>
<tr>
<td>Menthone</td>
<td></td>
<td>3210</td>
<td>2928</td>
<td>3010</td>
</tr>
<tr>
<td>Menthofurane</td>
<td></td>
<td>392</td>
<td>380</td>
<td>356</td>
</tr>
<tr>
<td>Isomenthone</td>
<td></td>
<td>443</td>
<td>412</td>
<td>425</td>
</tr>
<tr>
<td>Linalol</td>
<td></td>
<td>58</td>
<td>56</td>
<td>57</td>
</tr>
<tr>
<td>Menthy acétate</td>
<td></td>
<td>753</td>
<td>755</td>
<td>758</td>
</tr>
<tr>
<td>Néomenthol</td>
<td></td>
<td>681</td>
<td>685</td>
<td>803</td>
</tr>
<tr>
<td>Terpinène 4 OL</td>
<td></td>
<td>460</td>
<td>466</td>
<td>362</td>
</tr>
<tr>
<td>α-terpineol</td>
<td></td>
<td>53</td>
<td>52</td>
<td>51</td>
</tr>
<tr>
<td>Piperitone</td>
<td></td>
<td>104</td>
<td>99</td>
<td>103</td>
</tr>
</tbody>
</table>

TABLEAU III. TEST TRIANGULAIRE SUR DES INFUSIONS DE VERVEINE PREPAREES A PARTIR D'ÉCHANTILLONS TRAITÉS (10 kGy) OU NON

<table>
<thead>
<tr>
<th>Nombre de personnes</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>ayant participé au test</td>
<td>30</td>
</tr>
<tr>
<td>ayant distingué le produit différent</td>
<td>13</td>
</tr>
<tr>
<td>ayant préféré le produit différent</td>
<td>17</td>
</tr>
<tr>
<td>ayant distingué le produit différent et l'ayant préféré</td>
<td>10</td>
</tr>
</tbody>
</table>
des idées de nature et de tradition. Cela est-il compatible avec un traitement qui, même s'il est reconnu inoffensif et bénéfique, est associé à des idées diamétralement opposées aux précédentes? Cela revient à poser à nouveau le vaste problème de l'information du public et de l'étiquetage des produits ionisés.

REFERENCES

[16] Résultats non publiés d'une étude effectuée par le Laboratoire Monot à Quétigny (France) en 1983.


PILOT-SCALE STUDIES ON IRRADIATION AND STORAGE OF ONIONS

Institute of Food and Radiation Biology, Bangladesh Atomic Energy Commission, Dhaka, Bangladesh

Abstract

PILOT-SCALE STUDIES ON IRRADIATION AND STORAGE OF ONIONS.

Irradiation of onions (shallots) on a pilot scale and storage under various conditions was carried out in four separate studies in the years 1981—1984. The results show complete inhibition of both external and internal sprouting with a dose of 50—80 Gy gamma radiation if treated within two weeks of harvest. Late irradiation results in gradual death of the primordial buds leaving a distinct dark patch in the budding region. Storage losses owing to dehydration and rotting were significantly reduced in irradiated onions stored for 8—10 months at ambient conditions (20—37°C and 70-90% r.h.) and in cold storage (15°C). Periodical evaluations of the relevant physical properties revealed that onions irradiated within the optimum time (2 weeks of harvest) and in bulk storage on shelves have superior keeping qualities compared with the corresponding unirradiated samples. Low-temperature storage of irradiated onions does not appear to reduce storage losses to the extent expected if the relative humidity inside the cooler is not properly controlled. Onion varieties have been observed to respond differently to irradiation treatment and storage with regard to storage losses. Evaluation of organoleptic properties of unirradiated and irradiated onions stored under different conditions showed favourable ratings for the irradiated samples. Consumer acceptance tests and limited marketing conducted during and after termination of storage indicated consumer preference for irradiated onions.

1. INTRODUCTION

Bangladesh produces about 200 000 t of onions annually in a single season (December—April) with a peak harvest in late March. The produce is stored at ambient temperature for over eight months up to the next harvest. During this long storage period considerable losses are incurred through sprouting, rotting and weight loss owing to dehydration, resulting in shortages and raised price. The loss varies between 30 and 50%, depending on length and conditions of storage. Cold storage or other preservation methods are not practised in the country because of the non-availability of technical and economic data on the feasibility of such storage.

Ionizing radiation at low doses has been successfully used over the last two decades to inhibit sprout growth and to reduce storage losses of onions [1, 2]. Irradiated onions have been cleared for public consumption in many countries.
Irradiated onions and other irradiated foods have recently been cleared for human consumption in Bangladesh, too [3, 4]. The cost of irradiating onions has been found to be economically feasible if the overall benefits are taken into consideration [5, 6].

Laboratory-scale experiments showed that sprout inhibition in Bangladesh onions could be achieved by low doses of gamma radiation [7]. In an attempt to study the feasibility of large-scale irradiation and storage of onions, pilot-scale experiments were conducted with onions in the harvesting seasons from 1981 to 1984. The results of these studies are discussed in this paper.

2. MATERIALS AND METHODS

2.1. Sample collection

Onions were collected from both local markets and growers. In the 1981 season 3 t were collected from the local market. In 1982 about 6 t were collected from the market and the growers, and in 1983 and 1984 8 and 10 t were procured from the growers, respectively. The onions were collected 2—5 weeks post-harvest. The onions were brought to the laboratory by truck. The bulbs were then sorted to discard those injured or otherwise of inferior quality. The good quality onions were used for the study.

2.2. Irradiation

The onions were irradiated in the 50 kCi gamma beam-650 irradiator at ambient temperature (27—35°C) in wooden crates containing 20—40 kg each. They were treated within 2—5 weeks of harvest. Dose distributions at different positions and dose rates were determined by the Fricke method. The ratio $D_{\text{max.}}$ to $D_{\text{min.}}$ was found to be 1.6. The dose administered was 50—80 Gy at a rate of 130 Gy/h.

2.3. Storage

In the 1981 study control and irradiated onions were divided into two equal portions and stored in (i) wooden crates, (ii) bamboo baskets, and (iii) on elevated bamboo shelves at room temperature (20—37°C) and relative humidity (70—90%) with natural aeration. In the 1982 storage trial both irradiated and control onions were kept at ambient conditions in the pre-cooler zone (15—18°C) of commercial cold storage. For storage the onions were spread on raised shelves 15—18 cm deep and packed into net bags containing 20 kg each. Gunny bags were also used for the storage of onions. In 1983 and 1984 the storage trials were conducted under ambient conditions (20—37°C) and in coolers (15°C). The onions were packed into
net bags and spread on elevated shelves 15–18 cm deep with scope for sufficient natural ventilation around the shelves and the bags. In 1984 a storage trial was conducted with two common varieties.

The storage period was from April 1981 to February 1982 and April 1982 to February 1983 for the 1981 and 1982 storage studies, respectively, and from April to December for the 1983 and 1984 storage trials.

2.4. Analyses and evaluations

Control and irradiated onions were examined periodically for sprout development, sprout length, inner bud quotient, weight losses owing to dehydration, microbial rottage, texture, density, and the nature of the spoilage microbes. Radiation-induced blackening/dyscoloration of the growth centres was examined by cutting the onions in half. Organoleptic qualities of the cooked and raw samples were evaluated by a panel of trained judges using the 9-point hedonic scale [8]. The results were analysed using suitable statistical methods wherever necessary.

2.5. Consumer acceptance and test marketing

Consumer acceptability tests were conducted during storage periods and on termination of storage trials by free distribution of control and irradiated onions to a cross-section of knowledgeable consumers in the 1981 and 1982 studies and by restricted selling at two periods during and after the storage trial in 1983 (November 1983 and January 1984). Because of the late government clearance open-marketing trials of the experimental onions could not be made. Instead, the bulbs were sold to a cross-section of the public at competitive prices in the 1983 study. Both control and irradiated onions were offered initially at the same price, but later on the price of the control onions had to be reduced because of their inferior quality. About 600 consumers purchased the onions, either control or irradiated or both. Each consumer was given a printed card to record his assessment on the quality of the onions sold. About 300 consumers returned the cards with evaluations and comments.

In the study conducted in 1984 test marketing of the irradiated onions was made at various times during storage and on termination of the storage in December 1984. The irradiated onions were supplied at the wholesale price prevailing at the time to a number of shops, shopping centres and department stores in various parts of Dhaka City. Labels 'onions preserved by irradiation: govt. approved' for display at the irradiated stock and letters stating the safety and wholesomeness of the irradiated product were supplied to the shops and stores.
3. RESULTS AND DISCUSSION

3.1. Sprout inhibition of onions by radiation

Earlier laboratory-scale investigations carried out at this institute showed that a dose of 50—80 Gy gamma radiation inhibits sprouting in onions stored at ambient conditions (20—37°C) [7]. During 1981—1984 four separate pilot-scale storage trials were conducted with common varieties of onions grown in the country. Irradiation (50—80 Gy) within 2—5 weeks of harvest was found to completely inhibit external sprouting of onions stored in bulk for about 8—10 months at ambient conditions (Fig.1). Similar results of sprout inhibition of onions with low-dose radiation treatment have been reported [9—11]. However, the results obtained from the present studies do not agree with those reported by Nair et al. [12], who could not obtain complete inhibition of sprouting in irradiated onions (Indian varieties). Varietal difference and climatic conditions appear to affect radiation response. Irradiated onions stored at cooled temperature (15°C) were observed to have some initial sprouting which subsequently dried or dropped off in the course of storage (Table I). This confirms findings reported by other workers [12, 13].

3.2. Radiation induced discoloration of the germination region

Discoloration or blackening of the inner bud region owing to death of the growth zone was observed in about 50% of irradiated onions on storage for about 4—5 months at ambient conditions. Discoloration intensified with further storage time. Cool storage (15—18°C) was found to increase the degree of discoloration of the growth region and even to shorten the period of its onset. The nature and extent of discoloration of the growth centres of the irradiated bulbs can be observed when the onions are cut open (Fig.2). To confirm the conditions at which such discoloration or blackening occurs, a separate batch of one tonne of onions obtained from the growers in the second week of harvest were irradiated two to seven weeks after harvest and stored at ambient conditions spread on shelves. The incidence of discoloration of the budding region of irradiated onions stored for a period of 10—11 months is shown in Table II. It is evident from the data shown in the table that progressive discoloration occurred in the growth centres of the irradiated onions. The discoloration was found to increase with time between harvest and irradiation and with storage time and conditions. In onions irradiated within 2—3 weeks of harvest the percentage of bulbs with discoloration of the inner buds was found to be very small even after 8—9 months' storage and in such cases the darkening or discoloration was found to have spread to a very small area of the meristem region. Irradiation four to seven weeks after harvest and storage at ambient conditions resulted in linear increases of the percentage of bulbs with discoloration/darkening of the growth regions, which increases in number
FIG. 1. Sprout inhibition of onions by radiation and bulk storage on shelves and in net bags.
TABLE I. EFFECT OF IRRADIATION AND STORAGE ON SPROUTING, HARDNESS AND INNER BUD QUOTIENT (IBQ) OF ONIONS

<table>
<thead>
<tr>
<th>Storage conditions</th>
<th>Storage time (months)</th>
<th>% sprouted</th>
<th>Hardness$^a$ (kg/cm$^2$)</th>
<th>IBQ$^b$</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Control</td>
<td>Irradiated</td>
<td>Control</td>
</tr>
<tr>
<td>3</td>
<td>-</td>
<td>-</td>
<td>2.5</td>
<td>2.7</td>
</tr>
<tr>
<td>5</td>
<td>-</td>
<td>-</td>
<td>2.9</td>
<td>3.0</td>
</tr>
<tr>
<td>20–37°C: Spread on shelves</td>
<td>7</td>
<td>4.3</td>
<td>2.3</td>
<td>2.5</td>
</tr>
<tr>
<td>9</td>
<td>8.3</td>
<td>-</td>
<td>2.8</td>
<td>3.2</td>
</tr>
<tr>
<td>3</td>
<td>50</td>
<td>10$^d$</td>
<td>2.8</td>
<td>2.8</td>
</tr>
<tr>
<td>5</td>
<td>75</td>
<td>-</td>
<td>2.7</td>
<td>2.9</td>
</tr>
<tr>
<td>15°C: Spread on shelves</td>
<td>7</td>
<td>95</td>
<td>-</td>
<td>-$^e$</td>
</tr>
<tr>
<td>9</td>
<td>100</td>
<td>-</td>
<td>-$^e$</td>
<td>2.6</td>
</tr>
</tbody>
</table>

$^a$ Measured by fruit hardness tester of universal type as kg/cm$^2$. Mean values of random samples of 100 bulbs.

$^b$ Ratio of length of inner bud developing into sprout to total length of bulb. Mean values of random samples of 100 bulbs.

$^c$ Physiological death of the germination centres (discoloration).

$^d$ Some initiation of sprouting which, subsequently, dried with storage time.

$^e$ Control onions heavily sprouted and spoiled.
FIG. 2. Discoloration of the inner buds of onions irradiated at different times after harvest and stored by spreading on shelves and packed in net bags.

A. Irradiated 5 weeks after harvest and stored at 20–37°C for 4 months.
B. Irradiated 5 weeks after harvest and stored at 15°C for 4 months.
C. Irradiated 2 weeks after harvest and stored at 20–37°C for 8 months.
D. Irradiated 5 weeks after harvest and stored at 20–37°C for 8 months.
E. Irradiated 2 weeks after harvest and stored at 15°C for 8 months.
F. Irradiated 5 weeks after harvest and stored at 15°C for 8 months.
G. Control onions stored at 20–37°C for 8 months.
TABLE II. PERCENTAGE OF ONIONS WITH DISCOLORATION IN THE INNER BUDS ON IRRADIATION AND STORAGE AT AMBIENT CONDITIONS (20–37°C) AND SPREAD ON SHELVES

<table>
<thead>
<tr>
<th>Storage time (months)</th>
<th>Discoloration in bulbs irradiated at different times after harvest:</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>2nd week</td>
</tr>
<tr>
<td>3</td>
<td>–</td>
</tr>
<tr>
<td>4</td>
<td>–</td>
</tr>
<tr>
<td>5</td>
<td>–</td>
</tr>
<tr>
<td>6</td>
<td>–</td>
</tr>
<tr>
<td>7</td>
<td>–</td>
</tr>
<tr>
<td>8</td>
<td>–</td>
</tr>
<tr>
<td>9</td>
<td>–</td>
</tr>
<tr>
<td>10</td>
<td>–</td>
</tr>
<tr>
<td>11</td>
<td>–</td>
</tr>
</tbody>
</table>

Note: Storage period: April to February.

and magnitude with storage time. Irradiation soon after harvest when the bulbs are in the deepest state of dormancy may yield effective inhibition of both internal and external sprouting, and darkening of growth centres during post-irradiation storage can largely be avoided. Gradual darkening or discoloration of inner buds, owing to late irradiation of onions after the break of dormancy, and long storage was reported by many researchers [1, 9, 12, 13].

3.3. Storage losses

Figure 3 shows total storage losses in control and irradiated onions stored at ambient temperature (20–37°C) and 70–90% r.h. and spread on shelves. The total storage losses comprising the losses owing to dehydration and rotting were found to be different in various years. Irradiation decreased the storage losses considerably. The difference in storage losses between control and irradiated onions was found to increase linearly with increasing storage time. Similar results have been reported by other workers [14]. In evaluating storage losses, sprouted onions in the control samples were not discarded to an extent acceptable to consumers. Loss of weight owing to dehydration was observed to contribute
to a large extent to the total storage losses, while rotting added only a part. This was particularly true of irradiated onions, where rotting never contributed more than 10%, while the loss owing to dehydration was about double (Table III). In the control samples dehydration was observed to be much greater than that in the irradiated onions. In the months following October, when ambient temperatures gradually fall, sprouting in control bulbs increases rapidly, with more than 80% of the onions showing internal sprouting in the month of November, resulting in increased weight losses.

Figure 4 indicates storage losses of two common varieties of onions during storage at ambient conditions spread on shelves for eight months. Varietal difference in radiation response was observed. The Jhitka variety showed better keeping qualities owing, probably, to textural compactness and lower moisture content. Irradiation has a marked effect in reducing storage losses in this variety. Total storage losses owing to dehydration and rotting in the control and the irradiated onions during storage for about eight months at ambient conditions were about 50 and 30% (Fig.3) and 52 and 35% (Fig.4) in 1983 and 1984 storage trials,
<table>
<thead>
<tr>
<th>Storage time (months)</th>
<th>Storage conditions</th>
<th>Type of loss</th>
<th>Loss (%/month)</th>
<th>Control</th>
<th>Irradiated</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>20–37°C: spread on shelves</td>
<td>Dehydration</td>
<td>5.0 ± 0.7</td>
<td>3.6&lt;sup&gt;a&lt;/sup&gt; ± 2.2</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Rottage</td>
<td>2.0 ± 0.3</td>
<td>0.2&lt;sup&gt;b&lt;/sup&gt; ± 0.1</td>
<td></td>
</tr>
<tr>
<td></td>
<td>20–37°C: net bags</td>
<td>Dehydration</td>
<td>5.8 ± 1.2</td>
<td>1.5&lt;sup&gt;b&lt;/sup&gt; ± 0.8</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Rottage</td>
<td>2.0 ± 0.2</td>
<td>0.8&lt;sup&gt;b&lt;/sup&gt; ± 0.3</td>
<td></td>
</tr>
<tr>
<td></td>
<td>15°C: spread on shelves</td>
<td>Dehydration</td>
<td>5.3 ± 2.9</td>
<td>1.5 ± 0.8</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Rottage</td>
<td>1.0 ± 0.4</td>
<td>0.6&lt;sup&gt;c&lt;/sup&gt; ± 0.3</td>
<td></td>
</tr>
<tr>
<td></td>
<td>15°C: net bags</td>
<td>Dehydration</td>
<td>2.1 ± 0.5</td>
<td>2.3 ± 0.3</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Rottage</td>
<td>2.2 ± 0.3</td>
<td>2.2 ± 0.6</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>20–37°C: spread on shelves</td>
<td>Dehydration</td>
<td>4.8 ± 0.5</td>
<td>4.3&lt;sup&gt;d&lt;/sup&gt; ± 0.8</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Rottage</td>
<td>1.9 ± 0.3</td>
<td>0.1&lt;sup&gt;a&lt;/sup&gt; ± 0.7</td>
<td></td>
</tr>
<tr>
<td></td>
<td>20–37°C: net bags</td>
<td>Dehydration</td>
<td>5.3 ± 1.8</td>
<td>2.0 ± 0.5</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Rottage</td>
<td>2.0 ± 0.2</td>
<td>3.2 ± 0.5</td>
<td></td>
</tr>
<tr>
<td></td>
<td>15°C: spread on shelves</td>
<td>Dehydration</td>
<td>5.9 ± 0.6</td>
<td>2.9 ± 1.6</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Rottage</td>
<td>0.9 ± 0.2</td>
<td>1.0 ± 0.2</td>
<td></td>
</tr>
<tr>
<td></td>
<td>15°C: net bags</td>
<td>Dehydration</td>
<td>1.8 ± 0.4</td>
<td>1.04</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Rottage</td>
<td>1.2 ± 0.8</td>
<td>1.34 ± 0.3</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>20–37°C: spread on shelves</td>
<td>Dehydration</td>
<td>15.2 ± 2.8</td>
<td>3.5&lt;sup&gt;c&lt;/sup&gt; ± 1.0</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Rottage</td>
<td>2.8 ± 0.8</td>
<td>2.3&lt;sup&gt;b&lt;/sup&gt; ± 0.5</td>
<td></td>
</tr>
<tr>
<td></td>
<td>20–37°C: net bags</td>
<td>Dehydration</td>
<td>3.8 ± 1.6</td>
<td>2.9 ± 0.7</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Rottage</td>
<td>1.9 ± 0.3</td>
<td>3.6 ± 0.6</td>
<td></td>
</tr>
<tr>
<td>Temperature Range</td>
<td>Condition</td>
<td>Dehydration</td>
<td>Rottage</td>
<td></td>
<td></td>
</tr>
<tr>
<td>-------------------</td>
<td>--------------------</td>
<td>-------------</td>
<td>------------</td>
<td></td>
<td></td>
</tr>
<tr>
<td>15°C: spread on shelves</td>
<td>Dehydration</td>
<td>9.3 ± 0.8</td>
<td>4.2 ± 0.4</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Rottage</td>
<td>0.9 ± 0.4</td>
<td>1.0 ± 0.01</td>
<td></td>
<td></td>
</tr>
<tr>
<td>15°C: net bags</td>
<td>Dehydration</td>
<td>7.3 ± 3.1</td>
<td>2.5 ± 0.3</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Rottage</td>
<td>5.3 ± 4.9</td>
<td>0.8 ± 0.2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>6°C</td>
<td>Dehydration</td>
<td>13.7 ± 1.6</td>
<td>13.0 ± 2.8</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Rottage</td>
<td>0.9 ± 0.1</td>
<td>0.6 ± 0.2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>20–37°C: spread on shelves</td>
<td>Dehydration</td>
<td>9.9 ± 5.4</td>
<td>10.6 ± 4.2</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Rottage</td>
<td>2.5 ± 0.6</td>
<td>10.6 ± 0.03</td>
<td></td>
<td></td>
</tr>
<tr>
<td>15°C: spread on shelves</td>
<td>Dehydration</td>
<td>55.0</td>
<td>14.9 ± 2.7</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Rottage</td>
<td></td>
<td>9.2 ± 0.4</td>
<td></td>
<td></td>
</tr>
<tr>
<td>15°C: net bags</td>
<td>Dehydration</td>
<td>55.0</td>
<td>13.6 ± 9.6</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Rottage</td>
<td></td>
<td>9.9 ± 5.4</td>
<td></td>
<td></td>
</tr>
<tr>
<td>8°C</td>
<td>Dehydration</td>
<td>16.2 ± 5.8</td>
<td>11.5 ± 0.4</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Rottage</td>
<td>1.6 ± 0.3</td>
<td>1.5 ± 0.2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>20–37°C: net bags</td>
<td>Dehydration</td>
<td>23.7 ± 2.1</td>
<td>12.6 ± 1.2</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Rottage</td>
<td>7.3 ± 2.9</td>
<td>3.5 ± 0.8</td>
<td></td>
<td></td>
</tr>
<tr>
<td>15°C: spread on shelves</td>
<td>Dehydration</td>
<td>Discarded due to heavy sprouting and rottage</td>
<td>15.1 ± 3.2</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Rottage</td>
<td></td>
<td>14.2 ± 1.6</td>
<td></td>
<td></td>
</tr>
<tr>
<td>15°C: net bags</td>
<td>Dehydration</td>
<td>Discarded due to heavy sprouting and rottage</td>
<td>11.9 ± 0.6</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Rottage</td>
<td></td>
<td>18.3 ± 7.1</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

* Significant at 0.5% level.  
* Significant at 2.5% level.  
* Significant at 1% level.  
* Significant at 5% level (Paired t-test).
respectively, for the Jhitka variety. The per cent storage losses for Taherpur variety (Fig.4) was observed to be 57 and 44% in the control and in the irradiated lots after eight months' storage, respectively. The savings that would accrue from irradiation and suitable storage would be about 20% by weight of the stored bulbs. The storability of onions, both control and irradiated, packed into net bags under these conditions was also judged to be comparable with those stored on raised shelves. Storing onions by spreading them shallowly on raised shelves or by packing them into net bags and storing them on shelves with proper ventilation to allow dissipation of the heat generated may further reduce the storage losses. Storage in gunny bags, baskets or crates was not found suitable. The effect of irradiation in minimizing storage losses, as obtained in this study, is in agreement with reports by workers elsewhere [9, 12, 14]. Similar results for storability were observed in control and irradiated onions stored at cooled temperatures when spread on raised shelves and packed in net bags on shelves (Table III). The humidity of such storage could not be properly controlled, which seems to be a limiting factor in obtaining the maximum decrease in storage losses. However, irradiated onions under these storage conditions showed significantly reduced storage losses owing to sprouting, dehydration and rotting.
Three types of storage rotting were identified in stored onions: bacterial soft, dry rots and fungal dry rots. Soft rot accounted for 20–25% and fungal dry rots for about 15% losses of stored onions. The bacterial soft rots were caused by species of *Erwinia, Sarcina, Micrococcus* and *Pseudomonas* and fungal rots by *Fusarium* species. The organisms were found to be unaffected by irradiation.

### 3.4. Irradiation effects on inner bud quotient, hardness and density

During storage physical properties such as inner bud quotient, textural compactness and density were determined periodically on random samples of both control and irradiated bulbs. The inner bud quotient (IBQ), measured as the ratio of the inner bud developing into sprout to the length of the onions, was found to increase with storage time in the controls, while it was found to be almost negligible in the majority of the irradiated bulbs during the initial 4–5 months’ storage at ambient conditions. More than 50% of the control bulbs were on the verge of sprouting in the month of October (6–7 months’ storage), which continued as the cool winter temperature persisted till the end of the storage period (Table I). At 15°C the inner bud quotient of the irradiated onions increased with storage time in a number of cases, with budding region darkening. This indicates that the onions were irradiated after the break of dormancy and the irradiated lots contained onions of mixed harvests. The observation on inner bud development is in agreement with those reported by Nair et al. [12] and Kálmán and Tamasi [14].

Measurement of textural compactness of control and irradiated bulbs stored under different conditions did not reveal a consistent difference. This is in conformity with the results of other workers [14]. The density of the stored bulbs did not show a clear pattern nor was it indicative of irradiation or storage conditions (results not shown). This is contrary to the findings of Kálmán and Tamasi [14], who reported an increase in weight per volume after irradiation of onions.

### 3.5. Organoleptic properties

Assessment of the organoleptic and cooking qualities was made in the later part of each storage trial. Table IV summarizes the results of the organoleptic properties of control and irradiated onions stored on shelves at ambient conditions and cooled temperature. It would appear from the table that irradiated samples were judged to be superior in quality with respect to colour, texture, odour and taste when served raw, fried or boiled. Control onions stored under any of the conditions were on the borderline of acceptance or below in quality. Similar improvement in the sensory qualities of irradiated bulbs have been reported by other workers [12].
### TABLE IV. EFFECT OF IRRADIATION ON ORGANOLECTIC PROPERTIES OF ONIONS (JHITKA VARIETY) STORED FOR 8 MONTHS

<table>
<thead>
<tr>
<th>Storage conditions</th>
<th>Sample preparation</th>
<th>Colour</th>
<th>Texture</th>
<th>Odour</th>
<th>Taste</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Control</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>20–37°C: Spread on shelves</td>
<td>Raw</td>
<td>5.3(^a) ± 1.3</td>
<td>6.8 ± 0.6</td>
<td>5.2 ± 1.2</td>
<td>6.7 ± 0.7</td>
</tr>
<tr>
<td></td>
<td>Fried</td>
<td>6.3 ± 1.1</td>
<td>7.1 ± 0.9</td>
<td>6.0 ± 1.3</td>
<td>6.6 ± 0.5</td>
</tr>
<tr>
<td></td>
<td>Boiled</td>
<td>5.0 ± 1.3</td>
<td>6.0 ± 1.2</td>
<td>5.4 ± 1.1</td>
<td>6.7 ± 0.6</td>
</tr>
<tr>
<td>Cool temperature (15°C): Spread on shelves</td>
<td>Raw</td>
<td>5.6 ± 1.8</td>
<td>7.4 ± 1.0</td>
<td>5.7 ± 1.7</td>
<td>7.1 ± 1.0</td>
</tr>
<tr>
<td></td>
<td>Boiled</td>
<td>3.4 ± 1.3</td>
<td>6.2 ± 1.8</td>
<td>4.1 ± 1.2</td>
<td>6.1 ± 1.8</td>
</tr>
</tbody>
</table>

*Note: 9-point hedonic scale used for scoring by a trained panel of 12 judges.*

*Mean ± standard deviation.*
TABLE V. CONSUMER ACCEPTABILITY OF STORED ONIONS (JHITKA VARIETY)

% Consumer preference of overall quality

<table>
<thead>
<tr>
<th>Storage conditions</th>
<th>6 months' storage</th>
<th>8 months' storage</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Control</td>
<td>Irradiated</td>
</tr>
<tr>
<td>20—37°C: spread on shelves</td>
<td>63</td>
<td>98</td>
</tr>
<tr>
<td>15°C: spread on shelves</td>
<td>_&lt;sup&gt;b&lt;/sup&gt;</td>
<td>94&lt;sup&gt;c&lt;/sup&gt;</td>
</tr>
</tbody>
</table>

<sup>a</sup> Assessment of 300 consumers out of 600 supplied with the onions and cards to record their opinions. Consumer assessment on quality in respect of colour, texture, taste and appearance.

<sup>b</sup> Control onions deteriorated in overall quality and unacceptable owing to heavy sprouting, shrinkage and rottage.

<sup>c</sup> Some consumers reported blackening of the inner bud of the irradiated onions which became visible when the onions were cut in half.

3.6. Consumer acceptance and marketing trials

Control and irradiated onions supplied to consumers have been assessed with respect to overall quality. Table V summarizes this evaluation. It is evident from the data that consumers favoured the irradiated sample over the control because of the former’s better quality with respect to colour, odour, texture and overall acceptability. A few consumers, however, reported undesirable darkening of the inner buds of some irradiated onions. In view of the superior organoleptic performance and quality and the better condition of the irradiated onions, even after 10 months of storage, it was expected that general consumers would favour the irradiated samples. Because of the overall improved quality and favourable consumer response introduction of irradiated onions through normal marketing channels would entail only minimal difficulty.

During and on termination of storage in 1984 irradiated onions supplied to the market were widely accepted by both shopkeepers and consumers. About 3 t of irradiated onions, on storage for 6, 8 and 9 months, were sold to a number of grocery shops, shopping centres, and department stores in various parts in Dhaka City at the wholesale price prevailing at the time. The shopkeepers’ demands for
an increased supply could not be met because of the limited stock. It was learned from them that consumers prefer to buy older, stored onions in the months of December and January at a higher price than the freshly harvested stock, which enters the market in the days following late November. No adverse comments were received from either the retailers or the consumers. Similar market trials with irradiated onions stored for different periods were conducted in Hungary with an encouraging response from the tradespeople and consumers [6].

4. CONCLUSIONS

Sprout growth in the common varieties of onions grown in Bangladesh can be effectively inhibited with minimum discoloration of the inner buds if irradiated (50–80 Gy) within 2–3 weeks of harvest. Storage losses owing to sprouting, dehydration and rotting can be significantly reduced by irradiation. A saving to the extent of 20% or more of the storage losses may be achieved with irradiation and storage at ambient conditions (20–37°C) by spreading the onions shallowly on raised shelves with air circulating beneath the shelves to dissipate the heat generated during storage. Irradiated onions packed in net bags and stored on shelves under similar conditions as mentioned above may also yield an identical reduction in storage losses.

Storage of irradiated onions at cool temperatures (15°C) would require proper humidity control to get the optimum benefit.

In view of the additional expenditure required for cool temperature, storage of irradiated onions by spreading on raised shelves at ambient temperature with adequate ventilation may be economically feasible for reducing storage losses.

ACKNOWLEDGEMENTS

The paper was prepared under Research Contract No. 2835/JN with the International Atomic Energy Agency under the Asian Regional Co-operative Project on Food Irradiation (RPFI). Financial support of the IAEA under RPFI phase I is thankfully acknowledged. The authors express their thanks to Dr. M. Ahmed, Director, Institute of Food and Radiation Biology, for his assistance and keen interest in the work.

REFERENCES

IRRADIATION OF ONIONS, SPICES 
AND ENZYME SOLUTIONS 
IN THE GERMAN DEMOCRATIC REPUBLIC

K. WETZEL, G. HUEBNER, M. BAER
Zentralinstitut für Isotopen- 
und Strahlenforschung, 
Akademie der Wissenschaften der DDR, 
Leipzig, German Democratic Republic

Abstract

IRRADIATION OF ONIONS, SPICES AND ENZYME SOLUTIONS IN THE GERMAN DEMOCRATIC REPUBLIC.

Extensive research work in the field of food irradiation has been carried out in the German Democratic Republic in recent years. Technological and economic parameters were studied with the purpose of deciding on the most successful processes and the foods most suitable for irradiation. The main topics of this work were the irradiation of onions, spices and technical enzyme solutions. Different types of gamma irradiation facilities for bulk cargo irradiation, for batch-processing of enzyme solutions and for multipurpose use have been built or are under construction. Technological and economic data obtained by pilot experiments from 1981 to 1984 with 2000 t of onions demonstrate that irradiation is most suitable for sprouting inhibition and as a substitute for the cooling process during storage. Drastic reductions in storage losses and savings of energy are the most important advantages of this new technology. Germ-count reduction in spices and enzyme solutions by irradiation provides better product quality, reduction of product losses, and energy reduction. Over the past four years extensive work has been done in the field of food irradiation as a result of the recommended acceptance of food irradiation up to an overall average dose of 10 kGy by the Joint FAO/IAEA/WHO Expert Committee on the Wholesomeness of Irradiated Food (JECFI) in October 1980. The conclusion of JECFI that the irradiation of food up to this dose presents no toxicological hazards is very important for work on the radiation preservation of foods. On the basis of JECFI's recommendations, extensive research work has been carried out in the German Democratic Republic in recent years. On the basis of scientific results obtained by the Institute of Vegetable Production of the Academy of Agricultural Sciences of the German Democratic Republic in co-operation with the Central Institute of Isotope and Radiation Research, onion irradiation was launched in 1981.

1. IRRADIATION OF ONIONS

In 1981 a new type of bulk cargo irradiator was discussed, planned, constructed and put into operation within three months [1]. Taking into account radiation protection calculations and the technological solution of bulk cargo transport, the irradiation room was built as a subterranean bunker with interior dimensions of 6.0 × 6.0 × 2.1 m and slightly ascending inlet and outlet channels.
FIG. 1. Longitudinal section of the onion irradiator GBZ 81.

FIG. 2. Arrangement of the source tubes in relation to the onion layer.

with a width of 1.0 m and a height of 0.6 m in combination with vertical shafts of labyrinth structure (Fig.1). The irradiator is loaded with about $1.8 \times 10^{15}$ Bq $^{60}$Co. The $^{60}$Co sources are arranged in a tube system consisting of four tubes, two above and two below the onion layer on a turntable (Fig.2). Because of the different radial velocities of the onions at the inner and outer parts of the layer and the radiation absorption by the turntable (4 mm steel plate) the four tubes are differently loaded.
Physiological experiments on sprouting inhibition in our laboratory demonstrated that it is already inhibited at doses higher than 20 Gy and that 30 Gy are a safe lower limit to prevent onion sprouting [3]. JECFI recommends onion irradiation up to a dose of 150 Gy [4]. Therefore, an overdose ratio of 2.3 in the onion layer corresponding to a dose range from 30 to 70 Gy yields suitable conditions for onion irradiation in the present pilot plant. The throughput of the irradiator results from its geometrical conditions in

\[ X = dsR \rho \omega \]

where
- \( R \) = average radius of the circle on the turntable, 170 cm
- \( d \) = height of the onion layer
- \( s \) = width of the onion layer
- \( \rho \) = average density of the onions, 0.5
- \( \omega \) = angular velocity of the turntable [5].

Since 1981 nearly 2000 t of onions have been irradiated in this plant. In the 1981 irradiation period the plant was loaded with \( 1.17 \times 10^{15} \) Bq \( ^{60}\text{Co} \) and adjusted to a minimum dose of 30 Gy, resulting in an average angular velocity of 34.9/h. The theoretical throughput is \( X = 3.56 \) t/h at an average revolution time of 10.8 min. The throughput was 3.5 t/h. Thus, calculated on the basis of a \( D_{\text{min}} \) of 30 Gy, a minimum efficiency of \( \eta = 0.063 \) was realized. Related to the overall average dose of 43 Gy during the whole irradiation period the efficiency was 9.1%. Some changes in the geometrical arrangement of the tubes above and below the onion layer led to a higher minimum efficiency of about 7%. From optimizing calculations it follows that by an increase of the onion layer from the present 60 cm width and 20 cm height to a width of 80 cm and a height of 40 cm the theoretical minimum efficiency of the irradiation plant may be increased to 9%. Factors influencing the efficiency of the irradiation plant are the maximum filling of the volume available on the turntable and the organization of the whole process. A well-timed supply of onions from the field, their continuous and uniform transport to the turntable and foolproof equipment guarantee efficient operation of the irradiation plant. If filling of the turntable is improved, a real efficiency of more than 95% of the theoretical value should be reached. Thus, a capacity of about 7.5–8.0 t/h can be realized in this type of irradiator at a loading with \( 1.85 \times 10^{15} \) Bq \( ^{60}\text{Co} \). This capacity is the upper limit but is sufficient for irradiating about 2000 to 3000 t of onions within 2 to 3 weeks post harvest at a daily irradiation time of 20 hours. Usual warehouses for onions have a capacity of about 12 000 to 15 000 t. A portion of 3000 t of irradiated onions is a suitable amount to be integrated into such a system of storing and processing and a sufficient quantity for consumption in the period from May to July.
Technological and economic data obtained from the pilot experiments in the period 1981 to 1984 demonstrate that onion irradiation is the most suitable process for sprouting inhibition, and that there is no need to shift the onions into cooling chambers for the period of May to June. The power demand for storage of 360 kW·h per tonne is reduced to 53 kW·h per tonne and the storage losses are reduced by 28 to 12.5% on average as against the traditional process. The new process is of greatest economic benefit for traders and consumers as a result of the maintenance of quality and a 20% reduction of storage losses (25 to 5% on average).

Starting, for example, from 10 000 t of onions as required for the period from May to June, 18 400 t were needed in store using the cooling technology with high storage losses (total losses being 46%). Sixteen thousand tonnes out of the above total are to be stored in cooling chambers. The new process will reduce the total loss rate by 50%, i.e. only 13 000 t of onions will have to be irradiated [6].

On the basis of the reduced production volume the following amounts of material and funds can be saved:

<table>
<thead>
<tr>
<th>Material/Funds</th>
<th>Quantity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cultivated area</td>
<td>250 ha</td>
</tr>
<tr>
<td>Seed</td>
<td>3 500 kg</td>
</tr>
<tr>
<td>Power required for cold storage</td>
<td>5 000 MW·h</td>
</tr>
<tr>
<td>Transport</td>
<td>650 000 t·km</td>
</tr>
</tbody>
</table>

Investigations at our laboratory into the radiobiological fundamentals of sprouting inhibition in onions serve the extension of radiobiological knowledge as well as the further optimization and maximum precision of the process [3]. The lower limit of the effective radiation dose, the optimum dose range, the optimum irradiation period, the last possible time for irradiation after harvest, and the interactions between storage temperature before irradiation, optimum time for irradiation, and irradiation dose have been investigated. These experiments and additional cytological investigations of the cell division index for irradiated onions as a function of the radiation dose and the time of irradiation have yielded the following results:

- 20 Gy is the lowest effective radiation dose that guarantees sprout inhibition. Over the range of 20 to 70 Gy there are no dose-dependent differences in the inhibiting effect.
- The first three weeks after harvest is the optimum period for irradiation. This period may be prolonged up to 12 weeks post harvest, provided that those onions irradiated last are consumed first.
- The optimum period for irradiation treatment can be prolonged by low storage temperature (e.g. cool weather during the harvest).
- The irradiation of the onions has to be integrated into the technological process of the transport from the field to the warehouse. An additional
intermediate storage increases the proportion of damaged onions and, consequently, increases the storage losses.

- Sprouting inhibition in onions by irradiation is caused by inhibition of cell division. However, cell elongation is not affected by irradiation.
- Radiation treatment within the first three weeks post harvest makes possible storage outside cooling chambers. A storage temperature lower than 10°C from October to June is best suited to prevent any loss of quality. Moreover, it is extremely important to guarantee dry storage.
- Sprouts of irradiated onions die off after cell elongation. Brown colouring of the sprouts may be minimized by the use of well-ripened onions, irradiated immediately after harvest, and by careful processing.

No negative results such as those recently reported by Zehnder [7] have ever been obtained in our pilot experiments from 1981 to 1984 on 2000 t of onions. On the basis of our positive pilot-scale results, a new high capacity irradiation plant for the irradiation of 4000 t of onions and multipurpose use is now under construction.

2. IRRADIATION OF SPICES

The use of ethylene oxide for the reduction of microbial load in spices is prohibited in the German Democratic Republic. Therefore, the influence of ionizing radiation on the microbial load and taste of selected spices and spice mixtures was tested and it was proved that the use of spices of reduced microbial load in the production of deep-freeze ready cooked meals, preserves, and tins is reflected in the high quality of the products. To utilize these results immediately, the project was subdivided into three stages:

- Examination of the reduction of the microbial load and modification of the sensorial properties of spices and spice mixtures as a function of the dose applied
- Investigation into the influence of radiation on microbial loads and sensorial properties in test products manufactured with irradiated spices
- Testing the results obtained under production conditions.

In co-operation with other institutes and enterprises positive results were achieved in all three stages of this project. In spices such as pepper, paprika, thyme, marjoram, mustard powder and mixed spices (such as curry powder and mixed spices for special products) in general microbial loads of the order of $10^6$ to $10^7$ microorganisms per gram of spice were found. The yielded $D_{10}$ values by irradiation (Fig.3) and the initial microbial load of the spices permit calculation of the radiation dose, guaranteeing an acceptable reduction of the microbial load. With radiation doses of 7.5 kGy, a reduction in the initial number of viable microorganisms by a factor of $10^4$ to $10^5$ in various spices was achieved. Some sensorial differences
resulted from irradiation. In the case of individual spices, for which definite notions of taste and smell exist, sensorial deviations after radiation treatment can be detected more easily than with mixed spices. But there was no clear connection with the doses, and even with the highest doses used (10 kGy) these modifications were insignificant.

In the charges as well as under production conditions the following products have been made using irradiated spices:

- Beef goulash in gravy as a deep-frozen food
- Thick frankfurters
- Braised meat.

In the test product beef goulash, a considerable improvement in microbial quality as compared with the control could be ascertained. The irradiation of mixed spices for thick frankfurters also had a positive effect on bacterial contamination.
of the ready-made products. Comparative experiments on braised meat preserves yielded the result that the use of mixed spices irradiated at 7.5 kGy reduces the number of microorganisms in the product immediately after pasteurization; the growth of the remaining microbes, however, raises their number again after short storage. The use of mixed spices irradiated at 10 kGy combined with heat treatment with slightly raised temperature of the preserve yields a product which fully satisfies stability tests on the meat tins. Sensorial deviations found in the spices such as increase of hotness of pepper had little effect in the final products and can be compensated for by a modification of the spice mixture as well as of the amount of spice used [8].

Under production conditions the reduction in bacterial count in spices is not the only factor influencing the required hygienic status of the final product but it is also the prerequisite for solving other problems of the production regime implied. Moreover, various of our results indicate that the spores entering the product together with the spices are more difficult to inactivate by subsequent heat treatment than, for example, microorganisms growing on the meat. Apart from raising the hygienic status there are a number of other reasons for the use of irradiated spices, e.g. reduction of losses and storage stabilization of the spices themselves and of goods produced with them, insect disinfestation in spices simultaneously at irradiation for reduction of microbial load, and the manufacture of new products which otherwise would not be storable at all. Another aspect is the possibility of reducing the energy needed for the sterilization of tinned products, because a shorter heating period is required as a result of the reduced degree of contamination of the products or because lower core temperatures are sufficient for obtaining sterility [8].

3. IRRADIATION OF ENZYME SOLUTIONS

Biotechnology is gaining increasing importance in the production of drugs, foodstuffs, industrial auxiliary substances, and other products. Usually, the producing organisms or other contaminating microorganisms have to be separated from the final product. The microbial quality required can be achieved by multistage filtration or centrifugation. However, several disadvantages such as high expenditure of manual labour, uncertain results in the number of viable microorganisms in the reduction of the final products, and the prohibition of the use of asbestos materials in the food industry of the German Democratic Republic render more difficult or rule out the industrial application of filtration for enzyme production.

It has been demonstrated that irradiation is an interesting alternative for reduction of microbial load in technical enzyme solutions [9]. The radiation dose needed depends on the initial bacterial load, the \( D_{10} \) value of the microorganisms, and the microbial quality to be reached in the final product. To preserve the enzyme activity the radiation dose should be as low as possible. In model experiments in 250 and 1000 mL polyethylene bottles, in 50 L polyethylene canisters,
and in a 7 L model reactor it has been demonstrated that doses of 7 to 10 kGy reduce the counts of living bacteria by a factor of $10^3$ to $10^5$ in liquid enzyme, glucoamylase, and alpha amylase. No negative effects on the enzyme activity and stability in the irradiated samples in comparison with the untreated solutions were observed. The effectiveness of the radiation treatment by gamma radiation from a $^{60}$Co source was not influenced by

- temperature changes over the range of 15 to 30°C,
- changes of the pH-value between 5 and 6,
- water content of the enzyme solutions in the range of 55 to 83%,
- intermixing of the culture solution by ventilation or by a vibromixer,
- dose rates in the range of 1 to 8.2 kGy/h.

An important factor influencing the irradiation effects is the content of colloidal solutes of the enzyme solutions. An initial reduction of the number of microorganisms from $10^8 - 10^{10}$ per mL to about $10^5 - 10^6$ per mL in the culture solutions by rough filtration or centrifugation followed by an irradiation with a maximum dose of 10 kGy is most efficient in reducing this number to values less than $10^4$ per mL without any change in the enzyme activity.

On the basis of these results a special batch-process irradiator for enzyme solutions with a performance of 3000 m$^3$/a is now under construction by VEB PROWIKO, Schönebeck. The initial load of the GBE 82 irradiation unit is 2.33 PBq $^{60}$Co. The new technology of the reduction of microbial load by irradiation treatment of enzyme solutions yields the following advantages in comparison with the conventional filtration technique:

- Manpower reduction by a total of fifteen workers
- Decrease in the prime cost of the enzyme production by 8 to 10%
- Reduction of the amount of wastes
- Improvement of product quality.

4. A MULTIPURPOSE GAMMA IRRADIATION FACILITY

Calculations show that food irradiation is only an economically acceptable process if a minimum quantity of products can be irradiated and if the available cobalt-60 is used throughout the year. For these reasons a gamma irradiation facility for multipurpose use is under construction [10]. This facility is being built in an agricultural co-operative which produces onions. During the onion harvest about 4000 t will be irradiated in this facility. A great variety of products may be irradiated simultaneously at different doses during the rest of the year.

The multipurpose gamma irradiation facility consists of a central irradiation room, 5.5 x 7.5 x 3.5 m. The product containers are taken on and delivered in a storage hall. A labyrinth divided into an entrance line and an exit line connects
the storage hall and the irradiation room (Fig.4). The inner part of the labyrinth is single-line, in accordance with radiation safety calculations.

The irradiator will be loaded with about 10 PBq $^{60}$Co. A water pool with a depth of 6.50 m is used as source storage. The cobalt-60 sources are placed in a cylindrical arrangement.

The facility works on the container principle. The containers are transported by an active driving roller conveyor from the storage hall to the irradiation room and back. Within the irradiation room the transport of the containers is performed by roller conveyors and carrying chain conveyors. Thus the orientation of the container remains constant during the transport around the irradiation source making possible a four-sided irradiation. The containers have outside dimensions of $1.00 \times 1.20 \times 1.95$ m for onions and $1.00 \times 1.20 \times 2.40$ m for all other products. Each position of the transport system can be loaded with up to 1 t. Eight containers can be positioned round the radiation source.
The irradiation plant works with two different programmes, one for the irradiation of onions, garlic or potatoes, the other for all other products. Both programmes are computer-controlled. The programme for the irradiation of onions, garlic or potatoes works at the highest speed possible with the present conveyor system. The loading of the source arrangement is calculated for the dose needed for the product to be irradiated, i.e. 30–70 Gy for onions, considering the time for one irradiation cycle. Loading and unloading of the aluminium containers is computer-controlled following the same working rhythm. The whole onion irradiation process in this facility is integrated into the harvest and storage of the onions.

The computer-controlled program for all other products is planned in such a way that during each transport cycle around the source arrangement (8 sets of steps) an overall average dose of 2 kGy is absorbed by the products within the containers. According to the dose requested and considering the density of the product, the number of cycles in the irradiation room is calculated and controlled by the computer. After each cycle the computer compares the number of cycles programmed with the number completed and decides on another cycle or transport to the storage position after termination of the irradiation. This concept allows the simultaneous irradiation of different products with different doses. Containers with individual fixed doses may be placed at each of the eight positions on the conveyor system around the radiation source. Only the number of cycles (and the density of the product) is decisive for the total dose, which at a density of 0.3 is an integral multiple of 2 kGy. At a loading of the irradiation facility with 5.25 PBq $^{60}$Co the time for one cycle will be about 6 hours.

The radiation field, the distance of the containers from the radiation sources, the size of the containers, and the maximum density of the products are calculated for a maximum overdose ratio of 1.5. Maximum and minimum dose, dose rate, overall average dose, irradiation time, date, number of cycles, number of container and product are printed out at the end of the irradiation process.

For sprout inhibition of onions a dose of 30 to 70 Gy (overdose ratio 2.3) is sufficient. This dose is realized at the maximum conveyor velocity by a load of about $1.4 \times 10^{15}$ Bq $^{60}$Co which yields a capacity of about 15 t/h. Thus, only 15–20% of the total $^{60}$Co load of the facility is needed during the harvest for onion irradiation in the multipurpose irradiator. Therefore, it is planned to take most of the $^{60}$Co from the multipurpose facility during the onion harvest and to use it in bulk cargo irradiators of the type described in Section 1.

By combining both types of irradiators, the bulk cargo irradiator and the multipurpose gamma irradiator, an optimum utilization of the available cobalt-60 throughout the year is guaranteed. Calculations have proved that such a multipurpose irradiator works economically at a minimum load of about 4.5–5.5 PBq $^{60}$Co and about 5000 h/a. Consequently, the design and construction of a multipurpose gamma irradiation facility is recommendable and it can
operate economically only if the food irradiation programme in a country ensures a certain level of utilization of the available capacity. Food irradiation in the German Democratic Republic has reached this state.

REFERENCES

ECONOMIC EVALUATION OF RADIATION INHIBITION OF POTATO SPROUTING IN EGYPT

A.A. MAHMOUD, H.M. ROUSHDY
National Centre for Radiation Research and Technology,
Cairo, Egypt

Abstract

ECONOMIC EVALUATION OF RADIATION INHIBITION OF POTATO SPROUTING IN EGYPT.

The present study reviews the status of potato cultivation in Egypt, annual production, local consumption and export volume during the period 1976–1978. The data presented reflect the magnitude of annual crop loss due to sprouting, fungal attack, insect infestation and chemical changes. Attempts have been made to ensure longer and better keeping quality of potatoes through many conventional treatments, e.g. refrigeration and chemical treatment. However, the percentage of annual loss of potatoes harvested in Egypt is still far from being acceptable. Irradiation processing of potatoes for sprouting inhibition has always been considered a feasible technology in Egypt. Extensive studies have been carried out in Egypt since the 1960s to investigate the technological and nutritional status of irradiated potatoes. Nevertheless, not enough comprehensive studies have been undertaken to evaluate the economic feasibility of such a technology as calculated under local environmental conditions. This is the objective of the paper.

INTRODUCTION

Extensive research programmes carried out internationally since the 1950s have clearly shown that radiation preservation of food can significantly contribute to reducing the high rate of food losses. This has been of particular interest to many of the developing nations, especially where traditional preservation techniques cannot be applied, either through lack of the technical preconditions or through economic circumstances.

The problem of annual losses in cultivated potatoes was one of the first problems to be tackled by irradiation processing. Irradiation treatment of potatoes has proved to inhibit tuber sprouting during storage. Since such treatment results in only a slight (if any) rise in the temperature of the tubers while being irradiated, no alteration in the organoleptic, physical or chemical characteristics could be determined at the irradiation level technologically required to fulfil the objective of the process. Accordingly, the optimal radiation levels for fulfilling the preservation requirements ensure that there are no harmful chemical changes in the food-stuff and that the safety precautions for human consumption are maintained.
The public acceptability and the wholesomeness of irradiated potatoes have stimulated the interest of many investigators for more than two decades. After critical revision of the data accumulated world wide on the toxicological testing of irradiated tubers, clearances have been progressively issued by the competent health authorities of many countries, while the international campaign issued conditional clearances followed by unconditional ones. Late in 1980 unconditional clearance for all sorts of foodstuffs irradiated at a dose level not exceeding 10 kGy was recommended by the Joint WHO/FAO/IAEA Expert Committee, confirming that “toxicological testing is no longer necessary for any food conserved by radiation dose levels not exceeding 10 kGy”[1].

Since 1981 many countries of the world have resumed or initiated their studies in order to explore the potential application of radiation preservation of food under the prevailing local conditions. Egypt, like some other countries, did not discontinue its research programmes on radiation preservation of food started in 1964 [2—4]. Accordingly, Egypt seems to be in a better position to commercialize batch samples of certain irradiated foodstuffs including potatoes. Such an objective would require an economic feasibility study on the transfer and adaptation of the technology to local Egyptian conditions.

POTATO PRODUCTION AND LOSSES IN EGYPT

Egypt is one of fifteen countries of the world undertaking large-scale cultivation and production of potatoes (Fig.1) [5]. In this respect Egypt recognizes its own share of responsibility to decrease the rate of annual potato losses.

In 1977 the annual production from the cultivated area under potatoes in Egypt amounted to more than one million tonnes (Table I). Harvested potatoes are usually kept in ordinary storage where they are subject to sprouting, fungal attack, infestation by harmful insects and undesirable chemical changes. The magnitude of these incidences increases progressively. The average annual (estimated) loss in potato crops stored for 6—8 weeks has been evaluated at 88 kt (Table II), i.e. 9% of total production.

DECREASING POTATO LOSSES IN EGYPT

Attempts have repeatedly been made to minimize the rate of annual loss in potato crops, including low temperature storage and chemical treatment for sprout inhibition. However, the increasing opposition to food additives and the higher cost of refrigeration have shown the pressing need for an alternative method of preservation which can meet the requirements. Irradiation processing of potato tubers has proved to be successful in this respect. Economic feasibility studies for commercialization of such a technology under local environmental
conditions are required. As a comprehensive example “Egypt’s Mega Gamma I” industrial irradiator is considered for the present cost-benefit analysis.

MATERIAL AND METHODS

Potato varieties

Potato tubers of the Alpha variety were used in the experiment. This is a summer crop widely cultivated in the northern part of Egypt. Three thousand kilograms of potato tubers of medium size and almost symmetrical, uniform shape were chosen one month post harvest. Injured and infected tubers were eliminated.

The required sizes were obtained by using special sieves to obtain tubers of 5 to 6.5 cm diameter, which is the most suitable size for export. The sieves were arranged on top of each other. The upper one had holes of 6.6 cm diameter, the lower one had holes of 4.9 cm diameter.

FIG. 1. Average yield per feddan of the major potato producing countries in the world (in tonnes).
TABLE I. MAGNITUDE OF ANNUAL YIELD OF RIPE POTATO CROPS IN VARIOUS EGYPTIAN GOVERNORATES (in kt)

<table>
<thead>
<tr>
<th>Governorate</th>
<th>1976</th>
<th>1977</th>
<th>1978</th>
</tr>
</thead>
<tbody>
<tr>
<td>Alexandria</td>
<td>26 105</td>
<td>29 546</td>
<td>33 857</td>
</tr>
<tr>
<td>Behaira</td>
<td>221 324</td>
<td>252 758</td>
<td>194 731</td>
</tr>
<tr>
<td>Gharbia</td>
<td>145 186</td>
<td>167 825</td>
<td>80 417</td>
</tr>
<tr>
<td>Kafr el Sheich</td>
<td>4 609</td>
<td>6 115</td>
<td>3 125</td>
</tr>
<tr>
<td>Dakahlia</td>
<td>59 417</td>
<td>61 725</td>
<td>50 621</td>
</tr>
<tr>
<td>Damitta</td>
<td>10 818</td>
<td>10 691</td>
<td>10 627</td>
</tr>
<tr>
<td>Sharkia</td>
<td>6 400</td>
<td>10 415</td>
<td>10 633</td>
</tr>
<tr>
<td>Ishmailia</td>
<td>745</td>
<td>1 627</td>
<td>2 355</td>
</tr>
<tr>
<td>Suez</td>
<td>14</td>
<td>11</td>
<td>25</td>
</tr>
<tr>
<td>Monofia</td>
<td>188 803</td>
<td>211 538</td>
<td>122 993</td>
</tr>
<tr>
<td>Kalubia</td>
<td>22 675</td>
<td>22 770</td>
<td>20 524</td>
</tr>
<tr>
<td>Cairo</td>
<td>—</td>
<td>1 060</td>
<td>902</td>
</tr>
<tr>
<td><strong>Lower Egypt</strong></td>
<td>686 096</td>
<td>776 081</td>
<td>530 810</td>
</tr>
<tr>
<td>Giza</td>
<td>144 245</td>
<td>178 678</td>
<td>187 644</td>
</tr>
<tr>
<td>Beni Sueif</td>
<td>11 288</td>
<td>11 596</td>
<td>7 306</td>
</tr>
<tr>
<td>Fayoum</td>
<td>222</td>
<td>386</td>
<td>345</td>
</tr>
<tr>
<td>Minia</td>
<td>40 676</td>
<td>33 368</td>
<td>40 461</td>
</tr>
<tr>
<td><strong>Middle Egypt</strong></td>
<td>196 431</td>
<td>224 028</td>
<td>235 756</td>
</tr>
<tr>
<td>Assiut</td>
<td>1 100</td>
<td>925</td>
<td>410</td>
</tr>
<tr>
<td>Sohag</td>
<td>9 022</td>
<td>8 975</td>
<td>5 374</td>
</tr>
<tr>
<td>Qena</td>
<td>14</td>
<td>357</td>
<td>14</td>
</tr>
<tr>
<td><strong>Upper Egypt</strong></td>
<td>10 136</td>
<td>10 257</td>
<td>5 798</td>
</tr>
<tr>
<td><strong>TOTAL</strong></td>
<td>892 663</td>
<td>1 010 366</td>
<td>772 364</td>
</tr>
</tbody>
</table>

Agric. Econ. (1979).
TABLE II. ANNUAL PRODUCTION AND CONSUMPTION OF POTATOES IN EGYPT (in kt)

<table>
<thead>
<tr>
<th>Year</th>
<th>1975</th>
<th>1976</th>
<th>1977</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Parameters</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Production</td>
<td>720</td>
<td>893</td>
<td>1010</td>
</tr>
<tr>
<td>Export</td>
<td>100</td>
<td>158</td>
<td>166</td>
</tr>
<tr>
<td>Import</td>
<td>35</td>
<td>30</td>
<td>31</td>
</tr>
<tr>
<td>Local consumption</td>
<td>655</td>
<td>765</td>
<td>875</td>
</tr>
<tr>
<td>Seed potatoes</td>
<td>152</td>
<td>167</td>
<td>153</td>
</tr>
<tr>
<td>Losses</td>
<td>66</td>
<td>77</td>
<td>88</td>
</tr>
<tr>
<td>Human diet</td>
<td>437</td>
<td>521</td>
<td>639</td>
</tr>
<tr>
<td>kg/a</td>
<td>10</td>
<td>11.7</td>
<td>3.9</td>
</tr>
</tbody>
</table>

Agric. Econ. (1979).

In the experiments the tubers were stored in bags under ordinary room conditions, each bag containing 50 kg. The range of temperature fluctuation was 11—24°C and that of relative humidity was 45—80%.

EGYPT'S INDUSTRIAL IRRADIATOR

The AECL type JS-6500 industrial cobalt-60 gamma irradiator "Egypt's Mega Gamma I" has been in operation at the National Centre for Radiation Research and Technology (NCRRT) since January 1979 at an initial cobalt-60 capacity of 400 kCi.\(^1\) The plant is furnished with a ventilated concrete biological shield, a water pool for source storage, a principal mechanical conveyor, an extra research channel for pilot irradiation of high density products, a source pass mechanism with pneumatic pushers and all other devices for interlocks, radiation safety and absorbed dose measurements. The plant design has already been described [6] and the dosimetric calculations for irradiation processing have been worked out [7].

\(^1\) Ci = 3.70 \times 10^{10} \text{ Bq.}\)
COST CONSIDERATIONS FOR RADIATION PROCESSING OF POTATOES

For the present cost evaluation, the following parameters were taken into consideration:

- Capital cost: including cost of building, concrete biological shield, radioactive source and mechanical installations.
- Operation cost: including cost of labour, overheads, utilities and radiation dosimeters.
- Plant utilization and source efficiency.
- Rate of radioactive decay and depreciation.
- Interest and rate of return.

RESULTS

Cost-benefit studies revealed the following data:

- Source activity at time of calculation: \( \sim 187 \text{ kCi} \)
- Plant housing capacity for circulating boxes per run: 59 boxes
- Size of irradiation box: \( 0.19 \text{ m}^3 \)
- Weight of loaded potatoes per standard irradiation box: 70 kg
- Total weight of potatoes per run: 4.13 t
- Dose level required for sprout inhibition: 0.08 kGy
- Circulating time for product box: 10 minutes
- Circulating boxes per hour: 6
- Throughput per hour: 24.78 t
- Net cost of plant operation per hour: 30.30 L.E. \([8]^2\)
- Cost of irradiation processing of potatoes per tonne: 1.22 L.E.
- Cost of product irradiation per kilogram: \(1.22 \times 10^{-3} \text{ L.E.} \)
- Average annual production of potatoes: 1 000 000 t (Table II)
- Annual export of potatoes: 160 000 t
- Potatoes stored for local consumption: 840 000 t
- Operating time for potato irradiation: 33 898 h (1412 d = 3.92 a)
- Total annual cost: 1 024 800 L.E.
- Average percentage of annual potato losses (estimated): 9%
- Volume of annual losses: 88 000 t
- Cost at current rate: 7 040 000 L.E.
- Rate of return per annum: 700%
- Total cobalt-60 source activity needed for irradiation processing of potatoes in Egypt: 1.3 MCi.

\(^2\) L.E. = Egyptian pounds.
DISCUSSION

From the results of previous investigations [9] it has been proved that the radiation treatment of potato tubers during the deep dormancy period extending about two months is more effective for sprouting inhibition. Accordingly, radiation processing of the whole annual crop designated for local consumption could be accomplished during this two-month dormancy period. This would require larger sources with a high throughput. Nevertheless, the annual potato crop in Egypt is produced from two annual cultivations with two annual yields: the Nili and the summer crop. This contributes to actual saving of the source activity and, consequently, radioactive decay.

It should also be mentioned that a central facility offering irradiation processing for potatoes harvested all over the country would necessarily result in transport problems and increasing extra costs.

The idea of installing more than one facility covering the three main regions in Egypt, Lower, Middle and Upper, was considered as an alternative. However, it is still felt that a mobile irradiator of a suitable capacity and specifications, which could move with the potato harvest, would contribute significantly to the promotion of irradiation processing of many field crops [10]. This would significantly contribute to maximizing utilization of the radioactive source and increasing its throughput. However, the design of the irradiator, its weight and manipulation should be revised by the manufacturers in order to take into consideration the conditions prevailing in the rural areas with narrow roads and weak bridges crossing anastomosing water canals. Solving this problem would contribute significantly to spreading radiation processing of food commodities world wide.

REFERENCES

Abstract–Resumen

EFFECT OF GAMMA RAYS ON 'DELICIOUS' APPLES STORED UNDER ENVIRONMENTAL CONDITIONS AND UNDER REFRIGERATION.

This study was made with a Gammacell 200 irradiator, the radioactive source in which is cobalt-60. The following doses were studied in detail: 0.5, 1.0, 1.5, 2.0, and 4 kGy. As a comparison, an unirradiated sample was studied at the same time. The storage conditions for refrigeration were 2 ± 1°C and r.h. from 85 to 90%, while for environmental storage they were 26 ± 1°C and r.h. between 63 and 80%. During storage periodic checks were carried out to ascertain weight loss, appearance, titratable acidity, soluble solids and vitamin C. The results obtained for the tests during storage both under environmental conditions and under refrigeration show that there is no great variation between the doses applied. It is also found that irradiated apples stored in the environment can be kept 14—15 days more than the unirradiated ones. Similarly, the refrigerated irradiated apples have a shelf-life of more than 150 days, whereas the unirradiated ones last only up to 120 days. It was also found that a dose of 2 kGy is the best one for preserving apples, since they then last 240 days, while keeping a good colour and appearance.

EFECTO DE LA RADIACION GAMMA EN MANZANAS "DELICIAS" ALMACENADAS AL MEDIO AMBIENTE Y EN REFRIGERACIÓN.

La presente investigación se efectuó utilizando un irradiador Gammacell 200, cuya fuente radiactiva es $^{60}$Co. Se estudiaron en detalle las siguientes dosis: 0.5, 1.0, 1.5, 2.0 y 4.0 kGy. Asimismo, con fines comparativos, se estudió una muestra no irradiada. Las condiciones de almacenamiento en refrigeración fueron: 2°C ± 1 y una HR entre el 85 y el 90%, mientras que al medio ambiente se situaron en 26°C ± 1 y una HR entre el 63 y el 80%. Durante el almacenamiento se realizaron controles periódicos de pérdidas de peso, aspecto, acidez titulable, sólidos solubles y vitamina C. Los resultados obtenidos en los controles durante el almacenamiento tanto al medio ambiente como en refrigeración indican que no hay variación considerable entre las dosis utilizadas. También se encontró que las manzanas irradiadas almacenadas al medio ambiente se conservan de 14 a 15 días más que las no irradiadas. Asimismo, las manzanas irradiadas en refrigeración sobrepasan los 150 días de vida útil, mientras que las no irradiadas solo pueden conservarse hasta 120 días. Igualmente se halló que la dosis de 2 kGy es la más apropiada para la conservación de manzanas, pues éstas alcanzaron 240 días manteniendo sus características de buen color y aspecto.
INTRODUCCION

Las necesidades mundiales de alimentos siguen en aumento mientras que la producción y productividad son reducidas o limitadas. Así mismo, los problemas de almacenamiento y tratamiento de alimentos persisten, lo cual obliga a buscar nuevos métodos de conservación. El tratamiento de alimentos por partículas o radiaciones ionizantes es un método reciente y todavía poco utilizado que permite destruir en ciertos casos algunos o casi todos los microorganismos presentes en los alimentos; también se emplea para destruir insectos, inhibir o retardar procesos fisiológicos de maduración y germinación de productos vegetales. Estos tratamientos son posibles siempre y cuando no se afecte en forma adversa la comestibilidad de los alimentos; se debe tener en cuenta que según las dosis aplicadas se producen o pueden producirse modificaciones químicas en componentes alimenticios.

METODO

El presente trabajo se desarrolló siguiendo el diagrama mostrado en la Figura 1. Además, durante el almacenado, se realizaron controles físicos y químicos.

RESULTADOS Y DISCUSION

La variación del contenido de humedad en manzanas almacenadas al medio ambiente se muestra en la Fig. 2, donde se observa que las manzanas no irradiadas disminuyen de humedad con mayor rapidez que las irradiadas, lo cual indica que la radiación retarda los procesos fisiológicos de las manzanas. Con respecto a las manzanas refrigeradas tanto irradiadas como no irradiadas, después de los 120 días de almacenamiento, se presenta una marcada diferencia con respecto a la pérdida de humedad, pues las no irradiadas alcanzan humedades inferiores al 83%, lo que ocasiona encogimiento de la cáscara; mientras que las irradiadas, a los 150 días tienen humedades entre el 83,20%, y el 83,72%, lo que permite que la cáscara mantenga aún sus características de frescura.

En cuanto a la acidez titulable, las manzanas no irradiadas almacenadas al medio ambiente experimentan mayor pérdida de sus ácidos que las irradiadas, especialmente durante los 15 primeros días. Con respecto a las manzanas refrigeradas, la Fig. 3 muestra que las manzanas irradiadas y no irradiadas presentan una similar tendencia a perder sus ácidos, siendo más notoria la pérdida en las no irradiadas, pero éstas solo pudieron alcanzar un período de vida útil de almacenamiento de 120 días; no así las irradiadas que se conservaron más de 150 días. Estos resultados coinciden con lo reportado por Fernández [1].
La variación de los sólidos solubles en manzanas irradiadas y no irradiadas almacenadas al ambiente presenta la misma tendencia a incrementar su concentración. Similar fenómeno ocurre con las manzanas irradiadas y no irradiadas en refrigeración, cuyo resultado se muestra en la Fig.4. La alta variabilidad de los resultados obtenidos se puede atribuir a las diferentes características del mismo fruto, tales como tamaño, grado de madurez, composición, etc. El incremento de sólidos solubles indica que la irradiación en las dosis utilizadas atenúa el proceso de maduración y extiende el período de vida útil de las manzanas. Además, los sólidos solubles al incrementar aumentan el sabor dulce de las manzanas, pues están constituidos principalmente por azúcares [2].

La Fig.5 muestra el comportamiento de la vitamina C en manzanas almacenadas al medio ambiente, en donde se observa una tendencia general a disminuir en concentración. La destrucción de vitamina C es consecuencia
FIG. 2. Variación del contenido de humedad de manzanas no irradiadas e irradiadas durante su almacenamiento al medio ambiente (T: 26 ± 1°C, HR: 63–80%).

FIG. 3. Variación de la acidez titulable total en manzanas no irradiadas e irradiadas durante su almacenamiento en refrigeración (T: 2 ± 1°C, HR: 85–90%).
FIG. 4. Variación del contenido de sólidos solubles en manzanas no irradiadas e irradiadas durante su almacenamiento en refrigeración (T: 2 ± 1°C, HR: 85–90%).

FIG. 5. Variación del contenido de vitamina C en manzanas no irradiadas e irradiadas durante su almacenamiento al medio ambiente (T: 26 ± 1°C, HR: 63–80%).
de los cambios metabólicos de oxidación del fruto por efectos de la radiación, aunque ésta puede convertir a la vitamina C en ácido dehidroascórbico, que también puede ser metabolizado como vitamina C [3]. Asimismo, se puede afirmar que hay una mayor tendencia a disminuir de vitamina C en las manzanas no irradiadas. En cambio, las irradiadas muestran menor tendencia, posiblemente debido al efecto protector de ciertos ácidos, como el málico, el fumárico y el oxálico sobre la vitamina (Tappel y Knapp [4]), razón por la cual, según estos autores, las pérdidas de vitamina C en frutas rara vez exceden del 20 al 30% cuando las dosis son menores de 5 kGy.

CONCLUSIONES

De acuerdo con los resultados obtenidos se puede concluir que las dosis de 0,5, 1,0, 1,5, 2,0 y 4,0 kGy prolongan el periodo de vida útil de las manzanas almacenadas en refrigeración y al medio ambiente. Asimismo, los mejores resultados se obtuvieron con la dosis de 2 kGy.

REFERENCIAS

PROSPECTS AND PROBLEMS OF IRRADIATING PAPAYA
A case study in Hawaii*

J.H. MOY
Department of Food Science
and Human Nutrition,
University of Hawaii at Manoa,
Honolulu, Hawaii,
United States of America

Abstract

PROSPECTS AND PROBLEMS OF IRRADIATING PAPAYA – A CASE STUDY IN HAWAII.
The United States Environmental Protection Agency’s (EPA’s) ban of ethylene dibromide
(EDB) as a fruit fumigant has forced Hawaii’s papaya industry to search for alternative treatments.
Among various alternatives considered, irradiation process is the most efficacious because fruits
can be sorted, packaged, chilled and conveyed to an irradiator for low-dose treatments (0.26 kGy
for disinfestation) before shipment to export markets. The papaya industry in Hawaii, however,
has not assigned a high priority to the irradiation process. Instead, the industry opted for the
double-dip hot water treatment which was rushed to become an USDA-approved procedure
shortly before 1 September 1984. Three major concerns expressed by the papaya industry about
the irradiation process as a replacement for chemical fumigation are: (1) Capital investment;
(2) Logistics of irradiation processing and fruit transport; and (3) Consumer acceptance. The
outlook for radiation disinfestation of Hawaii-grown papaya is quite good in spite of these
concerns expressed by the industry. Some packers are beginning to feel that there are more
advantages and benefits in adopting this process than the disadvantage of negative publicity
about nuclear technology. With the availability of irradiation, the fruit and vegetable industry
in Hawaii could be expanded by increased production and sales of new or existing crops. A
worthwhile task ahead would be for the food industry, government agencies and researchers to
join forces in conducting an effective consumer education programme by assuring the public
that irradiated foods are safe. Concurrently, certain segments of the food industry should
consider and prepare for the processing and marketing of irradiated foods.

INTRODUCTION

Disinfestation of insects in food and agricultural products by ionizing radiation is one of six beneficial
applications of this food preservation technology. A few years after ethylene dibromide (EDB) became an officially
approved fumigant in the USA for quarantine treatment of fruits and vegetables, Balock and his co-workers foresaw the

* Journal Series No.2936 of the Hawaii Institute of Tropical Agriculture and Human
Resources, University of Hawaii, Honolulu, Hawaii.
potential application of irradiation to fruit fly control [1]. His proposal led to the initiation of a project in 1957 at the U.S. Department of Agriculture (USDA) Hawaii Fruit Flies Investigation Laboratory to study the effect of gamma-radiation on fruit flies infesting papayas in Hawaii. The effectiveness of gamma-radiation as a potential commodity treatment technology was recently reviewed by Burditt [2].

In 1965, an irradiation project supported by the then U.S. Atomic Energy Commission (AEC) was initiated at the University of Hawaii aiming at acquiring new knowledge and data on dosimetry, tolerance and shelf-life extension related to disinfestation of fruits and vegetables by gamma-irradiation. Primary emphasis was on factors related to quality and shelf-life, FDA clearance, marketing and economics, packaging and product handling, with major attention directed toward Hawaii-grown papaya and several other tropical fruits [3]. In 1967, the Hawaii Development Irradiator (HDI), one of two USAEC-funded pilot, quasi-commercial food irradiators, was built in Honolulu. Results of close working relations and cooperation between research workers at the Hawaii Research Irradiator (HRI), the Hawaii Development Irradiator and the USDA Hawaii Fruit Fly Investigation Laboratory have established that gamma-radiation at 0.26 kGy can disinfest the papaya of 3 species of fruit flies (Mediterranean, Oriental and melon flies) and that papaya can tolerate gamma-radiation at 1.0 kGy without any quality changes under laboratory conditions and after long distance surface and air shipments. In addition, the shelf-life of irradiated papaya can be extended for 3-4 days more than its fumigated counterpart when hot water treated at 49°C for 20 min. followed with irradiation at 0.75 kGy [4,5].

Until 1984, the two accepted quarantine treatment procedures for disinfestation of fruit flies in Hawaii-grown papayas were ethylene dibromide (EDB) and vapor heat treatment (47°C fruit surface temperature in 8-10 hrs). Chemical fumigation was predominantly used because it took less time and the fruit's ripening was not accelerated as was the case of the vapour heat process. Both were batch processes and fruits for both treatments had to begin at ambient temperature (21°C or above).

In December, 1977, the U.S. Environmental Protection Agency (EPA) published a notice that it was starting the Rebuttable Presumption Against Registration (RPAR) process for EDB and invited interested persons to submit rebuttals or other information on its hazards to human health [6]. In December, 1980, USEPA took the next major step by announcing that "the Agency has concluded that the presumptions for oncogenicity, mutagenicity and reproductive disorders resulting from handling
EDB-treated food products or using EDB as a pesticide has not been rebutted." Also announced was a preliminary decision to cancel the use of EDB on stored grain immediately and on citrus and tropical fruits effective 1 July 1983. Other uses would be continued but on a restricted basis. The 1980 EPA notice says flatly, "It should be emphasized that the Agency believes that, in the long run, measures short of outright cancellation will not reduce the risks sufficiently to alter the conclusion that the use of EDB for quarantine fumigation of citrus, tropical fruits, and vegetables poses unreasonable adverse effects on the environment..."

The request to USEPA for a hearing on EDB by several U.S. fruit industry groups resulted in an extension of the deadline for cancellation of EDB. Finally, EDB was banned as a grain, fruit and vegetable fumigant on 1 September 1984 [7]. Hawaii's papaya industry was forced to search for alternative quarantine treatments. The vapour heat method was not used because of the disadvantages mentioned.

PROSPECTS OF IRRADIATING PAPAYA

The processing of papayas up to 1 September 1984 involved: picking, hot water treatment (49°C, 20 min.; 23°, 20 min. for fungal disease control), fumigation, waxing, grading, packaged, cold storage, and shipping. Among various alternatives considered, which included phosphene, microwave, ultrasound, double-dip hot water, and irradiation, the irradiation process is easily the most efficacious because harvested fruits can be sorted, graded, packaged, chilled and conveyed to an irradiator for low dose treatments (ca. 0.26-0.30 kGy for disinfestation) in a very efficient flow system before shipment to export markets.

There are several advantages in using radiation to disinfest papayas of fruit flies: (1) there is no radioactivity or toxic residues remain on the fruit; (2) the fruit is not softened, nor is ripening accelerated; (3) it ensures complete disinfestation; (4) it can and will improve processing efficiency because it can be applied at any stage in the post-harvest processing line and is easily adaptable to a continuous flow system; and (5) it delivers a superior product to the market because the time saved in total processing could permit the fruit on the tree to be picked later for better appearance and taste, or allow more time for shipping and marketing, or a combination of these.

Extensive research and semi-commercial processing and shipping of papayas have demonstrated that the three species of fruit flies can be controlled, and the sensory, chemical and nutritional qualities of the papaya are retained [3,8].
Dependent upon which concept or criterion is used for quarantine treatment, the minimum absorbed dose can be either 0.26 kGy for probit 9 security, a quarantine terminology synonymous with negligible pest risk (less than 32 survivors per 1 million treated), or 0.05 to 0.10 kGy if the criterion is the inability of the insect to produce viable offspring [9]. If the latter criterion is used, which is currently being investigated, then the concept of a two-stage quarantine treatment schedule might become a reality in the future which will make the radiation processing even more attractive economically because of the low dose required.

With all the advantages mentioned, four main factors will govern the commercial application of radiation as a disinfection process:

Technical efficacy

There seems to be no question about the technical efficacy of radiation disinfection of fruits. It is supported and established by ample research data.

Government approval

Worldwide activities of food irradiation have gained momentum since the early 1980s largely because of the recommendation in 1980 by the Joint FAO/IAEA/WHO Expert Committee on Food Irradiation that "food treated up to an overall average dose of 10 kGy presents no toxicological hazard and no nutritional or microbiological problems" [10], and the adoption in 1983 of the International Standard for Irradiated Foods by the Codex Alimentarius Commission [11]. After an extensive review of all research data on irradiated foods by an internal task force, the U.S. Food and Drug Administration (FDA) published in 1982 the intent of proposed rule changes in irradiated foods, and subsequently on February 14, 1984 in the Federal Register the proposed rule changes in irradiated fruits and vegetables for insect disinfection and delayed maturation. These moves represent FDA's belief and position that food irradiated at doses up to 1.0 kGy is safe for human consumption.

Industry interest

Interest in using the radiation process for whatever purpose and application must be shown by the food industry because it is the beneficiary of all the research but it has to demonstrate "user" interest. There may be two scenarios to this factor, however. Food industries in the developed countries have not been too quick to participate in and consider
this technology because there are other competitive, established food preservation technologies available such as canning and freezing. They are also aware of the sizable capital investment a food irradiator will require. Food industries in the developing countries, on the other hand, might see the larger benefits of food irradiation because the need to minimize food spoilage is more urgent and other forms of processing and energy to preserve foods are not as readily available. However, economic factor still plays a role because a commercial irradiator of any size still requires a major investment.

Consumer acceptance

This is probably the most important factor in commercial application of food irradiation because of unfavorable events and negative publicity about nuclear energy in the past 12-15 years. Issues on nuclear weapon deployment and nuclear waste disposal, and documentaries on nuclear war and reactor leaks in nuclear power plants cast a shadow on the consumer's mind about the safety of irradiated foods.

CONCERN OF THE PAPAYA INDUSTRY

The papaya industry in Hawaii, quite well informed about the technical efficacy of radiation disinfestation, has not assigned a high priority to the irradiation process as one of the alternatives to chemical fumigation. Instead the industry opted for the double-dip hot water treatment which was rushed to become an USDA-approved quarantine procedure shortly before 1 September 1984. The other physical treatment methods tested, ultrasound and microwave, did not work because of problems in energy attenuation or overheating of the fruit.

Three major concerns have been expressed by the papaya industry in Hawaii regarding irradiation which are also the reasons for its not being ready to consider the irradiation process to replace chemical fumigation:

Capital investment

A number of papaya packers appear to prefer to be part owners of an irradiator facility instead of being a user on a fee basis. Depending upon the throughput, product type, package configuration, absorbed dose, and other requirements, a commercial scale irradiator to be built in Hawaii in 1984-85 could cost about U.S. $2 million or more. Even a fraction of this sum would be a sizable investment for some packers.

However, more than one irradiator manufacturers in the USA and Canada have indicated interest in building a papaya
irradiator for Hawaii. Methods of financing will vary. One company has offered the packers the option of buying shares into the irradiator facility which is exactly what some of the packers wanted.

A recent economic feasibility study on irradiation of Mexican fruits sponsored by IAEA and conducted by Moy and scientists at the National Institute of Nuclear Research, Salazar, Mexico [12] shows that with a projected throughput of 50 000 and 100 000 metric tons of mangoes irradiated per year, and 100 000 and 150 000 metric tons of oranges and tangerines irradiated per year, the irradiation costs will be U.S. $0.026 to 0.041 per kg of mangoes and U.S. $0.022 to 0.026 per kg of citrus at an assumed minimum absorbed dose of 0.30 kGy for controlling the emergence of Mexican fruit flies. The cost is realistic and is certainly very competitive with chemical fumigation ($0.050 per kg papaya in Hawaii). Still lower cost can be realized if the cost of the irradiator facility is less than that indicated in the study (ca. U.S. $2.1-3.3 million per irradiator plant).

Based on the above cost analysis, capital investment or cost of irradiation should not be a major concern of the user - the papaya industry in Hawaii.

Logistics of irradiation processing and fruit transport

Papayas are produced mainly on the Islands of Hawaii and Kauai for the export market with the volume ratio of about 7 to 3. Total production for 1984 was estimated to be 40 000 metric tons. The commerce center and air freight capacities are located on the Island of Oahu, about 300 km from the Island of Hawaii and 150 km from the Island of Kauai. Thus the locations and number of irradiators to be built to meet the required throughputs need to be carefully defined. Some packers feel that even if one irradiator can serve all the papaya packers on one island, there might still be a scheduling problem. The availability and the extra cost of interisland freights to move the fruits from an island without an irradiator to another island with an irradiator facility might present additional problems.

One irradiator manufacturer indicated that a minimum throughput for an irradiator to treat papaya in Hawaii should be about 20 000 metric tons per year, with design flexibility to increase the source strength for a higher capacity. Because of flexibility in fruit ripeness and fruit temperature during irradiation processing, the logistics problems seem to be solvable.
Consumer acceptance

Several members of the Hawaii papaya industry consider this a very important issue because of uncertainty about consumer reactions to irradiated foods. It is probably true that news in recent years about various negative aspects of nuclear technology have tended to invoke suspicion about the safety of irradiated foods. It is unfortunate that during the several decades when food irradiation research was conducted around the world, assurance of safety and quality of irradiated foods had not been well publicized to the consumers.

The recently adopted double dip hot water treatment has created a consumer acceptance problem of another kind. The high thermal energy applied to the papaya by this treatment has apparently inactivated two enzymes in the fruit responsible for its ripening and has also caused the production of a gas within the fruit called benzyl isothiocyanate which inhibits ripening. As a result, many of the treated papayas did not ripen and had a lumpy, hard texture with little or no flavor. Papaya sales in California has plummeted in recent months because of consumer resistance to the double-dip hot water treated fruit.

OUTLOOK AND CONCLUSION

The outlook for radiation disinfestation of Hawaii-grown papaya is good in spite of several concerns expressed by the industry. Some packers are beginning to feel that the advantages and benefits of irradiation will outweigh the concerns and negative publicity about nuclear technology. Legislation was introduced in the U.S. Congress in November 1983 to amend the classification of food irradiation from the category of a food additive to a food process [13]. The USFDA since the summer of 1984 has been reviewing the comments on the proposed rule changes in irradiated fruits and vegetables and has indicated that the legislation introduced by Congressman Morrison would not affect the rule changes. It is quite likely that the rule changes will become official before the summer of 1985.

In conclusion, adoption of the irradiation process would improve the handling of papaya from the time of harvest to delivery to the consumer by reducing the delays inherent in all of the other batch treatment processes. Besides a competitive treatment cost of about U.S. $0.05 per kg of fruit, the economics is additionally favored by using an efficient process which brings savings in inspection and packaging.

It is quite conceivable that radiation processing of papaya could be the beginning of a new postharvest technology
for other products in Hawaii. Disinfestation of mangoes, cucurbits and other tropical fruits is an obvious possibility. New or increased production and sales of these crops could make an important contribution to the agricultural industry in Hawaii.

A worthwhile task ahead would be to conduct an effective consumer education program on the safety and benefits of irradiated foods, a joint effort by the food industry, government agencies and researchers. Concurrently, certain segment of the food industry should seriously consider and prepare for the processing and marketing of irradiated foods.

REFERENCES

RADIATION DECONTAMINATION OF DRY CHAMOMILE FLOWERS AND CHAMOMILE EXTRACT

B. KATUŠIN-RAŽEM, D. RAŽEM, I. DVORNIK
‘Ruder Bošković’ Institute,
Zagreb

S. MATIĆ, V. MIHOKOVIĆ
Public Health Institute of Croatia,
Zagreb

Yugoslavia

Abstract

RADIATION DECONTAMINATION OF DRY CHAMOMILE FLOWERS AND CHAMOMILE EXTRACT.

Chamomile flowers show very high microbiological contamination, up to $10^8$ microorganisms per gram. It is demonstrated that about 2% of thermoresistant bacteria survive to chamomile tea, and about 3% of sporogenic bacteria survive the extraction with aqueous ethanol. Commercial concentrated chamomile extracts also contain a high level of microbial contamination which persists for a long time. The presence of microorganisms in herbs and extracts presents a health hazard and can cause the spoilage of food. For radiation decontamination of concentrated chamomile extracts higher doses are required than for dry chamomile flowers. The components of ethereal oil and hydrophilic components obtained from irradiated dry flowers did not change up to a 10 kGy dose. No immediate radiation-induced change of the components obtained from concentrated extract was observed at 15 kGy, except for a 17% decrease of herniarin. However, for commercial sterility, lower doses would be adequate. The content of en-in-dicyclo-ether decreased only over an extended storage time. Radiation is an efficient and convenient method for decontamination of dry plants and the only choice for decontamination of heat-sensitive extracts and concentrates.

1. INTRODUCTION

Microbiological contamination of plant materials used as dry food ingredients and processing aids is a widely recognized problem [1]. The survey of a number of dry tea herbs (chamomile flowers, mint leaves, dog-rose hips and linden flowers) marketed in Yugoslavia has also revealed a significant level of microbial contamination [2]. Chamomile flowers appeared to be the worst case with respect to both the spectrum and the number of microorganisms. Total count as high as $10^7–10^8$ microorganisms per gram was found in about 10% of suspected cases investigated, while about 80% of the samples contained between $10^5$ and $10^7$
microorganisms per gram. The presence of microorganisms indicative of faecal pollution was found in a majority of the samples. Similar findings in France, Belgium and Poland have also been published [3—5].

Apparently, chamomile has no significant inherent antimicrobial activity, such as found in some other plants [6]. One year old samples still contained a significant level of contamination. Other authors have also reported on the survival of Enterobacteriaceae in dry plant material after one year's storage [5]. Chamomile is one of the principal medical herbs in Yugoslavia, which is finding an increasing use in the food industry. The novel process of room temperature extraction assisted by ultrasound, enables essential components to be extracted with good yields and without appreciable destruction [7], yielding a valuable and versatile product. The convenient reduction of volume, unfortunately, is not accompanied by the reduction of microbial contamination.

As an extension of the previous work [2] we were interested in determining the microbial population which survived the processes of preparing infusions and extracts from dry chamomile flowers, as well as in the possibility of radiation decontamination of chamomile extracts.

The study of chemical changes in irradiated dry chamomile flowers was extended to 10 kGy and to hydrophilic components. The effect of storage time on the contents of essential components in irradiated and unirradiated extracts was also studied.

2. EXPERIMENTS

Dry chamomile flowers were obtained from the same location as for the previous study [2]. These samples were used in the studies of chemical composition of dry flowers as a function of dose. Contaminated samples withdrawn from the market were used for microbiological studies.

Commercial concentrated chamomile extracts were factory made by room temperature extraction with 56% ethanol, assisted by ultrasound and followed by vacuum evaporation of alcohol. A concentrated extract containing 71% of dry matter (γ = 1.366 g/mL) and 1% of ethereal oil was obtained. Extracts were also prepared in the laboratory by percolation of crushed dry flowers with 67% ethanol according to Ref. [8]. Extracts containing 60% ethanol and 0.2% ethereal oil (γ = 0.90 g/mL) were obtained.

Infusions were prepared by soaking dry chamomile flowers in hot water for 10 minutes. During this time the temperature would drop to 64°C. Dry chamomile flowers were irradiated in sealed polyethylene bags, while extracts were irradiated in stoppered test tubes. Irradiations with 60Co gamma rays were performed at a dose rate of 50 Gy/min.
Microbiologic analyses were performed according to the Yugoslav Official Code of Practice for microbiological analyses of food [9]. Enterobacteria were determined by direct inoculation on violet red bile agar [10].

To study eventual chemical changes brought about by irradiation of essential lipophilic constituents, dry chamomile flowers and concentrated extracts were subjected to steam distillation yielding ethereal oil. The composition of ethereal oil was analysed by gas chromatography and spectrophotometry as already described [2].

Hydrophilic constituents of dry chamomile flowers and concentrated extracts were extracted by a polar solvent, such as methanol. Total flavonoids were determined by spectrophotometry as a complex with Al$^{3+}$ [11].

The coumarin herniarin was first isolated by preparative thin-layer chromatography on silica gel, using benzene-ethylacetate mixture (9:1) as developing solvent and methylene dichloride for elution. It was determined spectrophotometrically in ethanol solution using molar absorbance at 323 nm of $(17 \pm 518) \mathrm{M}^{-1} \cdot \mathrm{cm}^{-1}$ as determined by six calibration experiments.

3. RESULTS

Commercial concentrated chamomile extracts were found to contain an unacceptably high microbial contamination, about $10^6$ microorganisms per gram. This population was persistent in the extract for many months. The test of inhibition revealed that *E. coli* only was affected by concentrated extract over a 2 mm zone, while *Sarcina flava* and *Pseudomonas aeruginosa* were unaffected.

Microorganisms surviving adverse treatments were studied in laboratory-prepared infusions and extracts from 'naturally' contaminated chamomile flowers. Table I shows that the most thermoresistant fraction of aerobic flora (2%) survives hot water treatment and is subsequently found in infusion. A non-trivial 3% of spore forming bacteria are also found to survive in the extract.

The survival of microorganisms in concentrated chamomile extract as a function of radiation dose is shown in Fig. 1. While the survival fraction of microorganisms in dry chamomile flowers was well approximated with a straight line, the corresponding function in the extract shows two different features. First, the efficiency of radiation, expressed as decimal reduction dose $D_{10}$, is lower in the extract (higher $D_{10}$, Table II), and second, the efficiency in the extract increases with increasing dose.

The results of chemical analysis of the components of ethereal oil of chamomile flowers irradiated with 5 and 10 kGy are shown in Table III. The results with 10 kGy are in agreement with the previous ones with 5 kGy, showing that no radiation degradation of lipophilic components takes place up to 10 kGy.
<table>
<thead>
<tr>
<th>Species or groups of microorganisms</th>
<th>Dry flower (m.o./g)</th>
<th>Infusion (m.o./mL) (m.o./g flower) (calculated)</th>
<th>Extract (m.o./mL) (m.o./g flower) (calculated)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total count of aerobic bacteria</td>
<td>6 200 000 ± 920 000</td>
<td>590 ± 140 120 000 ± 28 000</td>
<td>2 ± 1 6 ± 3</td>
</tr>
<tr>
<td>Spore-forming bacteria</td>
<td>38 000 ± 8 200</td>
<td>430 ± 340 1 400 ± 1 100</td>
<td></td>
</tr>
<tr>
<td>Germinating mould spores</td>
<td>1 100 ± 460</td>
<td>0 0</td>
<td>0 0</td>
</tr>
<tr>
<td>Enterobacteria</td>
<td>590 000 ± 82 000</td>
<td>0 0</td>
<td>0 0</td>
</tr>
<tr>
<td>E. Coli</td>
<td>2 200 ± 700</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sulphite-reducing clostridia</td>
<td></td>
<td>+−−</td>
<td>−−−</td>
</tr>
<tr>
<td>in 10</td>
<td></td>
<td>−−−</td>
<td>−−−</td>
</tr>
<tr>
<td>in 0.1</td>
<td>+++</td>
<td>−−−</td>
<td>−−−</td>
</tr>
<tr>
<td>in 0.01</td>
<td>++−</td>
<td>−−−</td>
<td>−−−</td>
</tr>
<tr>
<td>in 0.001</td>
<td>−−−</td>
<td>−−−</td>
<td>−−−</td>
</tr>
</tbody>
</table>

* Three determinations ± SD. m.o. = microorganism.

An analysis of hydrophilic components of chamomile flowers is shown in Table IV. Herniarin which is present in chamomile flowers in concentrations five times higher than the other coumarin umbelliferone shows a slight sensitivity to irradiation at 10 kGy. Total flavonoids, i.e. flavon aglycons forming complexes with Al³⁺, do not change with doses up to 10 kGy.

The composition of ethereal oil obtained from commercial concentrated extracts as a function of dose and storage time is shown in Table V. The irradiation with a dose of 15 kGy necessary for sterilization causes the content of en-indicyclo-ether to decrease faster than in unirradiated samples (~35% over 4 months). The content of chamazulene decreases in both unirradiated samples and in samples irradiated with 15 kGy at the same rate of about 3% per month. Chamazulene in dry flowers also decreases with storage and at a somewhat faster rate (~5% per month).

The effect of irradiation and storage time on the content of herniarin and flavonoids is shown in Table VI. The irradiation with 15 kGy caused an immediate

TABLE II. DECIMAL REDUCTION DOSE (D_{10}) IN DRY CHAMOMILE FLOWERS AND CONCENTRATED EXTRACT

<table>
<thead>
<tr>
<th>Species</th>
<th>D_{10}(kGy)</th>
<th>Dry flowers</th>
<th>Extract</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total count of aerobic bacteria</td>
<td>1.4</td>
<td></td>
<td>3.3</td>
</tr>
<tr>
<td>Spore-forming bacteria</td>
<td>1.5</td>
<td></td>
<td>3.2</td>
</tr>
</tbody>
</table>

17% decrease of herniarin which was not further affected by storage time. Total flavonoids expressed as apigenin did not change, either on irradiation or with storage time.

4. DISCUSSION

Dry herbs have been used as spices, condiments and flavouring aids since ancient times. Their extracts and concentrates have been used in the preparation of refreshing drinks and teas, cakes, candies and beverages. Many plants have also had a number of non-food related uses, mostly based on their pharmacologically active constituents. Chamomile is one such plant which is finding an increasing use in the food, pharmaceutical and cosmetics industries.
TABLE III. COMPOSITION OF ETHEREAL OIL OF DRY CHAMOMILE FLOWERS AS A FUNCTION OF DOSE

<table>
<thead>
<tr>
<th>Component</th>
<th>GC</th>
<th>0 kGy</th>
<th>5 kGy</th>
<th>10 kGy</th>
</tr>
</thead>
<tbody>
<tr>
<td>Farnesene</td>
<td></td>
<td>2.9 ± 0.2</td>
<td>2.8 ± 0.3</td>
<td>2.9 ± 0.1</td>
</tr>
<tr>
<td>Bisabolol oxide B</td>
<td></td>
<td>13.2 ± 3.4</td>
<td>12.5 ± 0.7</td>
<td>13.2 ± 0.9</td>
</tr>
<tr>
<td>(-)-α-Bisabolol</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Chamazulene</td>
<td></td>
<td>3.7 ± 0.3</td>
<td>3.5 ± 0.1</td>
<td>3.5 ± 0.1</td>
</tr>
<tr>
<td>Bisabolol oxide</td>
<td></td>
<td>13.6 ± 0.4</td>
<td>14.3 ± 1.3</td>
<td>14.4 ± 1.3</td>
</tr>
<tr>
<td>En-in-dicyclo-ether</td>
<td></td>
<td>5.8 ± 0.8</td>
<td>5.6 ± 0.8</td>
<td>5.7 ± 0.3</td>
</tr>
</tbody>
</table>

a Four determinations ± SD.
GC = gas chromatography.

TABLE IV. CONTENT OF HYDROPHILIC COMPONENTS (COUMARINS AND FLAVONOIDS) IN DRY CHAMOMILE FLOWERS AS A FUNCTION OF DOSE

<table>
<thead>
<tr>
<th>Dose (kGy)</th>
<th>Herniarin (mg/100 g flowers)b</th>
<th>Total flavonoidsa (mg/100 g flowers)b</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>35.9 ± 3.6</td>
<td>1630 ± 150</td>
</tr>
<tr>
<td>5</td>
<td>34.2 ± 3.0</td>
<td>1590 ± 30</td>
</tr>
<tr>
<td>10</td>
<td>32.3 ± 3.2</td>
<td>1660 ± 150</td>
</tr>
</tbody>
</table>

a Expressed as apigenin.
b Five determinations ± SD.

However, many plants and their parts harbour a variety of microorganisms, chamomile flowers being one of the most susceptible to microbiological contamination. Besides representing a direct health hazard to the consumer, microbiologically contaminated herbs facilitate the dissemination of harmful microorganisms. Concentrated extracts are a convenient form to handle and keep the essential constituents of plants in a much smaller volume for an extended period of time. Storage properties of extracts are therefore important from both the chemical and the microbiological point of view. The presence of microorganisms...
TABLE V. COMPOSITION OF ETHEREAL OIL OF COMMERCIAL CHAMOMILE EXTRACTS AS A FUNCTION OF DOSE AND STORAGE TIME

<table>
<thead>
<tr>
<th>Components</th>
<th>Dose (kGy)</th>
<th>% in ethereal oil&lt;sup&gt;a&lt;/sup&gt;</th>
<th>Time after irradiation (months)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>20</td>
<td>40</td>
</tr>
<tr>
<td>Bisabolol oxide B (GC)</td>
<td>0</td>
<td>2.5 ± 0.3</td>
<td>2.4 ± 0.3</td>
</tr>
<tr>
<td></td>
<td>15</td>
<td>2.6 ± 0.3</td>
<td>2.5 ± 0.2</td>
</tr>
<tr>
<td>(-)-α-bisabolol (GC)</td>
<td>0</td>
<td>2.6 ± 0.3</td>
<td>2.3 ± 0.2</td>
</tr>
<tr>
<td></td>
<td>15</td>
<td>2.7 ± 0.3</td>
<td>2.4 ± 0.2</td>
</tr>
<tr>
<td>Bisabolol oxide A (GC)</td>
<td>0</td>
<td>4.8 ± 0.7</td>
<td>4.7 ± 0.6</td>
</tr>
<tr>
<td></td>
<td>15</td>
<td>4.7 ± 0.5</td>
<td>4.4 ± 0.2</td>
</tr>
<tr>
<td>En-in-dicyclo-ether (GC)</td>
<td>0</td>
<td>4.1 ± 0.5</td>
<td>4.0 ± 0.6</td>
</tr>
<tr>
<td></td>
<td>15</td>
<td>4.0 ± 0.6</td>
<td>3.2 ± 0.2</td>
</tr>
<tr>
<td>Chamazulene (SP)</td>
<td>0</td>
<td>0.98 ± 0.06</td>
<td>0.88 ± 0.02</td>
</tr>
<tr>
<td></td>
<td>15</td>
<td>0.90 ± 0.04</td>
<td>0.84 ± 0.02</td>
</tr>
</tbody>
</table>

<sup>a</sup> Six determinations ± SD.

GC = gas chromatography; SP = spectrophotometry.

TABLE VI. CONTENT OF HYDROPHILIC COMPONENTS (COUMARINS AND FLAVONOIDS) IN COMMERCIAL CHAMOMILE EXTRACTS AS A FUNCTION OF DOSE AND STORAGE TIME

<table>
<thead>
<tr>
<th>Dose (kGy)</th>
<th>Herniarin&lt;sup&gt;b&lt;/sup&gt; (mg/100 g extract)</th>
<th>Total flavonoids&lt;sup&gt;a&lt;/sup&gt; (mg/100 g extract)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Time after irradiation (months)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>0</td>
<td>6</td>
</tr>
<tr>
<td></td>
<td>6</td>
<td>0</td>
</tr>
<tr>
<td>0</td>
<td>168.5 ± 9.4</td>
<td>2880 ± 150</td>
</tr>
<tr>
<td>15</td>
<td>138.9 ± 4.7</td>
<td>2860 ± 180</td>
</tr>
</tbody>
</table>

<sup>a</sup> Expressed as apigenin.

<sup>b</sup> Five determinations ± SD.
in extracts can cause the spoilage of food and pharmaceutical and cosmetics preparations to which the extract is added.

A fraction of the microbial population thriving on dry chamomile flowers is resistant to heat treatment and another one to percolation with alcohol, as shown in Table I.

Radiation decontamination of dry herbs appears to be a more promising method than fumigation, while in the case of extracts it seems to be the only reasonable choice if the advantages of the room-temperature process are to be preserved.

The concentrated extract provides a better medium for microorganisms than dry flowers as evidenced by the initial values of decimal reduction dose, $D_{10}$, amounting in the former case to 1.4 kGy as compared with 3.3 kGy in the latter. We hypothesize that this may be due to the enhanced availability of nutrients in the liquid as compared with the dry matter. On the other hand, the convex shape of the survival curve at higher doses can be attributed to the enhanced effect of damaging short-lived radiolytic products reaching microorganisms by diffusion from the bulk, while irradiation of the solid support was able to produce only direct damage to the microorganisms which were hit.

Indirect action of radiolytic products on en-in-dicyclo-ether in etherial oil from the extract is probably responsible for the radiation-induced degradation progressing with time. The aromatic nucleus of chamazulene is more sensitive to irradiation in solution than in the solid state, as was found for closely related compounds azulene [12] and guaiazulene [13]. The presence of other constituents probably exerts a protective effect on chamazulene in the concentrate preventing its radiolytic degradation. However, the loss of chamazulene is proportional to storage time in both irradiated and unirradiated samples. Herniarin was also found to be decreased by the immediate action of radiation on the extract, while prolonged storage had no further effect in irradiated samples and no effect whatsoever on herniarin in unirradiated ones.

5. CONCLUSIONS

Dry chamomile flowers withstand irradiation up to 10 kGy without detectable changes of the composition of ethereal oil or hydrophilic components.

To achieve commercial sterility of commercial concentrated extracts doses higher than 10 kGy may be necessary. Some of the essential lipophilic and hydrophilic constituents may be partially degraded by higher doses of radiation acting immediately or inducing slow post-irradiation decay. Radiation decontamination of extracts is not only possible, it is more practical than irradiation of bulky volumes of dry plants, and offers a better protection of the final product.
ACKNOWLEDGEMENT

The authors are indebted to Mrs. M. Rajković for technical assistance.

REFERENCES

TECHNOLOGICAL AND IRRADIATION CONDITIONS FOR RADAPPERTIZATION OF CHICKEN PRODUCTS USED IN THE UNITED STATES ARMY RALTECH TOXICOLOGY STUDY

E. WIERBICKI
United States Department of Agriculture,
Agricultural Research Service,
Eastern Regional Research Center,
Philadelphia, Pennsylvania,
United States of America

Abstract

TECHNOLOGICAL AND IRRADIATION CONDITIONS FOR RADAPPERTIZATION OF CHICKEN PRODUCTS USED IN THE UNITED STATES ARMY RALTECH TOXICOLOGY STUDY.

The paper describes the processing and irradiation conditions for the preparation of approximately 140,000 kg of meat for a multigeneration animal study of the wholesomeness of ionizing radiation sterilized chicken meat. This study was initiated by the US Army in 1976 at Raltech Scientific Services, Inc. in St. Louis, Missouri, United States of America. Four meat diets were prepared for the study as follows: (a) Frozen control chicken: Boneless, enzyme-inactivated (heated to an internal temperature of 73–80°C) chicken was canned and frozen. (b) Thermally processed chicken: Boneless, enzyme-inactivated chicken was canned and thermally treated to commercial sterility (F₀ = 6). (c) Cobalt-60 irradiated chicken: Boneless, enzyme-inactivated, canned in vacuo chicken was sterilized by gamma irradiation from cobalt-60 (45 to 68 kGy at —25 ± 15°C) and stored without refrigeration. (d) Electron-irradiated chicken: Boneless, enzyme-inactivated chicken was vacuum packed in flexible pouches and sterilized by 10 MeV electron irradiation (45 to 68 kGy at —25 ± 15°C) and stored without refrigeration. Representative samples of the irradiated and control chicken meat were analysed for their chemical and organoleptic qualities during a 2-year period, and for 7 years for lipid oxidation changes. Shelf stability was demonstrated by no increase in non-protein nitrogen and pH during storage. Irradiated samples had lower peroxide values and thiobarbituric acid reactive oxidation products than non-irradiated samples. The free fatty acid contents of the chicken fat of the thermal control and of the irradiated samples were directly related to the length of storage. The four chicken products received acceptable ratings for colour, odour, flavour, texture, and overall acceptance by trained panels over a 2-year period.

1. INTRODUCTION

During the period of June 1, 1976 through June 30, 1983 a large comprehensive toxicological study of chicken meat sterilized by ionizing radiation was conducted by the Raltech Scientific
Services\(^1\) (Raltech), a division of the Ralston Purina Company, St. Louis, MO. The Raltech study was sponsored and monitored by the U.S. Army under a research contract until September 30, 1980, then completed under the monitoring and supervision of the U.S. Department of Agriculture (USDA).

Twenty separate studies were involved in the evaluation of the nutritional and toxicological properties of irradiation sterilized chicken meat and these studies required production of over 140,000 kg of precooked chicken meat. The product preparation and irradiation processing followed the official protocol prepared by the U.S. Army Medical R&D Command [1]. The protocol was reviewed and efforts coordinated with the FDA, USDA, and the National Academy of Sciences, Committee on Food Irradiation [2]. The study final reports are available from the National Technical Information Service [3].

This paper summarizes the key technological and irradiation processing parameters, including shelf-stability and chemical and sensory properties, of the four chicken meat groups used in the Raltech toxicological studies. A detailed description of the product technology, industrial processing, irradiation by \(^{60}\)Co gamma rays and electrons, and post irradiation evaluations was described in a technical report by Wierbicki [4].

2. PRODUCT PROCESSING

2.1. Total quantity

Table I lists the quantity of the chicken meat of the four groups produced by Oscar Mayer & Co. in Madison, WI during 1976 through 1978. The total quantity of 135,405 kg of the enzyme-inactivated chicken meat (called "wholesomeness chicken meat") of the four groups (FC, TP, GAM, and ELE) represents about 96% of the total production; four percent of the meat was used as the samples retained by the U.S. Army Natick Research and Development Center (NLABS), rejected after post-irradiation inspection, and during packaging operation.

2.2. Processing

Fresh chicken broilers or friers, 3 to 3.5 lb carcass weight, were obtained, packed on ice, one day after slaughter, from USDA inspected poultry plants. Over 230,000 chilled, eviscerated broilers and friers were needed to produce the total quantity of the chicken meat shown in Table I.

\(^1\)Reference to brand name or firm name does not constitute endorsement by the U.S. Department of Agriculture over others of a similar nature not mentioned.
TABLE I. PRODUCTION OF THE "WHOLESONEMESS CHICKEN MEAT" AT OSCAR MAYER AND COMPANY, INC.

<table>
<thead>
<tr>
<th>Contract no. NLABS</th>
<th>Production no.</th>
<th>Production dates</th>
<th>Raw Meat kg</th>
<th>Enzyme-inactivated, kg:</th>
</tr>
</thead>
<tbody>
<tr>
<td>DAAG17-76-C-0042</td>
<td>1</td>
<td>April-May 76</td>
<td>57.2</td>
<td>FC: 6 435, TP: 5 677, GAM: 5 749, ELE: 6 052</td>
</tr>
<tr>
<td>DAAG60-77-C-0024</td>
<td>2</td>
<td>Feb.-Apr. 77</td>
<td>57.2</td>
<td>FC: 10 459, TP: 9 652, GAM: 10 196, ELE: 9 778</td>
</tr>
<tr>
<td>DAAG60-78-C-0023</td>
<td>3</td>
<td>Feb.-Apr. 78</td>
<td>57.2</td>
<td>FC: 9 925, TP: 10 425, GAM: 9 581, ELE: 9 448</td>
</tr>
<tr>
<td>Modification</td>
<td>3A</td>
<td>April-May 78</td>
<td>57.2</td>
<td>FC: 12 755, TP: 6 535, GAM: 6 320, ELE: 6 320</td>
</tr>
<tr>
<td>TOTAL, kg</td>
<td></td>
<td></td>
<td>228.8</td>
<td>TOTAL, enzyme inactivated meat: 135,405 kg</td>
</tr>
</tbody>
</table>

1 Codes used by Raltech for the experimental diets containing 35% of the meat in the total diet and are defined as follows:

FC: Frozen Control Chicken, Boneless, enzyme-inactivated (heated to an internal temperature of 73-80°C) chicken was canned and frozen.

TP: Thermally Processed Chicken, Boneless, enzyme-inactivated chicken was canned and thermally treated to commercial sterility (F₀ = 6).

GAM: Cobalt-60 Irradiated Chicken, Boneless enzyme-inactivated, canned in vacuo chicken was sterilized by gamma irradiation from Cobalt-60 (45 to 68 kGy at -25° ± 15°C) and stored without refrigeration.

ELE: Electron-Irradiated Chicken, Boneless, enzyme-inactivated chicken was vacuum packed in flexible pouches and sterilized by 10 Mev electron irradiation (45 kGy to 68 kGy at -25° ± 15°C) and stored without refrigeration.

The broiler carcasses were hand deboned into lean meat and skin with subcutaneous fat and were hung on a moving conveyor. Mechanically deboned meat from the residual carcasses was not used in the formulation of the meat product for this study. Table II gives the proximate composition of the lean meat and the chicken skin. The lean meat represented about 82% and the skin 18% of the deboned raw material.

Thus, the meat formula for the processed chicken meat consisted of 18% skin and 82% lean meat. For each 100 kg chicken meat and skin mixture were added 0.75 kg salt (sodium chloride) and 0.30 kg sodium tripolyphosphate (TPP) to reduce the loss of
TABLE II. PROXIMATE COMPOSITION OF RAW CHICKEN MEAT AND SKIN

<table>
<thead>
<tr>
<th>Component</th>
<th>No. samples</th>
<th>H&lt;sub&gt;2&lt;/sub&gt;O</th>
<th>Protein</th>
<th>Fat</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lean Meat</td>
<td>30</td>
<td>72.78 ± 1.68</td>
<td>20.12 ± 2.52</td>
<td>7.07 ± 2.52</td>
</tr>
<tr>
<td>Skin</td>
<td>20</td>
<td>49.59 ± 4.76</td>
<td>9.29 ± 1.80</td>
<td>40.47 ± 6.54</td>
</tr>
</tbody>
</table>

natural juices during enzyme-inactivation [5]. Also, 3 kg of crushed ice or cold water was added to each 100 kg meat formula to facilitate dissolution and distribution of the additives within the product. The added water was removed by evaporation during the enzyme inactivation process.

The meat, skin, and additives, mixed under vacuum, in 1 600 lb batches, were tightly stuffed into cellulose casings, laid horizontally on wire screened trucks and then enzyme inactivated by heat and steam in the smokehouse chambers, without smoking. One smokehouse (cookhouse) load was about 6 000 lb of the product. Drip loss was prevented by starting the chamber temperature at 46-52°C which assured the formation of a protective protein skin on the surface of the chicken rolls. Only moisture was lost during the process. At a final chamber temperature of 90°C the internal temperature of the chicken rolls was between 73 and 80°C and the yield was 87% of the total meat formula. Fig. 1 presents typical time and temperature parameters used for the enzyme inactivation process under industrial conditions. The chicken meat for the packaging in flexible pouches (ELE) was formed prior to the enzyme-inactivation processing by stuffing it into casings placed into stainless wire cages of 9.0 X 12.5 X 91.5 cm in size. A total of 61 cookhouse loads were processed with the yield of the enzyme-inactivated product to the raw product of 86.7 ± 0.7% [4].

2.3. Packaging

The FC, GAM, and TP products were packed in metal cans, No. 404 X 309, 10.8 cm in diameter and 9.0 cm in height. The cans were made from 80 to 90 basic weight, No. 25 tinplate, coated overall inside with an epoxy-phenolic enamel with aluminum pigment in accordance with Federal Specification PPP-C-29E, Canned Subsistence Items, Packaging and Packing [4]. The lids contained the can sealing compound designated as a blend of cured and uncured butyl rubber. Reliability of the commercially available tinplate containers were determined for the packaging of irradiation processed foods and described elsewhere [6, 7]. The cans were filled with 595 ± 7 g enzyme-inactivated product and sealed under highest attainable vacuum before collapse of the cans, which was -635 to -686 mm Hg. The cans were filled to about 84% of the can inside volume, thus allowing accommodation of hydrogen gas produced
in the can by irradiation as a result of radiolysis of water in the food and the food components [8, 9, 10].

After can closure, 24 cans (14.3 kg) of the FC product were packed in fiberboard shipping cases, arranged in a pattern of 4 cans in length, 3 cans in width, and 2 cans in depth with fiberboard separators between the individual cans. The packed shipping cases with the cans of the chicken meat were then stored in -23 to -40°C freezers until shipment in the frozen state to Raltech, where they were maintained in the frozen state until use as frozen control chicken meat in the toxicological studies.

For the TP chicken meat group, the product after the can closing was heat sterilized in commercial autoclaves at 115.6°C to the sterility level of $F_0 = 6$, by certified retort operators [4, 11]. Thermal sterilization of the TP chicken meat in this study was less severe than usually carried out by industry who operate their autoclaves at 121°C. The use of the retort temperature of 115.6°C [11] resulted in the end product which still could be sliced for sensory evaluation; retorting at 121°C resulted in a considerable loss in texture of the product [4]. Representative samples of the retorted product were subjected to incubation tests as required by the USDA inspection for the canned meats. The finished product was packed in shipping cases and shipped, nonrefrigerated, directly from the processing plant in Madison, WI, to Raltech, where it was stored, nonrefrigerated, until use.

The GAM chicken meat, after canning, packing, and freezing, was shipped frozen to Natick, MA where it was frozen stored before irradiation using $^{60}$Co gamma facility of the U.S. Army Natick R&D Center.

The ELE chicken meat was packed in flexible packaging. The enzyme-inactivated, chilled, rectangular chicken blocks were cut into 1-in (26 mm) thick slices and vacuum packed in preformed
flexible packaging. The flexible packages were 165 mm X 208 mm in size, fabricated with 0.025 mm polyiminocaproyl (Nylon 6) as the outside layer, 0.0090 mm aluminum foil as the middle layer, and 0.051 mm polyethylene terephthalate-medium density polyethylene as the food contacting layer [4]. The reliability of this flexible packaging for irradiation sterilization of prepackaged foods, using either 60Co gamma rays or electrons was demonstrated in previous experiments [12]. Medium density polyethylene, used as the food contactant in this flexible packaging does not produce extractives as the result of irradiation, over the levels designated by FDA, when in contact with nonirradiated foods [13, 14].

Single 1-in thick ELE chicken meat slices, in average 241 g product per slice, were packed into the flexible prefabricated pouches and sealed under maximum attainable vacuum of 28.5 to 29 in (-724 to -737 mm Hg). The evacuation time was preset so as to result in not more than 4 ml headspace gas in any pouch after sealing, as indicated by the method of Shappee and Werkowski [15]. The vacuum sealing of the filled pouches was accomplished at the rate of 32 pouches per min using the Swissvac, Model CVEP 100 vacuum sealing machine [4]. After vacuum packaging and sealing, the sealed pouches that passed visual inspection were held in a -2.2 to 5°C cooler overnight prior to assembly in the irradiation boxes. After being retained in the cooler overnight, each pouch was inspected for maintenance of the vacuum and tight adherence of the pouch to meat slice. The pouches that were observed with leaks in the seals or pinholes in the body of the pouch lost vacuum during this period in the cooler. The samples showing "poor vacuum" were rejected and the pouches opened, the meat repacked and resealed, and the inspection cycle repeated. Twelve filled and vacuum sealed pouches (four pouches in length, three pouches in width, and one pouch in depth) were placed into one "irradiation box" of proper dimensions [4]. Five irradiation boxes containing meat were than packed in a shipping box, the box sealed and placed into a -23 to -40°C freezer until shipment, in the frozen state, to the NLABS for electron irradiation.

In comparison with the GAM chicken meat that were vacuum packed in metal cans, the ELE chicken meat was exposed to much less residual air in the package. This was brought about as a result of the latter being sealed under higher vacuum and being kept overnight at a refrigerated temperature before freezing, thus allowing aerobic bacteria in the ELE packaged meat to consume the residual oxygen in the headspace and the air trapped by the meat.

Processing and packaging of the chicken meat in this study was carried out under continuous USDA inspection. At the time of packaging the enzyme inactivated chicken meat never exceeded the temperature of 10°C [4].
3. IRRADIATION PROCESS

3.1. The sterilizing dose used

At the time of the irradiation of the chicken product from the first procurement, May-June 1976, the 12-D irradiation sterilizing dose for chicken was still not determined. However, based on the data available for other foods the 12-D dose was estimated to be not higher than 45 kGy. Therefore, this sterilizing dose was selected as the minimum dose for processing the chicken product for this study. A 50% dose spread was added to provide a reasonable economical dose range for irradiation sterilization that might be carried out under industrial conditions. Consequently, the dose range selected for irradiation was 45 kGy minimum to 68 kGy maximum. The Microbiology Group at the U.S. Army Natick R&D Center was requested, at the same time, to determine by an inoculated pack study with Clostridium botulinum spores, the 12-D dose for this chicken product. This was accomplished, and the irradiation sterilizing dose (under the 12-D concept) for the chicken product used in this study was determined to be 42.7 kGy at the product temperature during irradiation of -30°C ± 10°C [16]. An area of concern in irradiation sterilization processing of foods is that viruses are more radiation resistant than the most-resistant bacterial spores (e.g., C. botulinum types A and B) [17]. For example, some members of the Moraxella-Acinetobacter group of bacteria are also more radiation resistant than C. botulinum spores [18]. These bacteria and viruses are, however, far more sensitive to heat [17, 19] and were inactivated during the heat inactivation of enzymes (Fig. 1).

3.2. 60Co irradiation of GAM chicken meat

The GAM chicken meat, packed in cans, was tempered in a liquid N2 cooler (-40°C ± 5°C) and irradiated, in the frozen state, at the U.S. Army Natick 60Co Irradiation Facility which had 2.5 million curies source strength in 1976. The facility has been described by McDonald [20]. Irradiation was performed in batches of eight cases per run, with each case containing 24 cans, or a total of 114.4 kg product per run. The case carrier was mapped for the dose distribution within the batch to ensure the minimum and maximum absorbed dose spread required. For compliance the cases of the product located in the minimum dose position in the carrier were monitored during irradiation. The carrier containing 8 cases of the product was equipped with liquid N2 line to control temperature in the carrier between -45°C and -30°C during irradiation as described by McDonald [20]. Table III gives a summary of 60Co irradiation of the GAM product. As the data indicate, the minimum dose received in the "minimum dose" location in the carrier was 46 kGy. The maximum dose was 68 kGy and the average dose 56 kGy. The ferrous-cupric sulfate chemical dosimeter was used to measure the dose absorbed as described by Jarrett and Halliday [21].
Table III. Summary of $^{60}$Co Irradiation of GAM Chicken Meat

<table>
<thead>
<tr>
<th>Prod. no.</th>
<th>Date</th>
<th>Dose rate Gy/min</th>
<th>Transient dose Gy</th>
<th>Run time min.</th>
<th>kGy $^1$ Received</th>
<th>Run no.</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>May-June 1976</td>
<td>$6.70 \times 10^2$</td>
<td>$1.95 \times 10^2$</td>
<td>68.37</td>
<td>46.0</td>
<td>1 - 52</td>
</tr>
<tr>
<td>2</td>
<td>Apr.-May 1977</td>
<td>$5.94 \times 10^2$</td>
<td>$1.70 \times 10^2$</td>
<td>77.15</td>
<td>46.0</td>
<td>53 - 142</td>
</tr>
<tr>
<td>3</td>
<td>March 1978</td>
<td>$5.26 \times 10^2$</td>
<td>$1.50 \times 10^2$</td>
<td>87.17</td>
<td>46.0</td>
<td>143 - 182</td>
</tr>
<tr>
<td>3A</td>
<td>Apr.-May 1978</td>
<td>$5.21 \times 10^2$</td>
<td>$1.48 \times 10^2$</td>
<td>88.01</td>
<td>46.0</td>
<td>183 - 283</td>
</tr>
</tbody>
</table>

$^1$ Dose received in the "minimum dose location" in the carrier.

Each run (batch) consisted of 8 cases of the product being irradiated, 14.3 kg product per case.

3.3. Electron irradiation of ELE chicken meat

Electron irradiation of ELE chicken meat has been performed using U.S. Army NLABS 10 MeV Electron Accelerator (LINAC), as described by Rees and Caspersen [22]. ELE chicken meat, packed in fiberboard shipping cases was stored in a liquid N$_2$ storage box (-45°C ± 5°C) before irradiation. Each shipping box contained five "irradiation boxes", each containing 12 packaged 1-in slices of ELE chicken meat, with an average of 241 g product per package. Two sequentially numbered "irradiation boxes" were placed into one polystyrene foam box (to keep the samples frozen during irradiation) for electron irradiation processing, representing one irradiation run (total 5.784 kg product per run). Details on the irradiation processing were described in Wierbicki's technical report [4]. In order to obtain the dose spread from 45 to 68 kGy the machine had to be set for the average dose of 59 kGy, 3 kGy higher than the average dose used for $^{60}$Co irradiation of GAM chicken meat. The chemical ferrous-cupric sulfate dosimeter was attached outside of the polystyrene foam boxes to cross-check the accuracy of the dosimetry [21]. For each irradiation run the energy of the electron beam used was automatically measured and recorded. The electron beam energy, as taken from the irradiation records [4], was 9.7 to 10.0 MeV. A total of 5 462 runs of electron irradiation of ELE chicken meat was performed, comprising 136 472 pouches of the packed product for a total net weight of 32 957 kg [4].

3.4. Product temperature control during irradiation

In the course of $^{60}$Co irradiation of 31 846 kg (Table I) GAM chicken meat, 54 cans were equipped with the thermocouples and the temperature of the product before and after irradiation was recorded. The product temperature before irradiation was
-39.5° ± 3.3°C and after irradiation -15.3° ± 3.2°C. This represented a temperature rise of 4.3°C for each 10 kGy absorbed gamma ray energy. During electron irradiation, 641 samples were checked for the product temperature, which was -40° ± 2.9°C before irradiation and -9.9° ± 1.8°C after irradiation. This represented a temperature rise of 5.1°C for each 10 kGy of electron energy absorbed [4].

For the electron irradiation, the temperature rise was about 0.8°C greater than for 60Co irradiation since no cooling could be provided during electron irradiation. For the best quality radappertized product, the product temperature after irradiation should be -20°C or lower [23]. This was not achieved during irradiation of these chicken products and was a deliberate decision made to obtain radappertized products under less than "ideal" conditions for toxicological studies.

3.5. Post-irradiation inspection

After irradiation, the GAM and ELE groups of the irradiated chicken product were moved to a noncontrolled area for defrosting at room temperature (21 to 25°C), for inspection of each can (GAM) and each pouch (ELE) for the absence of induced radioactivity [24], for packaging integrity, vacuum of the cans (undestructive), and marking of the samples (production no., samples no., dose, run no., and date of irradiation). Samples showing any sign of damage, or missing markings, particularly the qualitative "go-no-go" dosimeter (red after irradiation), were removed and destroyed. The inspected samples were repacked, palleted and shipped without refrigeration to Raltech for nonrefrigerated storage until the toxicological studies were performed.

4. PRODUCT EVALUATION

4.1. Radiolysis products

Radiolysis products in the four groups of the enzyme-inactivated chicken products used in the Raltech toxicological studies (FC, TP, GAM, and ELE), along with the frozen samples of raw chicken meat, have been reported separately in a comprehensive technical report by Merritt [25]. The radiolysis products were determined on duplicate samples for each chicken meat group initially and after storage for 12, 24, and 36 months. The raw chicken meat and the frozen control enzyme-inactivated chicken meat (FC group) were stored in -29°C freezers. The irradiation sterilized chicken meat (GAM and ELE) and the thermally sterilized chicken meat samples (TP) were stored in a 21°C room. The same storage temperatures were used for the FC, GAM, ELE, and TP chicken samples for the chemical and sensory quality evaluations at the NLABS. The subject report by Merritt [25] also contains radiolysis product information on radappertized beef, pork, ham, and bacon with
TABLE IV. CHEMICAL COMPOSITION OF ENZYME-INACTIVATED CHICKEN MEAT

<table>
<thead>
<tr>
<th>Composition</th>
<th>No. samples</th>
<th>FC</th>
<th>TP</th>
<th>GAM</th>
<th>ELE</th>
</tr>
</thead>
<tbody>
<tr>
<td>H₂O (%)</td>
<td>12</td>
<td>65.4 ± 0.7</td>
<td>65.3 ± 1.0</td>
<td>65.1 ± 0.8</td>
<td>65.3 ± 0.3</td>
</tr>
<tr>
<td>Protein (%)</td>
<td>12</td>
<td>20.2 ± 0.6</td>
<td>19.9 ± 0.7</td>
<td>20.0 ± 0.4</td>
<td>20.4 ± 0.4</td>
</tr>
<tr>
<td>Fat (%)</td>
<td>12</td>
<td>12.4 ± 1.1</td>
<td>12.7 ± 1.2</td>
<td>13.0 ± 0.9</td>
<td>12.6 ± 0.3</td>
</tr>
<tr>
<td>Ash (%)</td>
<td>12</td>
<td>1.9 ± 0.1</td>
<td>1.9 ± 0.1</td>
<td>1.9 ± 0.1</td>
<td>1.9 ± 0.0</td>
</tr>
<tr>
<td>NaCl (%)</td>
<td>12</td>
<td>0.85 ± 0.05</td>
<td>0.87 ± 0.05</td>
<td>0.85 ± 0.08</td>
<td>0.87 ± 0.05</td>
</tr>
<tr>
<td>P (mg/100g)</td>
<td>12</td>
<td>265 ± 9</td>
<td>263 ± 9</td>
<td>260 ± 10</td>
<td>266 ± 12</td>
</tr>
<tr>
<td>NPN¹</td>
<td>8</td>
<td>0.36 ± 0.02</td>
<td>0.35 ± 0.03</td>
<td>0.38 ± 0.02</td>
<td>0.38 ± 0.02</td>
</tr>
<tr>
<td>pH</td>
<td>8</td>
<td>6.39 ± 0.10</td>
<td>6.33 ± 0.08</td>
<td>6.40 ± 0.08</td>
<td>6.39 ± 0.08</td>
</tr>
</tbody>
</table>

¹ NPN = Nonprotein nitrogen as % total N.

computer analysis of the commonality of the radiolysis products in the five different meats.

4.2. Chemical composition

Table IV presents the chemical composition of the four groups of the enzyme-inactivated chicken meat (FC, TP, GAM, and ELE) as determined using the AOAC standard methods for food analyses [26]. The samples analyzed were withdrawn from all three production lots of the product and subjected to the analyses initially and after 6 and 12 months of storage; detailed tabulations of the results are available [4]. The data, as summarized in Table IV, indicate a very homogeneous product from group to group submitted to Raltech for toxicological studies. There were no changes of these chemical quality indexes during the storage of the items for 2 years [4]. The nonprotein nitrogen (NPN) is an index of proteolytic enzyme activities in protein foods. The NPN content was the same in the samples stored for 2 years (0.34 ± 0.02%) [4] as before storage (Table IV). The fact that there were no changes in the NPN content with the storage time without refrigeration in the irradiated products (GAM and ELE) indicate that the preirradiation enzyme-inactivation treatment as shown in Fig. 1 was effective for the purpose.

4.3. Headspace gas composition

Irradiation produces gases in packaged irradiation sterilized foods in the headspace of the cans. The gases produced may result in bulged or swelled cans. Therefore, since users of canned food will normally interpret a swelled can as a sign of
bacterial spoilage, the cans filled with food for irradiation should not be filled to more than 84% of the can volume. Hydrogen gas is the dominant gas produced by the radiation process [8, 9] as a result of radiolysis of water and the food components [10,27].

The headspace gases were analyzed for hydrogen (H₂), nitrogen (N₂), oxygen (O₂), carbon dioxide (CO₂), methane (CH₄), and carbon monoxide (CO) in the headspace gas removed from the packages by water displacement by the method of Pratt et al. [8, 9]. The headspace gas composition for the GAM, FC, and TP products packed in metal cans is given in Table V. As the data indicate, the frozen control (FC) and thermally processed chicken meat (TP) contain no hydrogen in the headspace. To the contrary ²⁰Co irradiated product (GAM) contained about 25% hydrogen. After 12 months storage traces of methane and carbon monoxide were also detected in the headspace gas of the GAM product. Similar headspace compositions were found for electron irradiated samples [4]. However, very little (<1-mL) headspace gas could be collected from the ELE chicken samples to allow accurate quantitative determinations. Determination of hydrogen in the headspace gas of irradiated foods packed in metal cans, may have the potential to be used to identify whether a product was irradiated or not.

### Table V. Headspace Gas Composition in Cans of ⁶⁰Co-Irradiated, NonIrradiated and Thermally Processed Products

<table>
<thead>
<tr>
<th>GAS</th>
<th>GAM³</th>
<th>FC⁴</th>
<th>TP³</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Initial²</td>
<td>12 Months</td>
<td>Initial²</td>
</tr>
<tr>
<td>H₂</td>
<td>24.5</td>
<td>25.3</td>
<td>0</td>
</tr>
<tr>
<td>N₂</td>
<td>62.8</td>
<td>60.6</td>
<td>88.7</td>
</tr>
<tr>
<td>O₂</td>
<td>1.1</td>
<td>0.9</td>
<td>1.5</td>
</tr>
<tr>
<td>CO₂</td>
<td>11.6</td>
<td>12.9</td>
<td>10.0</td>
</tr>
<tr>
<td>CH₄</td>
<td>0</td>
<td>0.4</td>
<td>0</td>
</tr>
<tr>
<td>CO</td>
<td>0</td>
<td>0.1</td>
<td>0</td>
</tr>
</tbody>
</table>

1 As percent of total headspace gas.
2 Samples frozen stored for 2 months before analysis.
3 Stored at 21°C.
4 Frozen stored at -29°C.
TABLE VI. EFFECT OF PROCESSING AND STORAGE ON FAT OXIDATION

<table>
<thead>
<tr>
<th>Fat oxidation index</th>
<th>FC(^1)</th>
<th>GAM(^2)</th>
<th>ELE(^2)</th>
<th>TP(^2)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Initial(^3) 81 Mon.</td>
<td>Initial(^3) 81 Mon.</td>
<td>Initial(^3) 81 Mon.</td>
<td>Initial(^3) 81 Mon.</td>
</tr>
<tr>
<td>PV(^4)</td>
<td>38.1 1.6</td>
<td>11.3 0.6</td>
<td>14.1 0.9</td>
<td>0 1.1</td>
</tr>
<tr>
<td>TBA(^5)</td>
<td>4.4 1.6</td>
<td>0.2 0.2</td>
<td>2.0 0.3</td>
<td>0.2 0.2</td>
</tr>
<tr>
<td>FFA(^6)</td>
<td>0.7 0.9</td>
<td>0.9 4.6</td>
<td>0.9 5.0</td>
<td>1.1 3.4</td>
</tr>
</tbody>
</table>

1 Stored frozen at -29°C.
2 Stored at 21°C.
3 3 month old samples (first evaluation).
4 PV = peroxide value as milliequivalent 0\(_2^\)/1000 g fat.
5 TBA = Thiobarbituric acid value in mg malonaldehyde/1000 g meat.
6 FFA = Free fatty acid as % oleic acid in the extracted fat.

4.4. Lipid oxidation indexes

Three fat oxidation indexes were determined to study the changes in lipid oxidation in the four groups of the product (FC, GAM, ELE, and TP), initially and after 6, 12, 24, 53, and 81 months of storage: (a) peroxide value (PV), which is an index for the primary lipid oxidation products, using iodometric techniques (where the PV is reported in milliequivalents of oxygen per 1 kg extracted fat) [26]; thiobarbituric acid value (TBA) which is the index of secondary oxidation products of polyunsaturated fatty acids containing two or more double bonds [28] (expressed in mg of malonaldehyde per kg sample) [29]; and free fatty acids (FFA) (expressed as percent of oleic acid in extracted fat from the food sample), using standard AOAC method [26].

Table VI summarizes the data for the PV, TBA, and FFA in the four groups of the chicken products, initially, and after 81 months of storage. This data best illustrates the effect of the further processing (\(^60\)Co and electron irradiation and thermal retorting) of the enzyme-inactivated chicken meat, when comparisons are made with the frozen control (FC). The data also shows the effect of long-term nonrefrigerated storage of the irradiated (GAM and ELE) and thermally sterilized (TP) chicken meat. In raw chicken meat before enzyme inactivation, the PV and TBA were below the 2.0 units [4]. Enzyme inactivation increased the PV and TBA, in the product as shown by the high initial data for the frozen control (FC) samples; prolonged frozen storage significantly reduced these fat oxidation indexes. Irradiation of the enzyme-inactivated chicken meat, packed in vacuo, greatly reduced, both PV and TBA values; storage for 81 months decreased these fat...
oxidation indexes to about a zero level. Thermal retorting destroyed both the PV and TBA fat oxidation indexes. This effect of the thermal processing of canned foods is well documented [30].

Irradiation and thermal retorting slightly increased the FFA and a further, significant increase took place during prolonged nonrefrigerated storage of these chicken products (Table VI). Since the enzyme-inactivation procedure (and in case of the TP chicken meat, the further thermal processing) destroyed (inactivated) the triglyceride hydrolyzing enzymes (lipases), the increase in the FFA in the GAM, ELE, and TP products represents an autooxidation of the lipids during storage at nonrefrigeration temperatures. In fact, the increase in the FFA in the fat of GAM, ELE, and TP chicken meat is directly related to the storage time, thus allowing approximate determination of the length of time the products were stored without refrigeration within 1 year accuracy. The increase in FFA for GAM and ELE chicken products was 0.524% and for the TP product 0.404% per year of nonrefrigerated storage [4].

4.5. Sensory quality

4.5.1. Expert panel evaluation

Ten permanent and four alternate members at the NLABS, were trained as "expert" evaluators for color, odor, flavor, and texture for the four groups of chicken meat used in this study [4]. The product, sliced into 1/4-in (6 mm) slices were served to the panelists, either cold or after reheating in a covered pan held over hot water (85 to 95°C). Scores were obtained by rating the four quality attributes using the following rating scale:

<table>
<thead>
<tr>
<th>Rating</th>
<th>Quality</th>
</tr>
</thead>
<tbody>
<tr>
<td>9</td>
<td>Excellent</td>
</tr>
<tr>
<td>8</td>
<td>Very Good</td>
</tr>
<tr>
<td>7</td>
<td>Good</td>
</tr>
<tr>
<td>6</td>
<td>Below Good - Above Fair</td>
</tr>
<tr>
<td>5</td>
<td>Fair</td>
</tr>
<tr>
<td>4</td>
<td>Below Fair - Above Poor</td>
</tr>
<tr>
<td>3</td>
<td>Poor</td>
</tr>
<tr>
<td>2</td>
<td>Very Poor</td>
</tr>
<tr>
<td>1</td>
<td>Extremely Poor</td>
</tr>
</tbody>
</table>
TABLE VII. EFFECT OF DIFFERENT PROCESSING AND STORAGE ON COLOR, ODOR, FLAVOR, AND TEXTURE OF ENZYME-INACTIVATED CHICKEN MEAT (Served Cold, Expert Panel, n = 10)

<table>
<thead>
<tr>
<th>Time of storage</th>
<th>Product group</th>
<th>Sensory Scores:</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Color</td>
</tr>
<tr>
<td>Initial</td>
<td>FC</td>
<td>6.4 ± 0.6</td>
</tr>
<tr>
<td></td>
<td>GAM</td>
<td>5.9 ± 0.9</td>
</tr>
<tr>
<td></td>
<td>ELE</td>
<td>5.9 ± 1.1</td>
</tr>
<tr>
<td></td>
<td>TP</td>
<td>5.7 ± 0.9</td>
</tr>
<tr>
<td>F:</td>
<td></td>
<td>0.67</td>
</tr>
<tr>
<td>LSD:</td>
<td></td>
<td>NSD</td>
</tr>
<tr>
<td>24 Months</td>
<td>FC</td>
<td>5.9 ± 1.9</td>
</tr>
<tr>
<td></td>
<td>GAM</td>
<td>5.6 ± 1.6</td>
</tr>
<tr>
<td></td>
<td>ELE</td>
<td>5.6 ± 0.8</td>
</tr>
<tr>
<td></td>
<td>TP</td>
<td>5.3 ± 1.1</td>
</tr>
<tr>
<td>F:</td>
<td></td>
<td>0.30</td>
</tr>
<tr>
<td>LSD:</td>
<td></td>
<td>NSD</td>
</tr>
</tbody>
</table>

¹ First evaluation after 3 months storage.

LSD = Least significant difference.

NSD = No significant difference.

ᵃᵇ = Means in the same column with different subscript letters are significantly different (P < 0.05).

Ratings of 5 and above indicated acceptable products. Ratings of 5 and 4 indicated the products were of marginal quality, whereas the rating of 3 (poor) and below indicated that the product might not be accepted by the consumers who are particularly demanding of this particular quality attribute. The four groups of the product (FC, GAM, ELE, and TP) were subjected to sensory evaluation for color, odor, flavor, and texture by the expert panels initially and after 6, 12, and 24 months of storage. The means (M) and standard deviations (SD) of the data obtained for each attribute, and for the least significant differences (LSD) between the means of the four groups of the product were evaluated using the statistical method of Duncan [31]. The results of the expert panel sensory taste testing of the four groups of chicken meat used in the Raltech toxicological studies were published in 13 tables in
TABLE VIII. EFFECT OF FURTHER PROCESSING ON COLOR, ODOR, FLAVOR AND TEXTURE OF ENZYME-INACTIVATED CHICKEN MEAT

<table>
<thead>
<tr>
<th>Product group</th>
<th>Overall sensory scores(^1):</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Color</td>
</tr>
<tr>
<td>FC(^2)</td>
<td>6.45(^b) ± 0.44</td>
</tr>
<tr>
<td>GAM(^3)</td>
<td>6.28(^b) ± 0.73</td>
</tr>
<tr>
<td>ELE(^3)</td>
<td>6.30(^b) ± 0.73</td>
</tr>
<tr>
<td>TP(^3)</td>
<td>5.35(^a) ± 0.89</td>
</tr>
<tr>
<td>M ± SD:</td>
<td>6.10 ± 0.72</td>
</tr>
<tr>
<td>LSD:</td>
<td>0.73</td>
</tr>
</tbody>
</table>

\(^1\) All data combined: 4 storage times X 2 preparations for serving (n = 80 for each product group).
\(^2\) Frozen stored at -29°C.
\(^3\) Stored without refrigeration at 21°C.

a, b, c = Means in the same column with different subscript letters are significantly different (P < 0.05).

Wierbicki's technical report [4]. Representative findings are summarized in Tables VII and VIII. In Table VII, ratings are given for the chicken meat served cold (held in a refrigerator for 3 days in unopened containers before serving), initially and after 24 month storage. Similar data were obtained on the samples served reheated and on other withdrawals (after 6 and 12 month storage) [4]. As the data indicate, during the initial evaluation there were no significant differences between the four groups for all four quality attributes. However, the frozen control samples (FC), which were not further processed after enzyme-inactivation (cooking), scored slightly higher than the chicken samples of the other three groups (GAM, ELE, and TP). After 24 months storage only the samples of thermally retorted meat (TP) received significantly lower scores for texture. In Table VIII the scores received in all tests at different times on the four groups of chicken meat were pooled together to more accurately determine the overall effect of further processing on the enzyme-inactivated chicken meat, by \(^{60}\)Co gamma irradiation (GAM), electron irradiation (ELE), or thermal retorting (TP), since only the processing affected the quality [4]. The data represent the pooled results of the total of 80 scores received by each product group for each attribute. The data indicate that FC samples received the highest ratings for all attributes.
Further processing, either by irradiation or thermal retorting decreased the quality ratings. However, the ratings for color for the irradiated samples were not significantly different from the nonirradiated frozen control and for flavor by electron irradiation of the meat. There were no significant differences in the ratings between 60Co and electron irradiated samples. The thermally retorted chicken meat (TP), scored significantly lower for color and texture than the irradiated and frozen control samples. However, all scores were high enough (over 5) to consider the products to be of acceptable quality.

4.5.2. Consumer panel evaluation

The "cold" and the "hot" chicken meat samples of the four groups of the product (FC, GAM, ELE, and TP) were evaluated for consumer acceptance using the 9-point hedonic scale of Peryam and Pilgrim [32]. The statistical treatment of the data used the randomized block method with 32 test subjects for means (M) and standard deviations (SD), least significant differences (LSD), and analysis of variance [31]. The test subjects were selected from a pool of about 800 volunteers who were employees at the NLABS. The subjects were not informed that two out of the four chicken samples served for each test were irradiation treated. Table IX gives the preference rating data for the four products when served cold to the panelist. Table X gives the ratings obtained when the chicken meat samples were reheated before serving.

---

**TABLE IX. PREFERENCE SCORES\(^1\) OF WHOLESOMENESS CHICKEN MEAT SERVED COLD TO A CONSUMER PANEL (\(a = 32\) Panelists)**

<table>
<thead>
<tr>
<th>Product group</th>
<th>Initial evaluation:</th>
<th>Production no. 2:</th>
<th>Production no. 3:</th>
<th>6 Months</th>
<th>12 Months</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Production no. 1</td>
<td>Production no. 2</td>
<td>Production no. 3</td>
<td>6 Months</td>
<td>12 Months</td>
</tr>
<tr>
<td></td>
<td></td>
<td>6.37(^b) ± 1.60</td>
<td>6.00(^b) ± 2.27</td>
<td>6.16(^c) ± 1.39</td>
<td>6.19(^b) ± 1.80</td>
</tr>
<tr>
<td>FC(^2)</td>
<td>5.00(^a) ± 1.64</td>
<td>4.28(^a) ± 1.63</td>
<td>5.28(^a) ± 1.97</td>
<td></td>
<td></td>
</tr>
<tr>
<td>GAM(^3)</td>
<td>4.62(^a) ± 1.77</td>
<td>4.06(^a) ± 1.34</td>
<td>5.06(^a) ± 1.97</td>
<td></td>
<td></td>
</tr>
<tr>
<td>ELE(^3)</td>
<td>5.03(^a) ± 1.80</td>
<td>5.03(^b) ± 1.71</td>
<td>5.23(^a) ± 1.95</td>
<td></td>
<td></td>
</tr>
<tr>
<td>LSD:(^4)</td>
<td>0.70</td>
<td>0.76</td>
<td>0.61</td>
<td>0.66</td>
<td></td>
</tr>
</tbody>
</table>

---

1 9-point hedonic scale: 9 = like extremely; 5 = neither like-nor dislike; 1 = dislike extremely.
2 Frozen stored at -29°C.
3 Stored without refrigeration at 21°C.
4 LSD = Least significant differences: means in the same column with different subscript letters are significantly different (\(P < 0.05\)).
### TABLE X. PREFERENCE SCORES\(^1\) OF WHOLESOMENESS CHICKEN MEAT SERVED REHEATED (HOT) TO A CONSUMER PANEL (n = 32 Panelists)

<table>
<thead>
<tr>
<th>Product group</th>
<th>Initial evaluation:</th>
<th>Production no. 2:</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Production no. 2</td>
<td>Production no. 3</td>
</tr>
<tr>
<td>FC(^2)</td>
<td>6.88(^b) ± 1.45</td>
<td>6.69 ± 1.69</td>
</tr>
<tr>
<td>GAM(^3)</td>
<td>5.78(^a) ± 1.64</td>
<td>6.09 ± 1.80</td>
</tr>
<tr>
<td>ELE(^3)</td>
<td>5.91(^a) ± 1.91</td>
<td>5.97 ± 2.01</td>
</tr>
<tr>
<td>TP(^3)</td>
<td>6.31(^a,b) ± 1.60</td>
<td>6.25 ± 2.03</td>
</tr>
<tr>
<td>LSD(^4):</td>
<td>0.58</td>
<td>NSD</td>
</tr>
</tbody>
</table>

\(^1\) 9-point hedonic scale: 9 = like extremely; 5 = neither like-nor dislike; 1 = dislike extremely.

\(^2\) Frozen stored at -29°C.

\(^3\) Stored without refrigeration at 21°C.

\(^4\) LSD = Least significant differences: means in the same column with different subscript letters are significantly different (P < 0.05).

The means of the ratings of the reheated samples from production lot 3 in the initial evaluation did not reveal significant differences between the groups (Table X). In all other tests the frozen control chicken meat (FC) received significantly higher scores. Reheating slightly increased the preference scores in all instances, indicating that consumers prefer the chicken meat served after reheating. Initial evaluations were performed on the products from production No. 2 and No. 3 to confirm that the quality of the products can be reproduced from one production lot to another. The 6 and 12 month storage studies used only the chicken meat from production 2. The consumer panel rated thermally processed (TP) chicken meat either equally high or slightly higher in preference to the irradiated samples (GAM, ELE), in spite of the fact that TP samples received the highest number of comments for "poor texture" [4].

The preference scores received by irradiated chicken meat in Tables IX and X are in the acceptable range, even though irradiation doses were relatively high, an ave. 56 kGy for 60Co and an ave. 59 kGy for electron irradiated samples. Improved preference scores were assigned by the same panel to a similar chicken product irradiated under better control of radiation dose (45 to 55 kGy) and temperature.
TABLE XI. PREFERENCE RATINGS OF IRRADIATED\(^1\)
CHICKEN BREAST MEAT ROLLS
(Consumer Panel, n = 32)

<table>
<thead>
<tr>
<th>Product preparation number</th>
<th>Additives, %:</th>
<th>Rating.(^2)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>NaCl TPP</td>
<td>Mean ± SD</td>
</tr>
<tr>
<td>1</td>
<td>0.0 0.0</td>
<td>5.1(^a) ± 2.1</td>
</tr>
<tr>
<td>2</td>
<td>0.75 0.5</td>
<td>6.7(^b) ± 1.4</td>
</tr>
<tr>
<td>3</td>
<td>0.75 0.0</td>
<td>6.3(^b) ± 2.0</td>
</tr>
<tr>
<td>4</td>
<td>0.75 0.3</td>
<td>6.2(^b) ± 1.9</td>
</tr>
<tr>
<td>4(^3)</td>
<td>0.75 0.3</td>
<td>6.5(^b) ± 1.8</td>
</tr>
</tbody>
</table>

Least significant difference (LSD, P < 0.05): 0.3

\(^1\) 45 to 55 kGy at -30°C ± 10°C.
\(^2\) 9-point hedonic scale: 9 = "like extremely," 5 = "neither-like-nor-dislike," 6 = "like slightly."
\(^3\) Nonirradiated sample from product preparation 4.

(-30° ± 10°C) (Table XI) [4]. The preference scores given in Table XI indicate also the importance of the additives, NaCl and TPP, to the quality of irradiated products.

5. CONCLUSIONS

(a) Production of over 140 000 kg of enzyme-inactivated chicken meat under industrial conditions for the Raltech toxicological studies showed that the industry is capable of processing and packaging large quantities of products for irradiation treatment.

(b) Irradiation processing by \(^{60}\)Co gamma rays and by 10 MeV electrons, of about 35 000 kg product by each of the irradiation source, showed that preservation of prepacked foods by sterilizing doses of ionizing energy is possible. However, packaging of the foods, under high vacuum with control of product temperature during irradiation are essential in obtaining products of acceptable quality.

(c) Enzyme-inactivated, vacuum packed chicken roll products preserved with sterilizing doses of \(^{60}\)Co gamma rays and 10 MeV
electrons within the dose range of 45 to 68 kGy ($D_{\text{max}}/D_{\text{min}} = 1.51$) were shelf-stable and were of acceptable quality. The quality and acceptability of the products might be upgraded by reducing the irradiation sterilizing dose to the range of 43 to 56 kGy ($D_{\text{max}}/D_{\text{min}} = 1.30$).

(d) The approval by the health authorities of the radap- pertization process is needed before its industrial application. The U.S. Army—USDA Raltech toxicology studies on chicken were conducted to provide information for this purpose.

ACKNOWLEDGMENT

The participation and assistance in execution of this project by the following scientists at the U.S. Army Natick R&D Center are gratefully acknowledged: Ari Brynjolfsson, Fred Heiligman, John J. Killoran, Gary W. Shults, John J. Howker, Joseph S. Cohen, Vera C. Mason, Irwin A. Taub, and Robert D. Jarret (presently with U.S. Department of Agriculture).

REFERENCES


PRESERVATION OF POTATOES BY IRRADIATION AND ECONOMIC CONSIDERATIONS

W. FISZER, J. ZABIELSKI, J. MRÓZ
Laboratory of Nuclear Methods in Agriculture,
University of Agriculture,
Poznań, Poland

Abstract

PRESERVATION OF POTATOES BY IRRADIATION AND ECONOMIC CONSIDERATIONS.

In Poland potatoes are a major food item for human consumption, fodder and industrial applications. Many experiments have been carried out in our laboratory during the past few years while studying the extension of the storage-life of irradiated potatoes. The paper describes the weight losses due to some biochemical changes, consumer acceptance and the economic evaluation of two varieties. The losses of irradiated potatoes were reduced by a factor of 2–2.5 in comparison with controls. Polyphenol oxidase activity and chlorogenic acid content, which are responsible for darkening of raw and boiled tubers, respectively, were of statistical significance; nevertheless, these changes seem to have no practical value. Irradiation of potatoes had a significant effect on the reducing sugars content, but no influence on quality for industrial applications. Consumers accepted those irradiated potatoes that had always received the higher scores. In view of the Polish climate, irradiation of potatoes is economically reasonable; however, the greatest advantage can be expected from a multipurpose irradiator.

1. INTRODUCTION

Poland is the second largest producer of potatoes in the world. Annual production amounts to 40–50 million tonnes. The cultivation area is about 2.5 million hectares and has remained stable at that level for many years because of the great importance and significance of potatoes in Polish agriculture, being 25% of the total mass crop production.

In Poland potatoes are mainly used for the following purposes:

- 12% for human consumption (160 kg per capita per year),
- 14% for reproduction,
- 60% for fodder,
- 14% for industrial applications and export.

The potato industry manufactures over 100 different products, of which starch and alcohol are the most important.
According to the vegetation period, properties and destination, the following groups of varieties may be selected: early, middle early, middle late, late and very late, for human consumption, fodder and/or industrial purposes. New material is developed along the following lines: eating quality, early maturation, starch and protein content, suitability for light soil and resistance to virus, phytophthora, common scab and storage diseases.

Owing to Polish climatic conditions potatoes are stored from the end of September till the beginning of July. The main part of the crop is stored in traditional clamps covered with a layer of straw and soil, resulting in high losses due to dehydration and respiration, sprouting and rotting. Only a small proportion is stored under controlled temperature and humidity conditions. The value of 1% of the potato storage losses in Poland is equal to 5−6 × 10⁹ zloty [1].

Radiation technology offers certain possibilities for reducing storage losses of potatoes as was confirmed by earlier laboratory experiments performed on several varieties.

The present study has been conducted under the IAEA Research Co-ordinated Programme. The aim was to gain experience in pre-commercial application of potato irradiation in Poland.

2. MATERIALS AND METHODS

Two thousand kilograms of two varieties, 'Ronda' and 'Mila', were used for the experiment performed from 1982 to 1984. Potatoes were harvested in September in the University Experimental Agricultural Station near the city of Poznań. The varieties are medium resistant to moulds and bacterial diseases.

After 2—3 weeks of storage and selection, the irradiation of potatoes was carried out in IFFIT Project’s gamma irradiator at the Dutch Pilot Plant for Food Irradiation in Wageningen with a dose of 75 Gy, which had been found earlier to be effective in inhibiting sprouting.

Both irradiated and control tubers were stored at ambient conditions for a period of 9 months in open plastic baskets in a dark basement equipped with mechanical ventilation only.

During storage the temperature and relative humidity varied from 7 to 17°C and 57 to 93%, respectively, depending on the weather conditions outside the building. The storage conditions were comparable with those in urban households in Poland.

The storage losses due to sprouting, dehydration and respiration were measured gravimetrically. The losses were calculated as a percentage of the initial weight of the portions used. Several batches of potatoes were taken to determine the weight of rotten tubers and the losses were calculated as a percentage of the initial weight of the batch.
Analyses of reducing sugars [2], polyphenol oxidase activity [3] and chlorogenic acid content [4] were carried out over the whole storage period at regular intervals.

The consumer acceptance of irradiated potatoes was determined in two separate experiments. The judges, members of the teaching staff of the Food Technology Faculty of the University of Agriculture, Poznań, and their families (the experiment was also conducted under domestic conditions), were invited to participate in the following tests: 9-point hedonic-scale description of the colour, flavour and texture of boiled potatoes and a food action rating scale for measuring food acceptance — FACT [5].

The economic calculations were performed on the basis of the savings resulting from the reduction in the loss of irradiated potatoes in the second part of the storage period.

3. RESULTS AND DISCUSSION

3.1. Storage losses

The relation between storage losses and time was calculated from the experimental data; the results are listed in Table I. These data indicate that the losses of both control and irradiated tubers increased linearly versus time, except those for rotting. The linear character of the relationship was statistically proved.

The intensity of the dehydration and respiration processes was significantly lowered in irradiated potatoes in comparison with the controls. For the 'Ronda' variety the dynamics of dehydration and respiration was +0.48% per week in irradiated tubers, as against +1.06% per week in controls. For the 'Mila' variety these values were +0.98 and +1.40%, respectively.

Because of the complete inhibition of sprouting at a dose of 75 Gy in both varieties, total losses were reduced by a factor of 2—2.5 in comparison with untreated potatoes.

The above results indicate also that the 'Ronda' variety was rather resistant to rotting. At the end of the experimental period (33 weeks) less than 2% rotten tubers were found, whereas in the 'Mila' variety rotten tubers appeared after the 9th, 22nd and 32nd week of storage. The susceptibility of tubers to rotting was slightly higher in irradiated material of both varieties. The preliminary phytoalexin determinations seem to confirm the higher intensity of rotting after irradiation. Phytophthora infestans predominates among the many microorganisms causing the rotting of tubers. Nevertheless, some data indicate that this microorganism is sensitive to radiation within the dose range for sprouting inhibition [6].
<table>
<thead>
<tr>
<th>Source of losses</th>
<th>Variety</th>
<th>Control</th>
<th>Irradiated</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dehydration and respiration</td>
<td>Ronda</td>
<td>$% = 1.06 \times t - 3.57$</td>
<td>$% = 0.48 \times t + 0.28$</td>
</tr>
<tr>
<td></td>
<td>Mila</td>
<td>$% = 1.40 \times t - 1.33$</td>
<td>$% = 0.98 \times t - 1.19$</td>
</tr>
<tr>
<td>Sprouting</td>
<td>Ronda</td>
<td>$% = 0.58 \times t - 3.96$</td>
<td>$% = 0.00$</td>
</tr>
<tr>
<td></td>
<td>Mila</td>
<td>$% = 0.62 \times t - 3.81$</td>
<td>$% = 0.00$</td>
</tr>
<tr>
<td>Rotting</td>
<td>Ronda</td>
<td>$% = 0.00$</td>
<td>$1.47 \pm 1.40 (t = 33)$</td>
</tr>
<tr>
<td></td>
<td>Mila</td>
<td>$1.84 \pm 1.71 (t = 9)$</td>
<td>$2.31 \pm 2.43 (t = 9)$</td>
</tr>
<tr>
<td></td>
<td></td>
<td>$3.32 \pm 2.19 (t = 22)$</td>
<td>$6.48 \pm 3.75 (t = 22)$</td>
</tr>
<tr>
<td></td>
<td></td>
<td>$0.54 \pm 0.53 (t = 32)$</td>
<td>$0.45 \pm 0.51 (t = 32)$</td>
</tr>
<tr>
<td>Total</td>
<td>Ronda</td>
<td>$% = 1.60 \times t - 6.57$</td>
<td>$% = 0.48 \times t + 0.28$</td>
</tr>
<tr>
<td></td>
<td>Mila</td>
<td>$% = 1.95 \times t - 3.52$</td>
<td>$% = 1.06 \times t - 0.86$</td>
</tr>
</tbody>
</table>

*Note:* The above relations were statistically significant at the level $> 95\%$.

*FIG.1.* Changes of the reducing sugars content during storage (mean of 2 varieties).
TABLE II. RELATIVE CHANGES OF POLYPHENOL OXIDASE ACTIVITY AND CHLOROGENIC ACID CONTENT DURING THE STORAGE PERIOD (IRRADIATED : CONTROL RATIO)

<table>
<thead>
<tr>
<th>Storage time (weeks)</th>
<th>Polyphenol oxidase activity</th>
<th>Chlorogenic acid content</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Ronda</td>
<td>Mila</td>
</tr>
<tr>
<td>5</td>
<td>1.09</td>
<td>1.26</td>
</tr>
<tr>
<td>10</td>
<td>0.86</td>
<td>1.06</td>
</tr>
<tr>
<td>15</td>
<td>0.40</td>
<td>0.97</td>
</tr>
<tr>
<td>19</td>
<td>0.94</td>
<td>0.89</td>
</tr>
<tr>
<td>23</td>
<td>0.89</td>
<td>0.76</td>
</tr>
<tr>
<td>29</td>
<td>1.07</td>
<td>1.06</td>
</tr>
<tr>
<td>34</td>
<td>1.17</td>
<td>0.35</td>
</tr>
</tbody>
</table>

3.2. Reducing sugars content

The results presented in Fig. 1 indicate that the irradiation of potatoes had a significant effect on the reducing sugars content at the beginning and end of the experimental period. The concentration of reducing sugars in potatoes determines the usefulness of the material for industrial and domestic purposes. It is known that below the level of 250 mg of reducing sugars per 100 g of potato tissue the raw material can be used for chip production [7]. A higher content of reducing sugars results in a brown discoloration.

Considering the reducing sugars content as an indicator of quality for industrial application, irradiation of 'Ronda' and 'Mila' varieties did not influence their usefulness.

3.3. Polyphenol oxidase activity

The polyphenol oxidase activity is responsible for enzymic darkening of wounded or peeled tubers. Since the enzymic activity might be related to the variety of potatoes as well as the conditions of cultivation, changes of this parameter are expressed in relative values, e.g. the ratio irradiated : control, and are listed in Table II.

Generally these results indicate that the changes in polyphenol oxidase activity were statistically significant; a slight increase was observed at the beginning of the storage period (var. 'Mila'). Nevertheless, these changes are of no practical value [7].
### TABLE III. SENSORY TESTS IN 9-POINT HEDONIC SCALE

<table>
<thead>
<tr>
<th></th>
<th>Ronda&lt;sup&gt;a&lt;/sup&gt;</th>
<th>Irradiated</th>
<th>Mila&lt;sup&gt;b&lt;/sup&gt;</th>
<th>Irradiated</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>A. Performed under domestic conditions</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>FACT</td>
<td>3.6</td>
<td>4.5</td>
<td>4.2</td>
<td>5.7</td>
</tr>
<tr>
<td>Colour of boiled tubers (hedonic)</td>
<td>4.4</td>
<td>5.8</td>
<td>4.7</td>
<td>6.3</td>
</tr>
<tr>
<td>Flavour (hedonic)</td>
<td>5.2</td>
<td>5.9</td>
<td>4.6</td>
<td>6.0</td>
</tr>
<tr>
<td>Texture (hedonic)</td>
<td>5.3</td>
<td>6.5</td>
<td>4.9</td>
<td>5.7</td>
</tr>
<tr>
<td><strong>B. Consumer acceptance</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>FACT</td>
<td>4.9</td>
<td>5.6</td>
<td>3.9</td>
<td>6.4</td>
</tr>
<tr>
<td>Colour of boiled tubers (hedonic)</td>
<td>5.9</td>
<td>6.8</td>
<td>6.3</td>
<td>7.4</td>
</tr>
<tr>
<td>Flavour (hedonic)</td>
<td>5.9</td>
<td>6.5</td>
<td>5.6</td>
<td>7.0</td>
</tr>
<tr>
<td>Texture (hedonic)</td>
<td>6.1</td>
<td>7.2</td>
<td>4.8</td>
<td>7.0</td>
</tr>
</tbody>
</table>

*Note:* The differences between irradiated and controls were statistically significant at the level $>95\%$.

<sup>a</sup> Tests performed in May after 7 months' storage.

<sup>b</sup> Tests performed in June after 8 months' storage.

### TABLE IV. COST-BENEFIT ESTIMATION DUE TO THE REDUCTION OF STORAGE LOSSES OF IRRADIATED POTATOES (Mean of 2 varieties)

<table>
<thead>
<tr>
<th>Probable storage time from 1 October to</th>
<th>26 March (25 weeks)</th>
<th>23 April (29 weeks)</th>
<th>28 May (34 weeks)</th>
<th>23 June (38 weeks)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control losses (%)</td>
<td>39.33</td>
<td>46.43</td>
<td>55.31</td>
<td>62.41</td>
</tr>
<tr>
<td>Irradiated losses (%)</td>
<td>18.96</td>
<td>22.04</td>
<td>25.89</td>
<td>28.83</td>
</tr>
<tr>
<td>Control losses (t)</td>
<td>4720</td>
<td>5572</td>
<td>6632</td>
<td>7489</td>
</tr>
<tr>
<td>Irradiated losses (t)</td>
<td>2275</td>
<td>2645</td>
<td>3107</td>
<td>3460</td>
</tr>
<tr>
<td>Savings (t)</td>
<td>2445</td>
<td>2927</td>
<td>3525</td>
<td>4029</td>
</tr>
<tr>
<td>Savings (zi)</td>
<td>36 675 500</td>
<td>43 905 000</td>
<td>52 875 000</td>
<td>60 043 500</td>
</tr>
</tbody>
</table>

*Note:* Material to be irradiated per season 12 000 t. Price of potatoes 15 000 zl/t.
3.4. Chlorogenic acid content

The chlorogenic acid content is responsible for the non-enzymic darkening of boiled tubers. No significant irradiation effect was observed in either variety at the beginning of the storage period. Between the 19th and the 23rd week of storage (March–April) a slight increase in chlorogenic acid content was found in irradiated tubers (Table II). This may be due to the significant temperature increase that occurs at the beginning of the spring season in Poland [8].

Considering this parameter as an indicator of discoloration of boiled tubers, the changes described were not confirmed by the sensory tests.

3.5. Sensory tests

Forty-three persons participated in the tests performed under domestic conditions for the ‘Ronda’ and 28 for the ‘Mila’ varieties. Consumer acceptance was determined by 45 and 51 participants in each test, respectively.

The results of these tests are presented in Table III. It is clear from these data that irradiation has a positive effect on the quality of potatoes stored up to 7–8 months. The irradiated material always received the higher scores and the differences were statistically significant (see Table IV).

It seems also important to emphasize that the consumers accepted the irradiated potatoes, as indicated by the results of the FACT test.

3.6. Economic evaluation

One factor severely limits the economic feasibility of potato irradiation in Poland and this is the operating time of the plant. Owing to the frosty temperatures that may occur in December or even earlier, the period for possible transport of the material to and from the plant is limited. As a result of this the effective operating time of a plant would not be longer than 900 hours per season. Taking these limitations into account, the economic feasibility of potato irradiation would be the following:

A. 1. Source $^{60}$Co: 100 kCi
   2. Materials to be irradiated per season: 12 000 t
   3. Operating time per season: 900 h.
   4. Throughput:13 t/h

B. Capital cost
   1. Cost of source
   2. Cost of conveyer system, safety and other electronics
   3. Transportation and source loading
   4. Building, storage, biological shielding and plant

<table>
<thead>
<tr>
<th>Description</th>
<th>Polish złt</th>
</tr>
</thead>
<tbody>
<tr>
<td>Source $^{60}$Co</td>
<td>23 100 000</td>
</tr>
<tr>
<td>Materials to be irradiated per season</td>
<td>25 000 000</td>
</tr>
<tr>
<td>Operating time per season</td>
<td>2 655 000</td>
</tr>
<tr>
<td>Throughput:13 t/h</td>
<td>40 000 000</td>
</tr>
<tr>
<td>Total</td>
<td>90 755 000</td>
</tr>
</tbody>
</table>
C. Annual operating cost

1. Operation and maintenance (10%) 9 075 500
2. Depreciation of source (12%) 2 772 000
3. Depreciation of equipment (20% of B.2.) 5 000 000
4. Miscellaneous charges (2%) 1 815 100
5. Transportation of the material to and from the plant 5 400 000
Total 24 062 600

D. Total expenses

10 years’ operation B + (C X 10) 331 381 000
Cost per tonne (12 000 t X 10) 2 761
Cost per kilogram 2.7

E. Capital recovery time on the storage period

Till March:
12 000 t – 18.96% = 9 724.8 t X 17.7 zł/kg = 172 128 960
9 724.8 t X 15 zł/kg = 145 872 000
Cost of irradiation 26 256 960
Material savings 36 667 500
Effective cost benefit 10 410 540
Cost recovered in 38.8 years
Till April: Cost recovered in 17.8 years.
Till May: Cost recovered in 11.5 years.
Till June: Cost recovered in 9 years.

It is clear from the above calculations that an increase in cost due to radiation treatment from 15 zł/kg to 17.7 zł/kg would be accepted by consumers. Nevertheless an investment recovery period as long as 9 years, makes the idea of a single-purpose potato irradiator debatable. Therefore a more pronounced economic benefit may be expected from a multipurpose plant.

REFERENCES

INTRODUCTION OF IRRADIATION TECHNOLOGY INTO THE HUNGARIAN FOOD INDUSTRY

B. KÁLMÁN, E. KÉKESSI
AGROSTER
Irradiation Company,
Budapest

R. SÁNTA
State Office for Technical
Development,
Budapest,
Hungary

Abstract
INTRODUCTION OF IRRADIATION TECHNOLOGY INTO THE HUNGARIAN FOOD INDUSTRY.

By the beginning of the 1980s basic technological research and development work in Hungary resulted in starting food irradiation on a pilot-plant scale. Pilot-plant and industrial-scale irradiation was carried out by an enterprise whose task was to introduce and spread this new technique in the food industry. The international possibilities of food irradiation, standardization, and favourable decisions by the responsible authorities of other countries combined with the results achieved in Hungary demonstrated the necessity of the industrial-scale application of this new technology. The above considerations were acknowledged by the Hungarian authorities who decided in favour of setting up a large-scale food irradiation centre in Budapest. The realization of this project will start in 1985 with the elaboration of plans to be carried out by the end of 1988. The irradiation centre will be equipped with an 18.5 PBq $^{60}$Co source. Preliminary economic calculations and production data support the belief that its operation will be profitable.

1. INTRODUCTION

Modern food industry is searching for new technologies and techniques to improve the production of larger volumes of food. Food irradiation is such a new technology. Research and development of this new technology has reached the point where its large-scale application can be introduced throughout the world, and thus also in Hungary.

Food irradiation on an industrial scale, under the conditions of the highly developed and export-oriented Hungarian food industry, has posed special problems. Only a complete economic analysis can enable the optimum parameters and most important tasks to be determined.
The paper summarizes the results and conclusions of the technological, technical and economic research that form the basis for its application, taking into account the potentialities of large-scale food irradiation in Hungary.

2. RESEARCH AND INVESTIGATIONS PRECEDING THE APPLICATION OF FOOD IRRADIATION ON AN INDUSTRIAL SCALE

2.1. Technology and consumer acceptance tests

Radiation research in the food industry started at the beginning of the 1960s under the direction of Prof. Dr. Károly Vas. In the course of this work the Hungarian researchers participated in many international programmes. Experimental radiation treatment was established in the middle of the 1970s and pilot-plant food treatment by the beginning of the 1980s.

Parallel with this intense technological research, the marketing possibilities of radiation-treated food were also systematically studied. An example of this work is shown in relation to radiation-treated onions.

The marketing study carried on for several years with onions irradiated to prevent sprouting strongly recommended that the Hungarian authorities grant unlimited clearance to this commodity.

Table I summarizes the marketing studies with radiation-treated onions. It can be seen that the volume of marketing tests continually increased from

<table>
<thead>
<tr>
<th>Year of marketing study</th>
<th>Number of towns participating in the study</th>
<th>Number of selling shops</th>
<th>Quantity of irradiated onions sold during marketing study (kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1976</td>
<td>1</td>
<td>4</td>
<td>3 500</td>
</tr>
<tr>
<td>1977</td>
<td>1</td>
<td>3</td>
<td>2 000</td>
</tr>
<tr>
<td>1978</td>
<td>5</td>
<td>15</td>
<td>30 000</td>
</tr>
<tr>
<td>1979</td>
<td>11</td>
<td>25</td>
<td>25 000</td>
</tr>
<tr>
<td>1980</td>
<td>a</td>
<td>a</td>
<td>300 000 has been stated.</td>
</tr>
</tbody>
</table>

* Irradiated onions were sold in more than three counties in Hungary.
year to year with regard to the quantity of the product marketed as well as the number of sales stalls.

The yearly sales were followed up by public opinion polls which provided very useful information.

The example of the onions shows that the technology of radiation treatment has been worked out and that the Hungarian customer received adequate information on food irradiation and its consequences.

2.2. Technical tests

Apart from the development of radiation treatment, the development of the equipment and technique enabling the most economical realization of irradiation began in the mid-1970s.

A study of the products that seemed likely to profit by radiation treatment suggested the necessity of setting up both a special-purpose plant and an irradiation centre in Hungary.

To deal with a large amount of produce grown in a given place the setting up of special-purpose plants seems to be the most suitable. These have to be fitted with specialized handling apparatus to avoid damaging the material and are operated only in the season.

This concept was sufficiently supported by experience gained over several years with the irradiator set up in 1979 in Rákóczifalva for the specific purpose of treating onions. The flow diagram of that onion treatment is shown in Fig.1.
For produce that can be treated all the year round in the dose range of 1 to 10 kGy, a centrally located facility seems to be the best expedient. Such a central arrangement requires a complete handling system taking account of the physical characteristics and packaging units of all the products to be treated.

2.3. Economic considerations

The decision to scale up any new technology for industrial production can be made only on the foundations of complex economic investigations and analyses. Thoroughly organized complex economic studies assist the final decision on the applicability of new methods considered useful from the aspects of technique, technology and hygiene.

The economy of no state can be separated from the general economic and trading mechanisms affecting the whole world. However, when introducing a new technology the national factors must be taken into consideration first and foremost.

This does not mean, naturally, that there are as many economic situations as there are countries. Many countries, and thus Hungary too, can be included in the same category as a number of other countries with similar potentialities. The given conditions and their consequences and local terms have to be taken into account.

In the economic analysis of industrial-scale food irradiation the following aspects and their positive or negative effects had to be considered:

- the state of technology and quality in the given branch of the food industry;
- the requirements in quantity and distribution of the food item to be treated within Hungary;
- the quantity and marketing structure of Hungarian and imported produce to be irradiated for the population;
- foreseeable advantages and disadvantages of radiation treatment in the export of products;
- comparison with other technologies leading to similar results.

3. INDUSTRIAL-SCALE FOOD IRRADIATION AS PLANNED IN HUNGARY

On the basis of investigations carried out for several years, the industrial irradiation of foods in Hungary is planned in two definite directions.

3.1. Irradiation of large masses of agricultural produce

The irradiation of onions grown in the southern part of Hungary is intended to start in the near future. A special-purpose facility of 20 t/h capacity is planned.
TABLE II. ECONOMICS OF ONION IRRADIATION ON A 10 000 TONNE/MONTH SCALE (1985 US$)

<table>
<thead>
<tr>
<th>Establishment cost</th>
<th>200 000</th>
</tr>
</thead>
<tbody>
<tr>
<td>-- building</td>
<td>120 000</td>
</tr>
<tr>
<td>-- machinery</td>
<td>80 000</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Running costs per year</th>
<th>63 500</th>
</tr>
</thead>
<tbody>
<tr>
<td>-- treatment per tonne</td>
<td>5</td>
</tr>
<tr>
<td>-- treatment per 10 000 tonnes</td>
<td>50 000</td>
</tr>
<tr>
<td>-- energy</td>
<td>1 000</td>
</tr>
<tr>
<td>-- labour</td>
<td>1 500</td>
</tr>
<tr>
<td>-- amortization</td>
<td></td>
</tr>
<tr>
<td>-- building</td>
<td>2.5%</td>
</tr>
<tr>
<td>-- machinery</td>
<td>10.0%</td>
</tr>
<tr>
<td></td>
<td>3 000</td>
</tr>
<tr>
<td></td>
<td>8 000</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Profit per year*</th>
<th>150 000</th>
</tr>
</thead>
<tbody>
<tr>
<td>-- loss reduction by irradiation</td>
<td>15%</td>
</tr>
<tr>
<td>-- onion price per tonne</td>
<td>100</td>
</tr>
</tbody>
</table>

* One year = one radiation season.

Preliminary investigations have shown that 10 000 tonnes of onion can be smoothly irradiated within 30 days with a 50 ± 20 Gy radiation dose by operating the above facility for 20 hours per day. As planned, the active charge of the equipment will be 3.7 PBq $^{60}$Co and 20% utilization can be expected.

Table II shows the economics of a special-purpose facility and it can be seen that the total investment is recovered in two seasons. A further special-purpose facility is being planned for the brewery industry and it is hoped, on the basis of results achieved so far, that this facility will operate all the year round.

As regards special-purpose facilities the irradiators used for the disinfestation of cereals are very important in Hungary. In this field the experience gained with the cereal irradiator operated at Odessa in the USSR was utilized.

Potato sprouting could also be prevented most economically with a local special-purpose facility. However, this question requires further complex analysis and study.

3.2. Establishment of a central industrial-scale food irradiation plant

A 'Study Document' prepared in the State Office for Technical Development in 1981 suggested the establishment of a central industrial-scale food irradiation
To establish large-scale radiation treatment, at the suggestion of the competent governmental authority the AGROSTER Joint Irradiation Development Company was established in 1982. This company started the irradiation of seasonings and packaging materials on a pilot scale. Apart from studying the technology and development the company assessed the requirements to be met by a large-scale industrial irradiator in the next 10 years.

The results are as follows:

(a) The establishment of a large-scale industrial radiation treatment centre in Hungary is necessary.
(b) Because of the central position of Budapest the radiation treatment centre should be built in the capital.
(c) From the aspect of economy treatment in the range of 1 to 10 kGy is envisaged, thus the economic structure should be adjusted accordingly.
(d) The capacity of the centre should amount to at least 7500 hours of treatment per year.
(e) The initial activity of the plant should be 18.5 PBq $^{60}$Co.
(f) Calculated on the irradiation of 1 kg of product with 1 kGy and taking into account the precalculated treatment, the cost should be US$ 0.04/kg (1985).
(g) Handling of the material on site should be mechanized and automated as far as possible.

On the basis of the above considerations the Hungarian authorities found the setting up of an industrial-scale radiation plant timely. In agreement with this decision, the irradiation centre should be a state firm; thus on 1 January 1985 the AGROSTER Joint Irradiation Development Company was replaced by the AGROSTER Irradiation Company which is operating under direct ministerial direction.

Operation is planned to start by the end of 1988. The investment costs are expected to amount to about US$ 6 million and will be covered partly by bank credit and partly by direct government subvention.

Economic calculations show that the requirements shown so far will ensure total utilization of the plant's capacity by 1989. The expected returns will pay off the long-term credit.

Preliminary economic calculations also show that, presuming an unchanged capacity for 10 years, the profit will enable the total investment to be repaid within 10 to 12 years, under prevailing conditions in Hungary.

To sum up, it may be said that as one of the pioneers of the technology of food irradiation Hungary is ready to introduce this technology on an industrial scale. This step enjoys the whole-hearted support of the competent Hungarian authorities because they realize that radiation treatment reduces food losses while achieving an improvement in quality through increased hygiene.
REFERENCES


FEED RADICIDATION IN ISRAEL – AN UPDATE

Y. KLINGER
Kimron Veterinary Institute,
Bet Dagan

M. LAPIDOT, I. ROSS
Soreq Nuclear Research Center,
Yavne
Israel

Abstract

FEED RADICIDATION IN ISRAEL – AN UPDATE.

There has been a continuous increase in the number of salmonella isolations and in the number of human cases of salmonellosis of animal origin in Israel in recent years. Salmonellosis also endangers the poultry industry itself, and prevents exports of poultry meat to a number of countries. The customary procedure to reduce salmonellae in poultry feeds, which represent the major source of salmonellae in poultry flocks, is pelletization. This, by itself, does not eliminate completely all enterobacteria and fungi, and there is a significant chance for recontamination. Radicidation is the most reliable method for drastic reduction of salmonellae and other enterobacteria as well as of pathogenic fungi in poultry feeds. The dose to achieve reductions of 6–8 logs in non-pelletized feeds or feed components is about 0.75 Mrad and in pelletized feeds about 0.375 Mrad. It has been demonstrated that radicidation has no detrimental effect on the composition or biological value of poultry feed. Clearance of gamma radicidized poultry feed, up to a dose of 1.5 Mrad, was granted in 1973, and of electron processed feed, up to the same dose, in 1985. A semi-commercial demonstration project in the largest local feed mill comprises a 75 kW accelerator (1.5 MeV and 50 mA), which allows throughputs of about 15 t/h unpelletized feed or 30 t/h pelletized feed. It also incorporates storage silos for untreated and treated feed, a conveying system, ventilation systems, radiation safety systems, a thick-walled biological shield, and automatic control systems for accelerator and conveyors. The feed will be tested in a specially adapted 80 000 chicken poultry farm.

1. INTRODUCTION

There has been a continuous increase in the number of salmonella isolations and in the number of human cases of salmonellosis of animal origin in Israel in recent years [1]. Salmonellosis was diagnosed here when poultry raising was still in the backyard stage, and it has not disappeared despite modern intensive husbandry methods. Salmonellosis endangers the poultry industry itself, particularly the turkey flocks (as experienced during a paratyphoid outbreak in 1973–75) [2] and also severely limits exports because of recent regulations in CEC and other countries [3].
One of the major sources of contamination of poultry is the mixed feed [4], in addition to other sources such as the polluted environment, animal and bird droppings, and even human attendants. Some components of the feed, particularly those of animal origin (bone-, meat-, blood-, and fish-meals) are more heavily contaminated than others. Indeed, some health authorities have recognized this hazard to flock and human health, and are attempting to combat it. Thus the Swiss authorities require all imported mixed feed components to be rendered salmonella free [5]. The veterinary services in Israel have issued conditions for the licensing of mills producing feeds for reproduction and breeder flocks [3].

2. REDUCTION OF SALMONELLA IN FEEDS

The most commonly used process in feed mills is pelletization. The exposure of mixed feed components to heat and pressure reduces contamination from $10^5 - 10^6$ enterobacteria per gram to $1 - 10$. However, during cooling and storage, recontamination of about one order of magnitude has been observed [6]. Also, this process became expensive in the years of the energy crisis, and it does not reduce all fungi [7].

Another method is based on the use of bacteriostatic or fungistatic chemicals, such as formic [8] or propionic acids [9]. These are even more expensive than heating, and may reach costs of the order of US $30-40 per tonne. Also, the treatment cannot be applied on line, since a contact time of several days may be required to achieve full penetration. The quantities of formic and propionic acids produced worldwide are limited, and may be insufficient to meet requirements of even a few countries.

The most adequate process for this need is, therefore, irradiation with gamma or electron rays. Experiments performed locally have shown that a dose of 7.5 kGy is effective, and achieves reductions of 6–8 logs in contaminations of non-pelletized and untreated feeds or feed components [6]. For pelletized feeds the radicidation dose could be reduced by one half. Experiments in other countries such as the Netherlands [10], Denmark [11], the United Kingdom [12], the Federal Republic of Germany [13], and Canada [14] have confirmed these results.

In another long-term experiment, an SPF\(^1\) poultry flock (200 birds) were fed radiation sterilized feed for a period of two years [15]. No disease or disease-induced mortality was observed, despite the absence of vaccination.

3. WHOLESOMENESS AND CLEARANCES

To demonstrate the wholesomeness of irradiated animal feeds, several multi-generation feeding studies have been performed on radicidized (10 kGy) and

\(^1\) SPF = Specific pathogen free.
radappertized (20–35 kGy) poultry rations in the USA [16] and Canada [17]. The positive results of these studies, as well as the reports and data, were incorporated in a petition to clear radicidized poultry feed in Canada [18], and clearance was granted by the Canadian Department of Agriculture in 1971 [19].

A local study has been performed to investigate the effects of radicidized (10–15 kGy) poultry feed concentrates in the case of a layer flock (groups of 300 hens and 50 roosters each) fed for one year (including 6 months of laying) and in the case of the hatched chicks for 2.5 months [20]. No detrimental effects (as compared with untreated feed) were observed with respect to weight of chicken, feed utilization, breeding eggs production, fertility, hatchability, and other characteristic parameters such as mortality. No metabolic diseases were observed. The vitality of the second generation chicks was also unaffected.

A petition for clearance of radicidized poultry feed was submitted in 1972 [21] based on the above data, as well as on additional studies performed locally and abroad [22]. An amended schedule of the Public Health (Preservation of Food by Radiation) Regulations was published in 1973, permitting radicidation of animal feed mixtures (for poultry) at doses of up to 1.5 Mrad (15 kGy) using cobalt-60 gamma radiation [23].

Economic considerations (given below) have required modification of this clearance. Therefore, a new petition, requesting clearance of poultry feed radicidized at a dose of up to 15 kGy, but using electrons accelerated to energies of up to 10 MeV, was submitted on 24 December 1983 [24]. In this petition the equivalence of gamma and electron radiation with respect to food irradiation was discussed on the basis of the recent Codex Alimentarius recommendations. The clearance has now been granted and the new schedule was published in March 1985 [25].

4. TECHNO-ECONOMIC ASPECTS OF POULTRY FEED RADICIDATION

4.1. Feed throughputs and radicidation power requirements

Many feed mills, producing various animal feed mixes, operate at throughputs of the order of 60 000 to 300 000 t/a. Usually these mills operate at one to two shifts, and only rarely is a third shift implemented. Assuming that the larger feed mills will be radicidizing only part of their annual production, techno-economic considerations here are centred on three throughputs of 10, 20, and 30 t/h, operating three shifts per day, five days per week and 50 weeks per year, i.e. a total of 60 000, 120 000 and 180 000 t/a, respectively.

---

2 1 rad = 1.00 X 10^-2 Gy.
TABLE I. ECONOMIC CONSIDERATIONS FOR UNPELLETIZED FEED RADICIDATION AT 7.5 kGy USING $^{60}$Co (in US $)

<table>
<thead>
<tr>
<th>t/h</th>
<th>10</th>
<th>7</th>
<th>20</th>
<th>14</th>
<th>30</th>
<th>21</th>
</tr>
</thead>
<tbody>
<tr>
<td>h/a</td>
<td>6000</td>
<td>8750</td>
<td>6000</td>
<td>8570</td>
<td>6000</td>
<td>8570</td>
</tr>
<tr>
<td>t/a</td>
<td>6000</td>
<td>6000</td>
<td>12000</td>
<td>12000</td>
<td>18000</td>
<td>18000</td>
</tr>
<tr>
<td>MCl $^{60}$Co</td>
<td>3.5</td>
<td>2.45</td>
<td>7</td>
<td>4.9</td>
<td>10.5</td>
<td>7.35</td>
</tr>
</tbody>
</table>

**Investments**

<table>
<thead>
<tr>
<th>Description</th>
<th>700 000</th>
<th>700 000</th>
<th>800 000</th>
<th>750 000</th>
<th>900 000</th>
<th>800 000</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hardware</td>
<td>4 900 000</td>
<td>3 430 000</td>
<td>9 800 000</td>
<td>6 860 000</td>
<td>14 700 000</td>
<td>10 290 000</td>
</tr>
<tr>
<td>Cobalt-60 (US $1.4)</td>
<td>350 000</td>
<td>320 000</td>
<td>450 000</td>
<td>390 000</td>
<td>600 000</td>
<td>480 000</td>
</tr>
<tr>
<td>Biological shield</td>
<td>150 000</td>
<td>135 000</td>
<td>200 000</td>
<td>180 000</td>
<td>300 000</td>
<td>220 000</td>
</tr>
<tr>
<td>Engineering installations</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total with $^{60}$Co</td>
<td>6 100 000</td>
<td>4 585 000</td>
<td>11 250 000</td>
<td>8 185 000</td>
<td>16 500 000</td>
<td>11 790 000</td>
</tr>
<tr>
<td>Total without $^{60}$Co</td>
<td>1 200 000</td>
<td>1 155 000</td>
<td>1 450 000</td>
<td>1 325 000</td>
<td>1 800 000</td>
<td>1 500 000</td>
</tr>
</tbody>
</table>

**Operating Costs**

<table>
<thead>
<tr>
<th>Description</th>
<th>120 000</th>
<th>115 500</th>
<th>145 000</th>
<th>132 500</th>
<th>180 000</th>
<th>150 000</th>
</tr>
</thead>
<tbody>
<tr>
<td>Amortization (10 years)</td>
<td>637 000</td>
<td>446 000</td>
<td>1 274 000</td>
<td>892 000</td>
<td>1 911 000</td>
<td>1 338 000</td>
</tr>
<tr>
<td>Cobalt-60 (13%)</td>
<td>610 000</td>
<td>458 500</td>
<td>1 125 000</td>
<td>818 500</td>
<td>1 650 000</td>
<td>1 179 000</td>
</tr>
<tr>
<td>Interest (10%)</td>
<td>12 000</td>
<td>17 000</td>
<td>18 000</td>
<td>25 500</td>
<td>24 000</td>
<td>34 000</td>
</tr>
<tr>
<td>Maintenance (US $2-4/h)</td>
<td>6 000</td>
<td>8 500</td>
<td>9 000</td>
<td>12 500</td>
<td>12 000</td>
<td>17 000</td>
</tr>
<tr>
<td>Utilities (#6/kW-h)</td>
<td>75 000</td>
<td>105 000</td>
<td>75 000</td>
<td>105 000</td>
<td>75 000</td>
<td>105 000</td>
</tr>
<tr>
<td>Manpower (5/7)</td>
<td>219 000</td>
<td>172 000</td>
<td>397 000</td>
<td>298 000</td>
<td>578 000</td>
<td>423 500</td>
</tr>
<tr>
<td>Contingencies (15%)</td>
<td>1 679 000</td>
<td>1 323 000</td>
<td>3 043 000</td>
<td>2 284 000</td>
<td>4 430 000</td>
<td>3 246 500</td>
</tr>
<tr>
<td>Total costs</td>
<td>4 300 000</td>
<td>3 246 000</td>
<td>2 722 000</td>
<td>1 850 000</td>
<td>3 040 000</td>
<td>2 468 000</td>
</tr>
<tr>
<td>Cost per tonne</td>
<td>28 22</td>
<td>25.4</td>
<td>19</td>
<td>24.6</td>
<td>18</td>
<td></td>
</tr>
</tbody>
</table>

1 Ci = 3.70 × 10$^{10}$ Bq.
TABLE II. ECONOMIC CONSIDERATIONS FOR PELLETIZED FEED RADICIDATION AT 3.75 kGy USING $^{60}$Co (in US $)

<table>
<thead>
<tr>
<th>t/h</th>
<th>10</th>
<th>7</th>
<th>20</th>
<th>14</th>
<th>30</th>
<th>21</th>
</tr>
</thead>
<tbody>
<tr>
<td>h/a</td>
<td>6000</td>
<td>8570</td>
<td>6000</td>
<td>8570</td>
<td>6000</td>
<td>8570</td>
</tr>
<tr>
<td>t/a</td>
<td>6000</td>
<td>6000</td>
<td>12000</td>
<td>12000</td>
<td>18000</td>
<td>18000</td>
</tr>
<tr>
<td>MCI $^{60}$Co</td>
<td>1.75</td>
<td>1.25</td>
<td>3.5</td>
<td>2.45</td>
<td>5.25</td>
<td>3.7</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Investments</th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Hardware</td>
<td>600000</td>
<td>550000</td>
<td>700000</td>
<td>700000</td>
<td>750000</td>
<td>700000</td>
</tr>
<tr>
<td>Cobalt-60 (US $1.4)</td>
<td>2450000</td>
<td>1715000</td>
<td>4900000</td>
<td>3430000</td>
<td>7350000</td>
<td>5145000</td>
</tr>
<tr>
<td>Biological shield</td>
<td>300000</td>
<td>280000</td>
<td>350000</td>
<td>320000</td>
<td>400000</td>
<td>360000</td>
</tr>
<tr>
<td>Engineering installations</td>
<td>120000</td>
<td>110000</td>
<td>150000</td>
<td>135000</td>
<td>175000</td>
<td>160000</td>
</tr>
<tr>
<td>Total with $^{60}$Co</td>
<td>3470000</td>
<td>2655000</td>
<td>6100000</td>
<td>4585000</td>
<td>8675000</td>
<td>6865000</td>
</tr>
<tr>
<td>Total without $^{60}$Co</td>
<td>1020000</td>
<td>940000</td>
<td>1200000</td>
<td>1155000</td>
<td>1325000</td>
<td>1220000</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Operating costs</th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Amortization (10 years)</td>
<td>102000</td>
<td>94000</td>
<td>120000</td>
<td>115500</td>
<td>132500</td>
<td>122000</td>
</tr>
<tr>
<td>Cobalt-60 (13%)</td>
<td>318500</td>
<td>223000</td>
<td>637000</td>
<td>446000</td>
<td>955500</td>
<td>669000</td>
</tr>
<tr>
<td>Interest (10%)</td>
<td>347000</td>
<td>265500</td>
<td>610000</td>
<td>458000</td>
<td>867500</td>
<td>686500</td>
</tr>
<tr>
<td>Maintenance (US $1−3/h)</td>
<td>6000</td>
<td>85000</td>
<td>120000</td>
<td>170000</td>
<td>180000</td>
<td>255000</td>
</tr>
<tr>
<td>Utilities ($/kWh)</td>
<td>4500</td>
<td>65000</td>
<td>600000</td>
<td>850000</td>
<td>750000</td>
<td>105000</td>
</tr>
<tr>
<td>Manpower (5/7)</td>
<td>75000</td>
<td>105000</td>
<td>750000</td>
<td>105000</td>
<td>750000</td>
<td>105000</td>
</tr>
<tr>
<td>Contingencies (15%)</td>
<td>128000</td>
<td>105500</td>
<td>219000</td>
<td>172500</td>
<td>308500</td>
<td>243000</td>
</tr>
<tr>
<td>Total costs</td>
<td>981000</td>
<td>808000</td>
<td>1679000</td>
<td>1323000</td>
<td>2364500</td>
<td>1861500</td>
</tr>
<tr>
<td>Cost per tonne</td>
<td>16.4</td>
<td>13.5</td>
<td>14</td>
<td>11</td>
<td>11.8</td>
<td>9.3</td>
</tr>
</tbody>
</table>
TABLE III. ECONOMIC CONSIDERATIONS FOR UNPELLETIZED\textsuperscript{a} AND PELLETIZED\textsuperscript{b} FEED RADIATION, USING AN 0.85 MeV ELECTRON ACCELERATOR (in US $)

<table>
<thead>
<tr>
<th>t/h</th>
<th>10</th>
<th>20</th>
<th>30</th>
</tr>
</thead>
<tbody>
<tr>
<td>h/a</td>
<td>6000</td>
<td>6000</td>
<td>6000</td>
</tr>
<tr>
<td>t/a</td>
<td>60</td>
<td>120</td>
<td>180</td>
</tr>
<tr>
<td>mA</td>
<td>$2 \times 30^a$</td>
<td>$2 \times 60^a$</td>
<td>$2 \times 90^a$</td>
</tr>
<tr>
<td>Investments</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hardware</td>
<td>900 000</td>
<td>1 000 000</td>
<td>1 200 000</td>
</tr>
<tr>
<td>Biological shield</td>
<td>250 000</td>
<td>300 000</td>
<td>400 000</td>
</tr>
<tr>
<td>Engineering installations</td>
<td>150 000</td>
<td>200 000</td>
<td>250 000</td>
</tr>
<tr>
<td>Total</td>
<td>1 300 000</td>
<td>1 500 000</td>
<td>1 850 000</td>
</tr>
<tr>
<td>Operating costs</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Amortization (10 years)</td>
<td>130 000</td>
<td>150 000</td>
<td>185 000</td>
</tr>
<tr>
<td>Interest (10%)</td>
<td>130 000</td>
<td>150 000</td>
<td>185 000</td>
</tr>
<tr>
<td>Maintenance (US $4—8/h)</td>
<td>24 000</td>
<td>18 000</td>
<td>36 000</td>
</tr>
<tr>
<td>Utilities ($6/kW-h)</td>
<td>54 000</td>
<td>108 000</td>
<td>162 000</td>
</tr>
<tr>
<td>Manpower (8)</td>
<td>136 000</td>
<td>136 000</td>
<td>136 000</td>
</tr>
<tr>
<td>Contingencies (15%)</td>
<td>72 000</td>
<td>87 000</td>
<td>108 000</td>
</tr>
<tr>
<td>Total costs</td>
<td>546 000</td>
<td>667 000</td>
<td>824 000</td>
</tr>
<tr>
<td>Cost per tonne</td>
<td>9.1</td>
<td>5.6</td>
<td>4.6</td>
</tr>
</tbody>
</table>

\textsuperscript{a} Dose: 7.5 kGy.
\textsuperscript{b} Dose: 3.75 kGy.
The amounts of radiation power required for such throughputs can be calculated for unpelletized and pelletized feeds, requiring a minimum of 7.5 and 3.75 kGy, respectively. Thus, at the three throughputs considered, the power required is 50, 100, and 150 kW for unpelletized, and 25, 50, and 75 kW for pelletized feed, assuming an absorption efficiency of 40% (at this efficiency, 1 kW will yield 1.5 kGy·t).

4.2. Radicidation facilities

Feed mills produce in bulk — products being flours, pellets, or crumbles. Some mills market their products in sacks. In this study bulk processing of feeds and feed components has been considered (bag processing will be somewhat more costly).

Cobalt-60 gamma irradiation facilities could apply some of the early designs developed by NUCHEM [26] and others [27] for gamma disinfestation of grains. In such continuous gravity flow systems the feed flows from large hoppers, through a series of concentric annular channels surrounding the cobalt-60 source rods, and is collected by means of a rotating tube flow regulator with adjustable orifices (controlling the flow rate through each channel, so that the residence time corresponds to the dose rate, which decreases with the distance from the source rods’cage at the centre).

Electron irradiators could apply 1.5—3.0 MeV accelerators for one-sided, vertical irradiation of feed conveyed in 6—12 mm layers, or 0.75—1.0 MeV accelerators for nearly horizontal, double-sided irradiation of free falling feed. The two acceleration tubes would draw power from a single high-voltage d.c. power supply, and would be placed opposite to each other, but staggered or at a slight angle, to avoid impingement of electrons from one to the other [28].

4.3. Economic feasibility

Economic considerations for radicidation of unpelletized and pelletized mixed feeds, using cobalt-60 gamma or accelerated electron facilities, are presented in Tables I—III.

In the case of gamma radiation facilities three outputs have been assumed — 60 000, 120 000, and 180 000 t/a, respectively. Operation for 3 daily shifts, 5 days a week, and 50 weeks per annum has been considered. However, the possibility of operating the facility for 3 daily shifts, 7 days a week, and 51 weeks per annum has also been considered, in order to allow full utilization of the cobalt-60 in the facility. One week should be enough for cobalt-60 replenishments and essential simple maintenance.

Amortization and interest rates of 10% each have been assumed in this simplified economic feasibility scheme, and an annual replenishment of 13% cobalt-60; maintenance costs have been assumed to be 2, 3, and 4 US $/h,
proportionate to the increasing throughput, and power consumptions of 16.7, 33, and 50 kW-h in proportion to the increasing throughput. The manpower required is 1 per shift, with 2 in reserve for 5 days a week and 4 in reserve for 7 days a week, the operator cost being assumed as US $15 000 per annum. Contingencies are 15%.

One must point out that the cobalt-60 requirements of these facilities are extremely high, even for pelletized feed radication. Very few of today's modern radiation facilities contain 3 MCI or more of cobalt-60. Assuming that facilities with several times that capacity could be built, and that such amounts of cobalt-60 were available (tens or perhaps even a hundred facilities might be needed in the next decade) the investment cost is still very high, even in the smaller facilities.

The cost of the treatment is high, and in the case of unpelletized feed it approaches that of formic or propionic acid treatments, when operating for five days a week. The cost estimates range from 28, 25.4, and 24.6 US $/t (for the 3 annual throughputs) at 5 days a week, or 22, 19, and 18 US $/t at 7 days a week, for the unpelletized feed, to 16.4, 14, and 11.8 or 13.5, 11, and 9.3 US $/t for the pelletized feed. These costs might decrease somewhat in the future if the cost of cobalt-60 were to decrease again in view of possible improvements in large-scale production facilities.

The economic feasibility changes remarkably in the case of the electron accelerator facilities. In Table III the same three annual throughputs have been assumed. However, since no isotope is wasted and more maintenance time will very likely be required, only 5 days a week operation has been considered.

The same amortization and interest rates (10% each) have again been assumed, with maintenance costs double those of the isotopic facilities (4, 6, and 8 US $/h, proportionate to the increasing capacity). Power requirements are considerable, and are assumed to be treble the actual power output of the electron beam (considering 80% power utilization in the accelerator, 125% for cooling, and some 50% for conveying, ventilation, etc.). Manpower requirements have been assumed fixed at all throughputs — 2 operators per shift, and 2 in reserve, at a somewhat higher cost of US $17 000 per annum, because of higher proficiency requirements. Contingencies are again 15%.

Investments range from US $1.2 to 1.9 million. Treatment costs per tonne decrease from US $9.1 and 8.1 at the lower capacity to US $4.6 and 3.5 at the higher capacity. These costs are quite competitive with those of chemicals at all levels, and with pelletization costs at the higher capacities.

4.4. Industrial demonstration facility

To enable the above techno-economic considerations to be checked, an industrial demonstration project was funded jointly by the largest local feed mill, the Soreq NRC, a US manufacturer of industrial accelerators, and the US-Israel
Binational Industrial R&D Foundation [29]. The accelerator power is 75 kW, and at 40% energy utilization the throughput capacity at full beam should be 15 t/h for unpelletized and 30 t/h for pelletized feed.

The major components of the facility are the accelerator itself, the biological shield, the conveyor system, storage silos for untreated and processed feed, auxiliary systems of the accelerator and the conveyor, automatic control systems, ventilation systems for removal of ozone and dust, radiation safety systems, and auxiliary devices.

The running in of the system has started. Management, economic, physiologic, microbiologic, mycologic, nutritional and veterinary aspects of feeding poultry with electron radicidized feed will be studied throughout 1985 in a poultry farm of 80,000 chicks.

Special measures protect the feed along the transport and dispensing chain from recontamination, and the chicken from exposure to contaminating agents.

REFERENCES


ECONOMIC PROSPECTS OF FOOD IRRADIATION IN ZAMBIA

B.E. CHISHYA, K.D. CHALWE
Food Technology Research Unit,
National Council for Scientific Research,
Lusaka, Zambia

Abstract

ECONOMIC PROSPECTS OF FOOD IRRADIATION IN ZAMBIA.
Instances of economic benefits which are likely to be considered when introducing food irradiation as an industrial and commercial food processing method in Zambia are discussed from a point of view of increasing both the local and external marketing potential of various local food commodities. The present status of the food irradiation programme is also briefly discussed.

INTRODUCTION

The National Council for Scientific Research of Zambia (NCSR), which was established under Parliament Act in 1967, three years after the country attained political independence, possesses several functions, three of which are:

(1) to advise the Government of the Republic of Zambia on the national scientific policy and activities within Zambia;
(2) to determine priorities in the national research programme, particularly in relation to national development plans;
(3) to promote and encourage such research as is required to meet the nation’s needs.

With these objectives in view the NCSR established the Food Technology Research Unit whose functions relate directly to the subject matter of discussion at this international symposium. Before discussing the economic prospects of food irradiation processing in Zambia the present status of Zambia’s food irradiation programme is outlined.

PRESENT STATUS OF THE FOOD IRRADIATION PROGRAMME IN ZAMBIA

For the past five years Zambia has embarked on a vigorous food production programme to diversify the country’s mono-economy based on copper earnings. This came about after recognition of agriculture as a precondition for economic
recovery and also the widening gap between food demand and supply which called for urgent action. If food imports had been allowed to increase to make up for the deficit in food supplies, it would have ultimately led not only to a crisis in terms of payments for food imports, but would also have impaired the development of the capabilities and means to increase home food production.

The task of increasing food supplies by growing more agricultural produce lies in the hands of the Ministry of Agriculture and Water Development. This task is elucidated in the two volumes of the Zambia Strategies for Agricultural Research and Extension of November 1984. However, in anticipation of the increase in food production as a result of the current food production strategies and also in view of the large energy input needed to grow more agricultural produce, 25 to 40% of which would again be doomed to perish under the present circumstances, it is logical that the search for methods of preserving existing and future food supplies by reducing food and crop spoilage constitutes a primary task for food research and technology. In this regard the NCSR gave the Food Technology Research Unit (FTRU) a mandate to create an infrastructure for research and experimental development in food processing, post-harvest and storage technologies, including up-scaling and improving the existing traditional methods of food preservations and post-harvest storage techniques.

Considering the present economic situation in the country and indeed in all parts of the world and also the ever-increasing costs and health hazards associated with current methods of food preservation such as canning, freezing and chemical fumigation, a search for new and cheaper methods of food preservation, including food irradiation techniques, which would cater for a wide range of foods and foodstuffs, is fully justified.

With this in mind, the FTRU, when setting up a Food Irradiation Programme, recommended the NCSR to approach the International Atomic Energy Agency (IAEA) for technical assistance to establish a multi-purpose gamma irradiation facility. The Agency responded favourably by providing expert service to enable feasibility studies for the establishment of the facility to be carried out. The Expert’s recommendations are contained in his report, Ref. No. IAEA-TA-2169 of December 1983. The Expert’s mission resulted in the Agency approving the assistance to the multi-purpose gamma-irradiation facility, project Ref. No. ZAM/8/003. This project includes, among other envisaged activities, food irradiation, the specific needs and objectives of which were submitted to the IAEA for consideration for further technical assistance.

Among the Zambian Government’s contributions towards the establishment of the multi-purpose gamma irradiation facility is the construction of the housing for the irradiation source and laboratories for analytical quality control. This structure is expected to be completed and the irradiation source installed in the course of 1985. Some activities planned under the Food Irradiation Programme are:

(1) to study the application of ionizing radiation for bacteria and parasite disinfection of foods, insect disinestation of stored grains, particularly
maize, rice, sorghum, millet etc. and increasing the shelf-life of perishable food commodities such as mangoes, bananas, strawberries, tomatoes, etc., including control of senescence in potatoes, onions and garlic;

(2) to carry out microbiological, nutritional and toxicological evaluation of irradiated foods. In this regard, we intend to carry out investigations on the absence of microorganisms, microbial toxins, and of any significant amounts of toxic compounds formed in foods as a result of irradiation and evaluate the nutritional value of irradiated foods;

(3) to make — on the basis of the results of the investigations — recommendations to the Government on the possible application of food irradiation technology at an industrial and commercial level.

The choice of foods to study the efficacy of food irradiation is based on the current research programme priorities of the Zambia agricultural research and extension project. These priorities are given in Table I. The results of the agricultural research project are expected to contribute to overcome the scarcity of food supplies in the near term and also to restructure the economy to make it more balanced.

ECONOMIC PROSPECTS

The subject of economic advantages or benefits of food irradiation is wide and very complex with several aspects to be considered, such as capital costs, operating or variable costs, energy input etc., to assess the total costs of irradiating a variety of food commodities. Therefore, when considering the economic prospects of food irradiation in Zambia we shall try not to examine the economic feasibility of food irradiation as such, since this has been the subject of discussion and research for some time now in many parts of the world. Instead we shall try to look at some instances of the economic benefits Zambia can anticipate from food irradiation.

Anticipated economic benefits

To obtain the economic benefits of food irradiation, the whole irradiation process must be weighed against its costs. A simplistic definition of economic benefit is: to be economically beneficial an undertaking must basically more than pay for its costs. Therefore, food irradiation must compete economically with a number of existing preservation methods (physical, chemical and biological) or, better still, prove its economic superiority over any other existing alternative. For further explanation, on a general basis, some of the anticipated economic benefits of food irradiation for a country like Zambia with respect to the production levels and market potential of selected local food items are outlined.
<table>
<thead>
<tr>
<th>Commodity</th>
<th>Growth</th>
<th>Equity</th>
<th>Food Sector</th>
<th>Trade</th>
<th>Nutritional value</th>
<th>Potential Market</th>
<th>Potential Resources</th>
<th>Expected payoff Magnitude</th>
<th>Expected payoff Probability</th>
<th>When</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Good</td>
<td>Med</td>
<td>Large</td>
<td>High</td>
<td>Soon</td>
</tr>
<tr>
<td><strong>PRIORITY I</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Excel</td>
<td>Med</td>
<td>Large</td>
<td>High</td>
<td>Soon</td>
</tr>
<tr>
<td><strong>Maize</strong></td>
<td>High</td>
<td>High</td>
<td>High</td>
<td>High</td>
<td>Med</td>
<td>Good</td>
<td>Med</td>
<td>Large</td>
<td>High</td>
<td>Soon</td>
</tr>
<tr>
<td><strong>Groundnuts</strong></td>
<td>High</td>
<td>High</td>
<td>High</td>
<td>High</td>
<td>High</td>
<td>Excel</td>
<td>Med</td>
<td>Large</td>
<td>High</td>
<td>Soon</td>
</tr>
<tr>
<td><strong>Cotton</strong></td>
<td>Med</td>
<td>High</td>
<td>Low</td>
<td>High</td>
<td>Low</td>
<td>Excel</td>
<td>Med</td>
<td>Large</td>
<td>High</td>
<td>Soon</td>
</tr>
<tr>
<td><strong>Sunflower</strong></td>
<td>Med</td>
<td>High</td>
<td>High</td>
<td>High</td>
<td>High</td>
<td>Excel</td>
<td>Med</td>
<td>Med</td>
<td>Med</td>
<td>Med</td>
</tr>
<tr>
<td><strong>Cassava</strong></td>
<td>Low</td>
<td>High</td>
<td>High</td>
<td>Low</td>
<td>Low</td>
<td>Med</td>
<td>Med</td>
<td>High</td>
<td>Med</td>
<td>Soon</td>
</tr>
<tr>
<td><strong>Sorghum/millet</strong></td>
<td>Med</td>
<td>High</td>
<td>High</td>
<td>Low</td>
<td>Med</td>
<td>Med</td>
<td>Large</td>
<td>High</td>
<td>High</td>
<td>Med</td>
</tr>
<tr>
<td><strong>PRIORITY II</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Good</td>
<td>Large</td>
<td>Med</td>
<td>High</td>
<td>Med</td>
</tr>
<tr>
<td><strong>Beans/grain legumes</strong></td>
<td>Med</td>
<td>High</td>
<td>High</td>
<td>Low</td>
<td>High</td>
<td>Low</td>
<td>Large</td>
<td>Med</td>
<td>High</td>
<td>Med</td>
</tr>
<tr>
<td><strong>Pastures and fodder</strong></td>
<td>Med</td>
<td>High</td>
<td>High</td>
<td>High</td>
<td>Med</td>
<td>Good</td>
<td>Med</td>
<td>High</td>
<td>Soon</td>
<td>Med</td>
</tr>
<tr>
<td><strong>Rice</strong></td>
<td>Med</td>
<td>High</td>
<td>High</td>
<td>High</td>
<td>Med</td>
<td>Good</td>
<td>Med</td>
<td>High</td>
<td>Soon</td>
<td>Med</td>
</tr>
<tr>
<td><strong>Tillage/machinery</strong></td>
<td>Med</td>
<td>High</td>
<td>High</td>
<td>Low</td>
<td></td>
<td>Excel</td>
<td>Med</td>
<td>High</td>
<td>Med</td>
<td>Soon</td>
</tr>
<tr>
<td><strong>Wheat</strong></td>
<td>Low</td>
<td>Med</td>
<td>High</td>
<td>High</td>
<td>High</td>
<td>Good</td>
<td>Large</td>
<td>Med</td>
<td>High</td>
<td>Med</td>
</tr>
<tr>
<td><strong>Sedentary livestock</strong></td>
<td>Med</td>
<td>High</td>
<td>Med</td>
<td>Low</td>
<td>High</td>
<td>Med/Good</td>
<td>Large</td>
<td>Med</td>
<td>Med</td>
<td>Med</td>
</tr>
<tr>
<td><strong>Transmigrant livestock</strong></td>
<td>Med</td>
<td>High</td>
<td>Med</td>
<td>Low</td>
<td>High</td>
<td>Med/Good</td>
<td>Large</td>
<td>Med</td>
<td>Med</td>
<td>Med</td>
</tr>
<tr>
<td>Priority III</td>
<td>Vegetables</td>
<td>Crop storage</td>
<td>Dairy</td>
<td>Tree crops (fruits)</td>
<td>Tobacco</td>
<td>Cashew</td>
<td>Kena/other fibres</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>-------------</td>
<td>------------</td>
<td>--------------</td>
<td>------</td>
<td>---------------------</td>
<td>---------</td>
<td>--------</td>
<td>------------------</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Priority IV</th>
<th>Poultry</th>
<th>Sheep</th>
<th>Pig</th>
<th>Goats</th>
<th>Sweet potato</th>
</tr>
</thead>
</table>
### TABLE II. PRODUCTION LEVELS AND MARKET POTENTIAL OF SELECTED AGRICULTURAL COMMODITIES

<table>
<thead>
<tr>
<th>Agricultural commodity</th>
<th>Production (t)</th>
<th>Year of production and marketing</th>
<th>Local market (t)</th>
<th>Export market (t)</th>
<th>Percentage of spoilage</th>
<th>Local and export potential</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maize</td>
<td>510 445.17</td>
<td>1982</td>
<td>357 308.0</td>
<td>3.26</td>
<td>30.0</td>
<td>High</td>
</tr>
<tr>
<td>Groundnuts</td>
<td>762.72</td>
<td>1982</td>
<td>522.04</td>
<td>166.10</td>
<td>12.5</td>
<td>High</td>
</tr>
<tr>
<td>Sunflower</td>
<td>21 303.70</td>
<td>1982</td>
<td>16 587.74</td>
<td>29.15</td>
<td>22.0</td>
<td>High</td>
</tr>
<tr>
<td>Pineapples</td>
<td>207.0</td>
<td>1984</td>
<td>147.58&lt;sup&gt;a&lt;/sup&gt;</td>
<td>3.53</td>
<td>27.0&lt;sup&gt;a&lt;/sup&gt;</td>
<td>Good</td>
</tr>
<tr>
<td>Mangoes</td>
<td>150 165.0&lt;sup&gt;a&lt;/sup&gt;</td>
<td>1984</td>
<td>60 063.0&lt;sup&gt;b&lt;/sup&gt;</td>
<td>3.0</td>
<td>60.0&lt;sup&gt;a&lt;/sup&gt;</td>
<td>Good</td>
</tr>
<tr>
<td>Onions</td>
<td>305.83&lt;sup&gt;a&lt;/sup&gt;</td>
<td>1984</td>
<td>295.1&lt;sup&gt;b&lt;/sup&gt;</td>
<td>1.56</td>
<td>3.0&lt;sup&gt;a&lt;/sup&gt;</td>
<td>Low</td>
</tr>
<tr>
<td>Tomatoes</td>
<td>457.52&lt;sup&gt;a&lt;/sup&gt;</td>
<td>1984</td>
<td>305.0&lt;sup&gt;b&lt;/sup&gt;</td>
<td>1.54</td>
<td>33.0&lt;sup&gt;a&lt;/sup&gt;</td>
<td>Low</td>
</tr>
</tbody>
</table>

<sup>a</sup> By proximation.

<sup>b</sup> By calculation.

Most of the spoilage is due to poor handling practices.
Insect disinfestation of grain

Cereal grains are the staple foods in Zambia, maize in particular. Table I gives the position of maize and other agricultural produce in relation to national goals and their respective market potential. This potential, together with production levels, is given in Table II for selected food items.

Insect disinfestation of maize, for example, by fumigation with methyl bromide in 1982 cost 0.55 Zambian Kwacha per 90 kg, that is excluding labour and capital costs (1 Zambian Kwacha was equivalent to 0.47 US dollars at the time of writing this paper.) Therefore, the cost of disinfesting an annual output of half a million tonnes of maize in 1982 amounted to over three million Zambian Kwacha. Hence, analysing this cost in comparison with the cost of irradiation treatment capable of achieving the same or a better end result (capital and labour costs excluded), it is reasonable to suggest that the cost of chemical treatment will be lower. In this case, the advantages of using irradiation treatment rather than fumigation for disinfestation are the absence of toxic residues on the treated grain, less time required to accomplish the treatment, and complete elimination of the insects and sterilization of their eggs. It is noteworthy, however, that if the chemicals to be used in place of irradiation caused health hazards to the consumer, then the economic advantage of the chemicals should not be a sufficient reason to use them. Therefore, the economic equality or superiority of irradiation is invalid. It should also be remembered that in some cases the cost of irradiation treatment can be lowered by increasing the volume of throughput.

Fruit preservation and extension of shelf-life

The relationship of fruit to national goals and the market potential are indicated in Table I, and their importance is largely associated with nutritional benefits.

According to current agricultural production programmes, fruit production in Zambia is anticipated to more than double the present production level in the coming decade. It is clear, therefore, that besides increasing the production output, much effort should be made to search for methods capable of preserving as much as possible of the fruit after harvesting. This effort will undoubtedly lead to the opening up of several markets and distribution of fruit to areas where demand exists. Attention must also be paid to the enhancement of fruit quality in order to compete economically, especially on the export market, with similar or other food products from the same source or elsewhere. The export potential for selected local fruits is given in Table II.

One of the serious problems facing the fruit industry in Zambia is the distribution of fresh fruit because of distances which have to be covered to reach the markets. Generally, fruits have poor keeping quality under local
Referring to Table II, great losses, for instance, are encountered in mangoes due to lack of adequate preservation. To this list (Table II) we can add fruits such as oranges, lemons, guavas and papayas which, like mangoes, suffer from high losses, usually in the range of 60—70%.

It is a common feature in Zambia that a lot of the fruits are eaten fresh at production localities and only a small fraction reaches the market and/or is processed into jam, puree and fruit juices. Any process which can improve the keeping quality of fresh fruits to enable uniform distribution and the opening up of new markets, therefore, merits great attention. Although irradiation may not solve all the problems associated with fresh fruit preservation, it can play a very important role. For example, irradiation can delay ripening of fruits (bananas). It can be applied to control mould growth on many fruits. In certain cases much better results are achieved by irradiation in combination with other methods.

It is worth noting here that the use of chemical disinfectants is prohibited in many countries because of their residual toxicity and potential carcinogenicity. The International Programme on Chemical Safety, the United Nations Environmental Programme and other national and international programmes, for instance, have expressed great concern at the indiscriminate use of hazardous chemical substances in human and non-human environment. Since Zambia has embarked on a programme to increase fruit production by the coming decade, it should, therefore, be expected that the use of disinfectants as a means of fruit preservation may double or even treble, thus posing a great health hazard to the country’s population. On the other hand, application of other preservation processes such as refrigeration at sub-zero temperatures can be comparatively more expensive than irradiation because of enormous energy requirements. The energy requirements for frozen poultry can serve as an example for refrigeration at sub-zero temperatures.

Inhibition of microbial growth and sprouting in tubers

Tubers in Zambia have been traditional sources of food for centuries. However, in the course of industrial development in the country tubers are increasingly gaining popularity as raw materials for the manufacture of industrial products such as starch (from cassava, sweet potatoes, etc.) and formulations of new foodstuffs. Despite this industrial potential, their keeping quality poses problems associated with fungal diseases and sprouting. Many of these problems can be solved by irradiation. The efficacy of irradiation to prevent microbial growth and sprouting has been demonstrated by various research workers and still further improvements are taking place to make the process of irradiation of greater economic value and nutritional significance.

The examples cited above clearly demonstrate evidence of the potential economic benefits food irradiation processing can bring to Zambia.
CONCLUSION

There is ample evidence and opportunity for Zambia to make full use of the new technology in the fight against the plagues of hunger, malnutrition and disease. At this stage in Zambia we lack sufficient experience to determine all beneficial factors. However, only by experimenting, testing both in the laboratory and market place, by being alert to opportunities for doing something which could not be accomplished or by seeing an opportunity to solve old problems, can we derive meaningful economic benefits from this new and versatile process.

ACKNOWLEDGEMENTS

Grateful acknowledgement is given to the IAEA for technical assistance to the Food Irradiation Programme in Zambia. The authors are indebted to the NCSR for technical guidance and the sanctioning of the programme.

BIBLIOGRAPHY


COMMERCIAL EXPERIENCE IN INTRODUCING RADURIZED FOODS TO THE SOUTH AFRICAN MARKET

H.J. VAN DER LINDE, H.T. BRODRICK
Chemistry Department,
Nuclear Development Corporation of South Africa (Pty) Ltd,
Pretoria, South Africa

Abstract

COMMERCIAL EXPERIENCE IN INTRODUCING RADURIZED FOODS TO THE SOUTH AFRICAN MARKET.

In the wake of the test marketing campaign with radurized products in 1978, the stage has now been reached where food radurization has become a fully commercial undertaking in South Africa, with three facilities involved in the processing of a wide variety of foodstuffs. During the past three years several thousand tonnes of products have been radurized and sold on the South African market. During this period the complexity of the food chain, from producer to consumer, was repeatedly encountered and it was realized that the transfer of a new technology is both a complex and a difficult task and that the application of radurization in this chain has to be precisely determined in order to achieve maximum benefit from this new process. In general, it was found that the technology transfer with processed products presented far fewer problems than in the case of fresh produce, but in both cases it was found that the transfer was not a single-step exercise from R & D to the actual retailing stage but should embrace a fully integrated interaction between the scientist or food technologist and all the other participants in the food chain. The involvement of the R & D scientist(s) should be a continuous and ongoing exercise which never should or can be terminated at the transfer stage, as involvement is necessary for the transfer of the technology. If it is terminated, a vacuum ensues which could lead to the collapse of the transfer process itself. It is essential that a well-planned strategy be developed and executed in order to overcome the numerous problems encountered during technology transfer. The involvement and responsibility of the various partners in the transfer of technology require the implementation of a comprehensive strategy. The strategy and various factors influencing the transfer of technology to private industry in South Africa are discussed in greater detail.

INTRODUCTION

Since the initial introduction of irradiated foods to the South African market in 1978, radurisation has progressed to become a fully commercial process today in our country. Three gamma irradiation facilities are at present involved in irradiating
a wide variety of both fresh and processed food products. Even though not all the problems relating to universal acceptance by consumers and food handlers have been solved totally as yet, radurisation is starting to become an established food processing technique next to the existing traditional ones. The prospects for further growth and expansion look very promising but are presently hampered by the severe economic recession and the current strength of the dollar against major world currencies.

In spite of the successes achieved up to now our efforts in commercialising radurisation have not been without some failures and disappointments. During the past seven years we have learnt the hard way that the introduction of a new technology is no easy and straightforward exercise but a very complicated affair with many unknown and unexpected parameters affecting its successful implementation. Before discussing these factors in greater detail it is necessary to have a brief look at the strategy developed in our country to introduce radurisation on a commercial scale and to summarise the most important milestones reached up to the present.

**Strategy for commercialising food irradiation**

In order to attain our ultimate goal of establishing radurisation as a commercial process, we recognised at a very early stage that it was necessary to formulate and execute a well-planned strategy involving all partners in the food production and distribution chain, from farmers and producers, to food handlers, retailers, consumers and government departments involved in controlling and regulating food production and distribution country-wide. The strategy would consist of various phases which should be carried out consecutively.

- Research and Development Programme
- Meeting of Regulatory Requirements
- Information and Test Marketing Campaign
- Transfer of Technology to Food Industry
During the past decade we have progressed through all the various phases and the most important lesson learnt was that the various stages cannot be separated chronologically in the sense that one phase can or should be completed before the next one starts. They all form an integral whole of, and play an equal role in, the technology development exercise and are therefore all ongoing processes which should be carried out simultaneously.

Initial marketing trials

In order to monitor consumer reaction towards irradiated foods and also to test radurised food under commercial conditions, a limited marketing campaign was launched in 1978. The results of the marketing trials are well documented by now [1,2,3], and it will suffice to summarise them briefly.

During the period August 1978 to May 1979, 133 t of potatoes, 20 t mangoes, 20 t papayas and 7 t strawberries were processed in two open-pool irradiators, one at Pelindaba and one in the North-eastern Transvaal at Tzaneen, and also in the experimental loop of the package irradiation plant at Pelindaba. The radurised products were sold through 20 supermarket stores in Johannesburg and Pretoria for a nine-month period. All products were marked with the RADURA emblem and information was given and questions answered at the point of sale for the first few weeks. The names and addresses, or telephone numbers, of consumers who bought the products were recorded and they were contacted telephonically afterwards to document their findings and opinions. A ninety percent acceptance figure was recorded.

This marketing campaign was followed by a National Symposium with the purpose of informing the food industry, consumer organisations, representatives from agricultural control boards and other interested parties about the outcome of the marketing trials. The symposium was held to discuss further prospects with special reference to the wide range of applications of irradiation in the agricultural sector in general, and the food industry in particular. The symposium was
well attended by approximately 160 delegates from various organisations involved in food research, inspection and quality control, processing and marketing, many of whom participated actively in the proceedings.

The marketing campaign, although very successful, also revealed the many problems facing a new technology and a strong need developed for the protection of the process, the processors and also the retailers. Consequently, a National Steering Committee was constituted. This committee with representatives from various government departments, the trade, the radiation processors and other interested organisations, acts in an advisory capacity to the Minister of Agriculture. Ideally, the committee should co-ordinate all aspects relating to the marketing of radurised food and form the link between the research and development activities and the food industry.

Expansion of marketing trials

The successful outcome of these trials led to the formation of a private company which commissioned a batch irradiator in February 1982 for the radurisation of fresh produce. With the commissioning of this irradiator, three fullscale facilities in South Africa became involved in the radurisation on foodstuffs [3]. These are:

(i) The Pelindaba irradiator: AECL JS 6500

This irradiator is fully automated and was recently upgraded, both by increasing the source strength to 320 kCi and by increasing the conveyor speed by a factor of four. This plant can at the time of writing, process 7t of product per hour at a dose of 2 kGy and a density of 0.4 g/cm$^3$. Several different food products such as various meats, spices, potatoes, onions and asparagus, have been treated during the past four years. However, most of the emphasis up to now has been on the radurisation of strawberries. More than 1000 t of this product have already been radurised. Recently, several new products
were added and NUCOR now irradiates 50 t/week of items such as herbal tea, sugar cane yeast, mango achar and vegetable pastes.

(ii) The HEPRO irradiator: AECL JS 8200

This is a batch irradiator with a present cobalt-60 loading of 100 kCi and capable of treating 1.7 t of product per hour at a dose of 1 kGy and a density of 0.4 g/cm. During the past three years, products such as mangoes, papayas, bananas, mango achar, avocados, litchis and tomatoes have been radurised on a commercial scale.

(iii) The ISO-STER irradiator: AECL JS 8900

This facility is primarily used for the sterilisation of disposable medical products but lately has also been involved in the radurisation of a large variety of processed products such as dehydrated vegetables, spices and large quantities of herbal tea (more than 500 t during the past 2 months).

With these three facilities several thousand tonnes of products have been radurised in South Africa during the past five years and we are confident that this technology is in the process of becoming accepted by the food industry and the consumers. However, it was also realised that the transfer of a new technology is both a complex and a difficult task with many factors influencing its eventual acceptance, as stated previously at several international meetings [4, 5, 6].

Factors influencing the technology transfer process - the role of the various participants in the food chain

The most important lesson learnt during the past few years was that the transfer process was not a single-step exercise from R & D to Industry but rather an ongoing process requiring the full participation of all the various participants. The interrelationship between the various participants and the control position of the R & D activity as set out in Fig. 1 are the crucial factors
determining the successful transfer of the technology.

Let us now look in greater detail at the activities and responsibilities of the various partners.

R & D Scientist /Food Technologist

(i) Product development

The goal of the scientist is to identify commodities which can benefit from the application of a new technology and offer economic benefit to the country. The product development programme should involve a progression from laboratory-scale experiments to large-scale trials involving simulated and non-commercial tests carried out under market conditions. This should
be followed by semi-commercial trials and large-scale test marketing prior to full commercialisation.

(ii) **Compilation of data for clearances**

Although many governments accept the recommendations of the 1980 JECFI of WHO/FAO/IAEA on wholesomeness of radurised foods, national health authorities in general require petitions for individual commodities before these products can be traded commercially. This is where the R & D scientist has an essential function in the compilation of data for clearances.

(iii) **Transfer of information**

One of the major problems facing the transfer of the new technology is the fact that the scientist has for too long been isolated from industry. It is imperative that he should play an active role in "selling" his findings to industry. In order to achieve this he must be prepared to carry this information into the grey area of marketing and co-operate with experts in this field in order to bring it to the attention of the producer/farmer, radiation processor, wholesaler, retailer and consumer. This involves the transfer of information to the various participants through scientific and technical articles, close co-operation with the food research institutes, the food industry and consumer organisations and the organising of national and international symposia and conferences. The successful commercialisation of the technology greatly depends on the support that the research scientist receives from his management.

The central role that the R & D scientist plays in the technology transfer process in relation to the various participants can be summarised as follows.

**Farmer and Producer**

The support and enthusiasm of the primary producer of food is dependent on his degree of familiarity with the new technology. The execution of joint projects is of great importance to achieve this
and to convince him of the potential benefits. He must be convinced that the success of radurisation is dependent on a sound GMP\(^1\) programme involving quality control such as orchard and factory sanitation, packaging, handling and transport. It is therefore necessary that close collaboration between the scientist and the producer exists at all stages of the development programme and that contact exists at all times.

**Radiation Processor**

One of the major stumbling blocks in establishing food irradiation on a commercial scale is the availability of large irradiation plants, and a "chicken and egg" situation exists. These plants are highly capital intensive and will only function economically with large throughputs. These large processing quantities can only materialise once the food industry is convinced of the benefits and this can only be experienced when it is being done on a large enough scale to be commercially attractive. Specifically pertinent in this regard is the question of converting the scientific benefits into financial profits. It is therefore necessary to go through a pilot-plant stage where the research scientist should collaborate with potential users of the technology in feasibility and pilot-plant studies and in the evaluation and, if necessary, modification and design of new facilities. We experienced that with the success achieved during the test marketing trials and the subsequent expansion of our trials, many potential radiation processors appeared on the scene. In most cases they had very little or no experience of radiation processing or the food industry. Even experts in the field of medical sterilisation require much more background knowledge of foods, especially fresh produce, because the latter differs markedly in diversity and complexity from plastic materials, used for medical disposables, as far as their radiation behaviour is concerned. The scientist has therefore an extremely important role to play in transferring his knowledge and expertise to potential radiation processors. An important responsibility in this regard is quality

\(^1\) GMP = Good manufacturing practice.
control through a Code of Practice compiled for specific commodities. It was invariably found that all problems relating to the end product, e.g. poor quality, damage due to transport or handling, etc were ascribed to the process and not to the product. This point is very critical and could easily lead to the collapse of an exciting and viable technology.

**Wholesaler**

In order to overcome the prejudices of the agents handling produce on the market who are often reluctant to accept something new, it was necessary to familiarise them with radurised products over an extended period. This involved the erection of display cabinets demonstrating the benefits of the treated product over the untreated control under identical commercial conditions, i.e. in the marketplace. The assessment of trials under actual market conditions cannot be emphasised enough as laboratory experiments are often carried out under near ideal conditions and do not reflect the performance of the commodity under commercial conditions. During our marketing trials it was observed that certain radurised products do not behave in the same way as their untreated counterparts e.g. irradiated bananas are more susceptible to cold injury and radurised papayas should not be subjected to the forced ripening process using high temperatures as this leads to a break-down in quality. It is advisable that guidelines be drawn up and that the food handlers be familiarised with the recommended procedures on the correct handling, storage and transport of radurised products.

**Retailer**

Unless the full co-operation of retailers is obtained, irradiated foods cannot be successfully sold to the consumer. Familiarisation with the technology is therefore a prerequisite before embarking on test marketing. The R & D scientist has also in this case, a very important role to play in convincing the retailer of the possible advantages of the process. This can be achieved by repeated discussions and especially by
co-operative trials carried out simultaneously by the research organisation involved and the retail store which has the necessary infrastructure.

Initially, it was found that many retailers were reluctant to sell irradiated food because of fear of their competitors. To overcome this it was decided that a National Steering Committee under the auspices of the Minister of Agriculture should be formed whose main task would be to handle all problems relating to the retailing of irradiated foods. In spite of this, however, some retailers still did not want to commit themselves during the first few years, but as the acceptance grew, more and more have been getting involved. In this context the efforts of the scientist developing the technology are indispensable on a continuous basis to supply information and technology country-wide. Because of lack of knowledge of the technology by the retailer it is also necessary that the scientist draws up guidelines on the RADURA products with respect to handling, storage, display, price structuring and labelling. It is inherent in the establishment of a new technology that unexpected problems can be experienced and a "fire brigade" activity becomes necessary to counteract them, e.g. quality problems ascribed by retailers or consumers to the radurisation process and not the product itself. Therefore regular inspections and monitoring of the performance of RADURA products throughout the season with proper controls are of the utmost importance.

Consumer
The most important link in the food distribution chain is the consumer. Unless consumers are convinced of the benefits of the new process they will be unwilling to purchase the treated food. It is thus necessary that the consumer be properly informed about the reason for irradiating food and the benefits that can accrue through this process. The R & D scientist is therefore responsible for planning and executing a comprehensive and extended information campaign dealing with these matters. Such a campaign should not be a one-time effort to coincide with the introductory phase but a continuous activity involving schools, universities, consumer organisations and the food
industry through popular articles in the press, scientific magazines, programmes on radio and television and the publication of information brochures and booklets.

Due to the anti-nuclear feeling prevailing, in some countries, and the confusion of the terms radiation and radio-activity, the question of acceptance of irradiated foods and the associated question of labelling have been the major issues regarding the acceptance of irradiated foods during the past three decades. Although this question has been posed at many international meetings no unanimous agreement has been reached or final decision taken on this issue.

In South Africa the Department of Health has accepted the 1980 JECFI WH0/FAO/IAEA recommendation on wholesomeness and accepted irradiation as a process, therefore no labelling is required for radurised products other than that needed for other preservation techniques. Products are to be labelled with the RADURA emblem at the wholesale level and it is up to the retailer to advertise openly whether his product is radurised or not. As probably could be expected no retailer initially committed himself to this but as the process is becoming increasingly accepted, this fact is starting to become advertised.

It is interesting to mention that during the test marketing campaign, individual products were labelled in order to test consumer reaction; however, endless problems were encountered which were ascribed to the process but which were, in fact, inherent in the product itself. This has led us to the present policy of labelling only at the wholesale level.

SUMMARY

It is clear from the foregoing that the activities of the Research and Development Scientist and food Technologist form the bridges on which the interrelationships between the various partners in the food chain are built. The involvement of the R & D scientist should be a continuous and
ongoing exercise which never should or can be terminated at the transfer stage as this is necessary for the transfer of the technology. If this involvement is terminated, a vacuum ensues which could lead to the collapse of the transfer process itself.

In conclusion I would like to reiterate that the transfer of a new technology is a long and arduous task beset with pitfalls and complex problems; therefore it is hoped that the experience we have gained during the past seven years can be of some benefit to other countries embarking on the same path.

REFERENCES


PILOT-SCALE
FEASIBILITY STUDIES

(Poster Session I)
No significant difference has been found between the damaging ability of male and female larvae irradiated with low disinfestation doses of gamma radiation.

The longevity of *Ephestia cautella* larvae detected in dry date packages was significantly shorter when these packages were treated with 0.7 kGy, exposed to 40°C for 48 h, then transferred to 25°C and stored for 15 days as compared to the irradiated control which was kept at 25°C only.

Treatment with 0.35 kGy and heat also brought about some decrease in longevity. On the other hand, the damaging ability of irradiated *E. cautella* larvae was significantly lower when last instar larvae treated with 0.7 kGy gamma radiation were exposed to 40°C for 72 h.

Thus combination treatment could lead to a decrease in the feeding ability of the highly date damaging stage of *E. cautella*, and to a shorter period of time to cause 100% mortality which will comply with conventional quarantine restrictions. Other types of treatments also showed the superiority of combination treatments for date disinfestation.
SEMICONMERCIAL TRIALS ON RADIATION PRESERVATION OF POTATOES UNDER TROPICAL CONDITIONS*

I. KHAN, A. SATTAR, M. WAHID, M. JAN
Nuclear Institute for Food and Agriculture,
Tarnab, Peshawar, Pakistan

Four varieties of potatoes — Cardinal, Desiree, Multa and Patrones — were irradiated at a dose of 0.1 kGy and stored at 20°C and under ambient conditions (30–45°C). The percentage of sprouting, rotting and weight loss was determined during storage. Samples were analysed for ascorbic acid and sugars as well as evaluated for sensory characteristics such as colour, taste and texture in the form of boiled potatoes and potato chips. The effect of packaging materials and mode of transport over a distance of 1000 km on rotting of potatoes was studied. The

TABLE I. EFFECT OF IRRADIATION AND STORAGE ON THE QUALITY OF POTATOES

<table>
<thead>
<tr>
<th>Variety</th>
<th>Rotting (%)</th>
<th>Weight loss (%)</th>
<th>Sensory scoresa</th>
<th>Ascorbic acidb</th>
<th>Reducing sugarsc</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>Chips</td>
<td>Boiled</td>
<td></td>
</tr>
<tr>
<td>Cardinal</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Control</td>
<td>30.0</td>
<td>14.0</td>
<td>5.1</td>
<td>5.5</td>
<td>4.2</td>
</tr>
<tr>
<td>Radiated</td>
<td>20.0</td>
<td>9.0</td>
<td>5.9</td>
<td>5.0</td>
<td>3.9</td>
</tr>
<tr>
<td>Patrones</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Control</td>
<td>20.0</td>
<td>13.0</td>
<td>5.0</td>
<td>5.3</td>
<td>5.7</td>
</tr>
<tr>
<td>Radiated</td>
<td>17.0</td>
<td>8.0</td>
<td>6.0</td>
<td>5.2</td>
<td>4.9</td>
</tr>
<tr>
<td>Mean</td>
<td>21.7</td>
<td>11.0</td>
<td>5.5</td>
<td>5.2</td>
<td>4.6</td>
</tr>
<tr>
<td>C.V.</td>
<td>26.2</td>
<td>26.7</td>
<td>9.5</td>
<td>4.7</td>
<td>17.1</td>
</tr>
</tbody>
</table>

Note: Storage period was 6 months at 20°C.

a Maximum scores = 10.
b Initial ascorbic acid = 18.5 – 20.4 mg/100 g.
c Initial reducing sugars = 0.9 – 1.0%.
d C.V. = coefficient of variance.

* Supported by the IAEA under Research Contract No.3016/RB.
data revealed that irradiation completely suppressed sprouting regardless of storage temperature and variety. The percentage rot was significantly higher (60–85%) in potatoes kept at ambient conditions than at 20°C (3–5%) during the initial two months' storage (P = 0.05). Weight loss varied between 12 and 40% under ambient conditions and between 4 and 11% at 20°C. At the end of six months' storage at 20°C, there was higher rot (20–30%) and weight loss (13–14%) in unirradiated than in the irradiated potatoes having a rot of 17–20% and a weight loss of 8–9% depending on the variety, as shown in Table I. The effect of irradiation and storage was severe on ascorbic acid but negligible on reducing, non-reducing and total sugars. The sensory quality of potato chips was improved as a result of radiation treatment. Data on transport trials as shown in Fig. 1 indicated that there were significantly higher losses when using jute bags and transport by truck than when wooden crates and transport by train was chosen (P = 0.05). The irradiation cost, using a 100 kCi source, was estimated to be US $3.00/t of potatoes. It was concluded that irradiated tubers (0.1 kGy) could be stored with minimal losses for six months at 20°C.
The storability of apples and pears was examined. The fruits were irradiated, Ca-treated and subjected to combined treatment. The ultrastructure and Ca-mobilization in the fruit were studied and the texture and other parameters of the fruits were determined.

It was established that there was a close relationship between surface spoilage (physiological disorders) and Ca-content of the fruit. The spoilage of the fruits increases with Ca-treatment, while it decreases with irradiation treatment. The spoilage of the fruit is further decreased by the effect of the combined treatment. The structure of the epidermal layer in combined-treated samples is similar to that of fresh controls. The cell walls have slackened in the stored control and irradiated samples and the middle lamellae have frequently been dissolved. The cell walls of samples treated with calcium showed a compact fibril structure. The cells of combined-treated samples are of a gradually looser structure from the cytoplasm to the outside. Even if the middle lamellae show signs of dissolution they are not structureless and frequently seem to be intact, even in the vicinity of intracellular lamellae.

The calcium content of the flesh diffuses towards the skin and core seeds during storage. It is likely that this process has a connection with the pectin dissolved from the middle lamellae of cell walls and the calcium released, thereby contributing to the softening of the fruit.

From the point of view of the nutritive value of fruit, the combined-treated sample proved to be the best in the majority of cases.

The positive effect of a combined treatment cannot yet be explained.
GARLIC IRRADIATION FOR SPROUT PREVENTION IN ISRAEL*

M. LAPIDOT, M. MOLCO, R. PADOVA, K. ROSENBERG, I. ROSS
Soreq Nuclear Research Center, Yavne, Israel

Israeli agriculture has an economic interest in applying gamma radiation to extend the storage life of garlic from 6–8 to 10–12 months. No data on the effect of radiation on the composition and quality of garlic were found in existing petitions, and hence a project was initiated to collect such data with a view to preparing a local petition for clearance of irradiated garlic.

Preliminary tests in 1965 and 1966 showed that doses of 7.5 to 17.5 krad effectively eliminated sprouting and reduced weight loss in garlic.\(^1\) Irradiation of two new cultivars in 1974 at doses of 2 to 10 krad eliminated internal and external sprouting, lowered weight loss, and extended shelf-life until the new crop was harvested. A four-year project centred on the two current dominant varieties — Ethiopian and Brazilian, which are harvested in March and May, respectively. Bulbs were irradiated at different intervals from harvest, at doses of 2, 10, and 50 krad, and were kept up to 11 months mostly at ambient temperature but also at 2°C. The two lower doses effectively eliminated sprouting and reduced weight loss and emaciation, increasing the proportion of saleable garlic. Composites of 10 bulbs each were analysed for dry matter, protein, crude fibre, ash and NFE\(^2\) (individual variability in fat content prevented consideration of this component). Radiation at doses up to 50 krad did not influence the composition of the non-volatile macro-components of garlic. Special organoleptic studies of garlic showed no discernible difference in taste or aroma between unirradiated garlic and irradiated garlic (50 krad). An adapted TLC technique showed no difference between the chromatograms of unirradiated garlic and irradiated garlic (50 krad). A petition for clearance of garlic, incorporating these results, was submitted to the Ministry of Health, and clearance was granted (published in March 1985). A 1 t lot was irradiated to allow consumer acceptance tests.

---

* Partially supported by the IAEA.
\(^1\) 1 rad = 1.00 \(\times\) 10\(^{-2}\) Gy.
\(^2\) NFE = Nitrogen-free extract.
FEASIBILITY OF EXTENDING SHELF-LIFE OF MATURE STRAWBERRY FRUIT BY IONIZING RADIATION

A.A. MAHMOUD, H.M. ROUSHDY, M.A. HUSSEIN, R.A. HEGAZY
National Centre for Radiation Research and Technology,
Atomic Energy Authority,
Cairo

M.B. DOMA
Faculty of Agriculture,
Mansoura University,
Cairo

Egypt

The present investigation has been undertaken to illustrate the possible application of gamma irradiation processing to prolong the shelf-life of mature strawberry fruit. Dose levels were 1, 2 and 3 kGy and the storage temperature was 4 ± 1°C.

The paper discusses the effect of gamma irradiation on moisture content, sugar content, pH values, ascorbic acid level, anthocyanin pigments, carbonyl compounds and total volatile acidity of mature strawberry fruit.

In general, irradiation at levels of 1, 2 and 3 kGy effectively prolonged the shelf-life of strawberries stored at 4 ± 1°C by 5, 13 and 16 days, respectively, over the shelf-life of the unirradiated control fruits.
OPTIMIZING IRRADIATION PROCESSING AND PACKAGING OF PAPAYAS*

J.H. MOY
Department of Food Science
and Human Nutrition,
University of Hawai at Manoa,
Honolulu, Hawai

J.G. PARKER, E. O'SULLIVAN, G. PARKER
International Nutronics, Inc.,
Palo Alto, California

United States of America

In the tropical and subtropical regions of the world, where many species of fruit flies exist, fresh fruits and vegetables must be treated for shipment to non-infested export markets. The ban of ethylene dibromide (EDB) in the United States of America on 1 September 1984 necessitated the search for alternatives to chemical fumigation by the fruit and vegetable export industries.

Irradiation processing in the form of gamma radiation is one of several alternatives. The technical efficacy of using ionizing radiation to disinfect a variety of fruits as a quarantine treatment has been studied and proven. The minimum absorbed dose to meet quarantine requirements for Hawaii grown papayas is 0.26 kGy [1], while a hot water treatment (49°C, 20 min) combined with a dose of 0.75 kGy would extend the marketable life of papayas by three to four days beyond that for fumigated fruits [2]. Recent studies on California grown stone fruits and citrus showed qualities of irradiated peaches, nectarines, plums and oranges retained at 0.50 kGy [3]. To achieve Medfly egg mortality, however, a gamma-radiation dose of 0.40—0.60 kGy was required [4].

Since transit bruising and fungal diseases have been problems affecting the marketability of papayas, experiments were conducted to determine if combining irradiation with a modified polyethylene film wrap of the papaya might offer some advantages such as: (1) protecting the fruit from transit bruising; (2) synergizing hot water and irradiation treatments for maximum shelf-life; and (3) providing a clean and attractive looking fruit. This film has the following permeability in cm$^3$/m$^2$ per 24 hours: oxygen, 9000; CO$_2$, 3000; ethylene, 2200 and moisture 1.3. Treatment variables included single hot water (49°C,

20 min) versus double hot water dip (42°C, 40 min; 49°C, 20 min), irradiation at 0.26, 0.50 and 0.75 kGy with and without the film wrap. After treatment, the fruits were refrigerated at 10°C up to 6 weeks and then moved to 22 ± 1°C to simulate supermarket display conditions.

Results showed that the film wrap did protect the papayas from bruising and gave the fruit a shiny, attractive appearance. Measured in days as post-refrigeration marketable shelf-life, the film-wrapped, irradiated and the film-wrapped, double-hot-water-treated fruits were comparable with about 6—7 days as compared to 3—4 days for those unwrapped. The flavour of the irradiated papayas was superior to that of the double-hot-water treated. The flavour in the latter probably did not develop normally due to the hot water treatment. Results from duplicate experiments indicated the optimal shelf-life and quality were obtained with irradiated fruits refrigerated at 10°C up to 3 weeks and maintained at 21—23°C for an additional 6—7 days. The film used in the experiment could not be considered completely satisfactory. Small air pockets have caused moisture retention leading to fungal decay and gas permeability of the film might not be the most optimal for papayas. While more research is needed, these results did suggest some advantages of combining suitable packaging and low-dose irradiation to retain quality with an extended marketable life for export shipment of fresh fruits.

REFERENCES

RADICIDATION OF PRE-COOKED FROZEN TROPICAL SHRIMP
A microbial ecological study

N. WONGCHINDA, Y. PRACHASITTHISAKDI, H. STEGEMAN, J. FARKAS
International Facility for Food Irradiation Technology, Wageningen

D.A.A. MOSSEL
Department of the Science of Food of Animal Origin, Faculty of Veterinary Medicine, The University of Utrecht, Utrecht
Netherlands

The impact of gamma irradiation on the psychrotrophic and mesophilic microflora of frozen pre-cooked and peeled shrimps originating from Malaysia was studied. In addition, the microflora of thawed shrimps was determined after low (12°C) and high (21°C) temperature abuse storage simulating mishandling. Deep-frozen blocks were irradiated with doses up to 4 kGy. Radiation with 4 kGy resulted in 3 log cycles reduction of the aerobic psychrotrophic and mesophilic colony counts. Enterobacteriaceae Lactobacillus spp., Lancefield D streptococci and Staphylococcus aureus were sensitive to irradiation and not detected in 1 g aliquots with doses between 2 and 4 kGy. In the initial psychrotrophic flora of the frozen shrimps Micrococcus spp. were predominant and in the mesophilic flora Staphylococcus spp., followed by Streptococcus spp. and the coryneform group. In the frozen shrimps irradiated with 2 or 4 kGy, psychrotrophic Micrococcus spp. and mesophilic Micrococcus spp. and Staphylococcus spp. were the most prevalent organisms.

After thawing and storage for 84 hours at 12°C the spoilage flora of the non-irradiated shrimps consisted of psychrotrophic and mesophilic Moraxella spp. and the coryneform group, followed by no coagulase-positive mesophilic Staphylococcus spp.

Moraxella spp. became the predominant organisms in the irradiated shrimps.

The main spoilage flora of non-irradiated shrimps which developed in 36 hours at 21°C was more heterogeneous than the flora at 12°C and consisted mainly of psychrotrophic and mesophilic Moraxella spp., the coryneform group, Lactobacillus spp., mesophilic Micrococcus spp., and psychrotrophic Acinetobacter spp.
Moraxella spp. followed by Acinetobacter spp. were predominant in the irradiated samples held at 21°C.

No growth of Staphylococcus aureus could be detected in the two kinds of shrimps held at 12 and 21°C.

These results support the view that irradiation does not present a hazard resulting from a shift in the microflora in the event that frozen shrimps are thawed and stored in temperature abuse situations. Irradiation can be recommended to improve the safety and quality of frozen products.

IAEA-SM-271/88P

PRESERVATION OF SAUSAGE BY $^{60}$Co GAMMA IRRADIATION

Renli YANG, Shupei LIU, Qixun CHON,
Yongzhi WANG, Huachuan DENG
Institute of Applied Nuclear Technology of Sichuan Province Sha He Bao,
Chengdu, Sichuan, China

Sausage freshly produced from the workshop was packaged in vacuumized plastic bags and irradiated with $\gamma$-rays at doses of 5–8 kGy from a $^{60}$Co-source at ambient temperature.

Since the bacteria were killed by irradiation, and oxidization and recontamination were prevented by vacuumized plastic bags, the irradiated sausage may be preserved for as long as six months at ambient temperature. There was no loss of water and nutrients, no oxidization, no change of taste or decay during storage. The colour of the lean meat was redder than the control and its red and white colours were clear and fine. The physical and chemical hygienic parameters, such as water, salt, peroxide value, acid value, bacteria count and saprophytic germs, were in agreement with the 'Food Hygienic Standards of China GBN16-77'. Moreover, by reducing the amount of nitrite used the health hazard is probably reduced. The transport, preservation, carry-over and sales of irradiated sausage were improved, which is of great advantage.

The economic effects of 'irradiated sausage' are as follows:

1. Sausage can be produced in any season instead of only in winter, therefore the utilization of the equipment was doubled.
2. It can be transported by carriage or truck instead of by air or cooler, thus the cost of transport was considerably reduced.
(3) The cost of cool storage, about 45 yuan per tonne per month, is saved.
(4) The good quality brought about an increase in price in the country and abroad.
    A profit of 1.4 yuan may be gained on every kilogram in the province of
    Sichuan, 2.2 yuan in other provinces and 4—5 yuan in certain regions of
    our country.
(5) The waste from decay and losses through heavily reduced prices were
    obviously decreased.
(6) 'Irradiated sausage' promotes the production and supplies the market demand,
    thereby advancing the development of the processing, packaging and
    manufacturing of sausage in China.

MULTIPURPOSE PICOWAVE PROCESSING PLANT (M 4 p)

J.N. GOEBEL
NUKEM GmbH,
Hanau, Federal Republic of Germany

The new design of the Multipurpose Picoware Processing Plant offers
excellent flexibility at low cost for all kinds of industrial picowave processing
using $^{60}$Co or $^{137}$Cs as energy sources. The advantages are the following:

Original packaging. The goods will be treated in their original packaging,
stacked on pallets. No extra packing work is necessary.

Dose homogeneity. Owing to intelligently positioned attenuators a
reproducible dose homogeneity will be applied. An overdose factor of 1.3 is
achievable for goods with a density of 0.5 g/cm$^3$. For medical products the
overdose factor is $<1.1$.

Savings. There are 70% less area and 20% less $^{60}$Co requirements and about
50% lower costs for handling and maintenance of the M 4 p compared with a
traditional flat source plant.

Flexibility. Goods with four to eight different densities and subjected to
different doses can be processed simultaneously, depending on the size of the plant.
EFFECT OF OXYGEN-FREE PACKING
AND IRRADIATION ON THE KEEPING QUALITY
OF DRIED ANCHOVIES (Engraulis anchoita)

M. MAHA, D. MUSTAFA
Centre for the Application of
Isotopes and Radiation,
National Atomic Energy Agency,
Jakarta Selatan, Indonesia

In the study, the effect of oxygen-free packing and irradiation on the keeping quality of dried anchovies packed in PVDC laminate and polypropylene pouches was investigated. The oxygen-free condition was obtained by incorporating an oxygen absorber called ‘ageless’ in the pouches. The irradiation dose used ranged from 0 up to 4 kGy. Storage life of the samples at ambient conditions was determined using subjective evaluation supported by chemical parameters such as TBA, FFA and TVBN numbers, and browning intensity, as well as microbiological tests. In packages without ‘ageless’, the fish turned yellowish to light brown within seven days, and became darker with the increase of storage time. Oxygen-free packing in PVDC film laminate was found to be effective to prevent oxidative browning and rancidity in stored dried anchovies. Samples packed in such a way and irradiated at 2 to 4 kGy were still in good quality even after six months’ storage, while the unirradiated ones released putrid odour after three months’ storage. The use of ‘ageless’ in PP film packages is less effective to protect the quality of dried anchovies, as PP film is still permeable to oxygen.
INTRODUCTION

Bangladesh produces annually about 0.2 million tonnes of pulses, 0.12 million tonnes of mustard and 0.022 million tonnes of oil and large quantities of tobacco leaves. The average storage losses caused by insects are found to vary from 6—15%, despite the traditional methods of pest control. The insects identified as causing considerable damage to the above-mentioned agricultural products include: *Callosobruchus chinensis* (L.), *Callosobruchus analis* (Fab.), *Sitotroga cerealella* (Ol.), *Oryzaephilus surinamensis* (L.), *Lasioderma sericorne* (F.).

SUBJECTS OF STUDY

(i) Survey of economic losses caused by insect pests in pulses, oil seeds and tobacco leaves in various areas of Bangladesh.

(ii) Determination of lethal and sterilizing doses of major insect pests of pulses, oil seeds and tobacco leaves.

(iii) Selection of suitable packaging materials to prevent reinfestation of treated products and the irradiation of jute/gunny bags before repeated use to avoid insect contamination.

(iv) Comparative study of the economic feasibility and efficiency of radiation for the disinfestation of pulses, oil seeds and tobacco leaves as against traditional methods of pests control.

RESULTS AND CONCLUSIONS

The extent of insect infestation was found to be variable in agricultural commodities and losses increased with storage time. The maximum infestation was recorded in grams (50—55%) and the minimum in oil seeds (6—10%).
The dose range for the control of different developmental stages, e.g. egg, larva, pupa and adult of the above-mentioned insects, was found to vary from 0.04 to 0.1 kGy, 0.1 to 0.35 kGy, 0.2 to 0.4 kGy and 0.2 to 0.5 kGy, respectively. PVC and high density polyethylene were found to be resistant to insect penetration, compared with gunny bags, gunny bags lined with polyethylene, polypropylene, polypropylene lined with craft paper, etc.

Irradiated products did not show further infestation compared with insecticidal treatments when these were kept in insect-resistant packages. Irradiation (1 kGy) confirmed 100% kill of the above insect pests.

The authors gratefully acknowledge the assistance and financial support of the IAEA and BAEC in carrying out the research work.

Broad bean (Vicia fabae) is the most important legume among pulses for human and livestock consumption. The crop is known to be attacked by Bruchus rufimanus Bot. and Bruchidius incarnatus Schm., rendering the seeds unsuitable for planting or for human consumption. An average of 12.5% natural infestation with both insect species, B. rufimanus and B. incarnatus, was found initially in broad bean seeds.

The three doses tested (400, 600, and 800 Gy) were sufficient to kill the larvae and pupae of both B. incarnatus and B. rufimanus inside broad bean seeds directly after irradiation. The same effect was found in the adult stages of B. incarnatus inside the seeds before emergence.

With regard to adult B. rufimanus present inside the seeds, only dead non-emerging adults were found in all four different treatments with 0, 400, 600, and 800 Gy during nine successive observations, before and after irradiation. This is justified by the fact that the adults of B. rufimanus lay eggs only on the flowers of broad bean plants in the field and do not infest broad bean seeds during storage periods. Subsequently, immature stages that develop to adults
during storage die inside the broad bean seeds and fail to emerge from the seeds. This is emphasized by the absence of alive or dead adults inside the sacks.

With regard to *B. incarnatus*, 800 Gy was effective against adults present in the sacks after 20 days, while 400 and 600 Gy were effective after one month from irradiation. Adults of *B. rufimanus* were not tested because none emerged from the seeds inside the sacks during the storage period.

**DISINFESTATION OF WHEAT GERM AND BRAN BY IRRADIATION AND MARKETING**

E. KOVÁCS*, I. KISS*, M. HORVÁTH-MOSONYI**, Cs. FARKAS***, Ny. HORVÁTH****, Gy. JÁKSÓ****,
* Central Food Research Institute, Budapest
** Department of Dietetics, Faculty of Advanced Paramedical Training at the Institute for Postgraduate Medical Education, Budapest
*** Canning Research Institute, Budapest
**** Cereal Industry, Budapest
Hungary

Wheat germ and bran are very important foods in Hungary, the former because of its high vitamin content, and the latter for its high dietary fibre content.

At present wheat products cannot be stored for more than 30 days since *Tribolium confusum* infestation progresses very quickly.

Our aim was to irradiate these products to inhibit both infestation and propagation.

1. The artificially infested samples (imagos) were irradiated with 0, 0.2, 0.4 and 0.8 kGy, and stored at different temperatures (5°C, 20°C, 18—28°C). L50, L90, L99 values were determined. Low temperature (5°C) retarded the vital functions of insects, and by combining irradiation with cooling insects were destroyed after approximately 20 days. Larvae are more sensitive than imagos.
(2) The tocopherol content of wheat germ was reduced to 50% of the initial value during a storage period of 1 year (in absolute values between 14.0 and 18.7 mg%).

(3) An analysis of the free fatty acids in the samples showed that the main component of these acids was linolic acid (more than 50%). It was found that there was no difference between the control and irradiated samples (at 5°C). In the fresh control the ratio of the saturated to unsaturated fatty acids was 17.6:80.8. The fraction of the saturated fatty acids increased by about 2—3% in the irradiated samples, which were stored at 1—28°C. This difference was not significant.

(4) Dietary fibre is a very important component of wheat bran. Its formation was determined after 6 months' storage. No significant difference could be detected in the dietary fibre content and the amount of dietary fibre components of irradiated (0.4 kGy) samples compared with fresh samples.

(5) The irradiation dose was 0.4 kGy from a $^{60}$Co source. The maximum absorbed dose within a lot must not exceed 0.8 kGy. Both the individual and collective packages must indicate that the contents have been irradiated. No. of permission: 40.409/1984 and 40.056/1984. Ministry for Agriculture and Food, Department for Animal Hygiene and Food Hygiene (2000 kg wheat germ and 2000 kg wheat bran).

(6) As packaging material paper, impregnated paper, foils of paper character, single and combined foils on PP base (K-23, L-1 and L-2) were used. From the foils tested only foil L-2 showed a destructive effect on insects because of its selective gas permeability.
DISINFESTATION OF COPRA, DESICCATED COCONUT AND COFFEE BEANS
BY GAMMA RADIATION

E.C. MANOTO, L.R. BLANCO, A.B. MENDOZA,
S.S. RESILVA
Philippine Atomic Energy Commission,
Atomic Research Centre,
Diliman, Quezon City, Philippines

Several pests were observed attacking copra in storage, the most prevalent of which is the copra beetle (CB), Nocrobia rufipen DeGeer. While in coffee, the coffee bean weevil (CBW), Araecerus fasciculatus DeGeer showed preference for arabica, liberica and excelsa varieties but none for robusta coffee.

For mass rearing, the most efficient diet for CB was a combination of desiccated coconut and yeast (2:1) and for CBW, dried cassava chips and yeast (3:1). Using the above diet, the life cycles were completed in 43 to 60 days and 42 to 56 days in CB and CBW, respectively.

Irradiation studies for the two species showed the eggs to be the most sensitive, followed by the larvae and the pupae. A dose of 0.05 kGy prevented adult emergence from irradiated eggs and younger larvae, while doses of 0.10 to 0.25 kGy were effective in eliminating adult survival from irradiated older larvae and pupae. Organoleptic tests showed no changes in aroma, flavour and general acceptability between treated and untreated coffee bean samples.

A dose of 1.0 kGy caused 40% reduction in the initial count of Salmonella enteritidis, while a dose of 6.0 kGy was sufficient to eliminate any surviving bacteria. Thus, for disinfestation of copra and coffee beans, a dose of 0.25 kGy would be required to prevent initial infestation of CB and CBW in the respective products, and 6.0 kGy for a zero bacterial count in desiccated coconut.
DISINFESTATION OF MEDFLY IN ORANGES
BY COMBINING GAMMA RADIATION
AND COLD TREATMENTS

J.H. MOY
Department of Food Science
and Human Nutrition,
University of Hawai'i at Manoa,
Honolulu, Hawaii

A.T. OHTA, K.Y. KANESHIRO
Department of Entomology,
University of Hawai'i at Manoa,
Honolulu, Hawaii

N.Y. NAGAI
Honolulu Poi Co. Ltd,
Honolulu, Hawaii

United States of America

Low dose gamma radiation followed by cold treatment was tested for its effectiveness in disinfesting the Mediterranean fruit fly (*Ceratitis capitata*) in oranges (var. Navel) and for retention of fruit quality (var. Valencia). After treatment at 0.30–0.6 kGy, the infested oranges were stored at 6°C for egg hatchability and larval survival studies. For quality study, non-infested oranges were irradiated at 0.30–1.0 kGy and then stored at 7°C for seven weeks (Storage I) or 7°C for four weeks, then at 21°C for two weeks (Storage II). These time-temperature schedules simulated post-harvest storage, surface shipment, and supermarket display conditions.

Results show that fruits irradiated at 0.30 kGy or higher and stored at 6°C for 14–21 days had very low or no hatching of mature medfly eggs. Neither was there any adult eclosion when mature larvae in infested fruits were irradiated at the same dose. The same suppression of egg hatchability or adult eclosion was obtained in 7 days when infested fruits were irradiated at 0.50–0.60 kGy and stored at 6°C.

The quality of oranges irradiated up to 0.75 kGy was retained for at least seven weeks when kept at 7°C. Storage II conditions (7°C, 4 weeks, 21°C, 2 weeks) retained the quality of fruits irradiated up to 0.50 kGy.

These results demonstrate that radiation disinfestation of oranges at 0.26 kGy for probit 9 security is technically achievable while preserving their market quality.
IRRADIATION DISINFESTATION OF APPLES

C.J. RIGNEY
NSW Department of Agriculture,
Gosford Horticultural
Postharvest Laboratory,
Gosford, NSW, Australia

B. SUDATIS
Office of Atomic Energy for Peace,
Bangkok, Thailand

M. IZARD
Australian Atomic Energy Commission,
Lucas Heights, NSW, Australia

Old larvae of Queensland fruit fly (*Dacus tryoni*) are the most tolerant stage of this insect in apple fruit to irradiation. Treating infested fruit in air at a dose of 50 Gy resulted in 100% mortality of Queensland fruit fly eggs and young larvae, but only 98.736% mortality of old larvae; the standard of survival was the emergence of an adult insect. On treating more than 250,000 old larvae in apples with 75 Gy, 100% mortality was achieved. These results are virtually identical with those of earlier studies with this insect in oranges and avocados, two markedly different fruit types, suggesting that a general commodity treatment of fruit with 75 Gy is suitable to provide quarantine security against this insect pest.

Irradiation of Jonathan, green Granny Smith and tree-ripened Granny Smith apples with doses from 0 to 600 Gy led to no dose related change in the respiratory pattern of the fruit. The production of ethylene by the Jonathan and tree-ripened Granny Smith apples was suppressed by the irradiation treatment, while that by the preclimateric green Granny Smith fruit was increased, albeit slightly. Softening of the fruit was not effected by treatment with 600 Gy, at which dose disinfestation should be achieved against Queensland fruit fly, Mediterranean fruit fly (*Ceratitis capitata*) and codling moth (*Cydia pomponella*).
Radiation disinestation of tobacco was carried out on 36 export-size tobacco bales (each about 100 × 75 × 40 cm in size and 100 kg in weight). Each bale was infested with 25 larvae, 25 pupae and 50 adults of *Lasioderma serricorne*. One week after infestation the bales were divided into three groups: the first group were untreated controls, the second group was irradiated at a dose range of 0.30 to 0.60 kGy and the third group was fumigated with 3 g phosphine/m³. Insect density and leaf moisture content were controlled two months during a six-month storage period. Supporting experiments were performed separately to study the dose distribution, packaging material, and the effects of gamma radiation on chemical characteristics of tobacco leaf. Radiation disinestation of coffee beans was carried out on 24 bags (2 kg each) of Arabica coffee beans. Each bag was infested with 100 adults of 3 to 8 day old *Araecerus fasciculatus*. One month after infestation the bags were divided into six groups (four bags each). Five groups were irradiated with doses of 0, 0.05, 0.10, 0.20 and 0.40 kGy, while the sixth group was fumigated with about 3 g phosphine/m³. Insect population and weight loss of the beans were controlled every 2 weeks during a 24-week storage period.

There were still about 13% insects surviving in irradiated bales up to two months of storage. As long as the Trade Regulations demand that no live insects (even sterile) should be found in tobacco bales, a dose higher than 0.60 kGy will be required in order to kill all the insects within a week. It seems that carton boxes can be used as additions to the traditional packaging in an attempt to prevent the reinfestation and to maintain the aroma of tobacco after irradiation. Gamma radiation at a dose of 5 kGy does not change the nicotine, volatile-oil and moisture contents, the volatile-oil characteristics and the pH value of tobacco leaves. A dose of 0.40 kGy apparently would be effective to disinfest small-size samples of coffee beans. However, to kill all the insects in a commercial-size bag within a short time (less than a week), a higher dose will be required.
DISTRIBUTION OF MICROORGANISMS IN SPICES
AND THEIR DECONTAMINATION BY
GAMMA IRRADIATION

H. ITO, H. WATANABE, S. BAGIAWATI,
L.J. MUHAMAD, N. TAMURA
Takasaki Radiation Chemistry
Research Establishment,
Japan Atomic Energy Research Institute,
Takasaki, Japan

Heavy contamination by microorganisms in imported spices causes serious problems for the food industry in Japan, the high summer humidity being especially responsible for mould or bacterial growth.

A survey of 26 kinds of imported spices revealed that 50% of the spices exceeded $10^4$ spore-forming bacteria per gram. The most highly contaminated spices were black pepper, white pepper, turmeric and basil with $2 \times 10^6$ to $4 \times 10^7$ per gram. Coliforms were also counted in eight spices as $2 \times 10^2$ to $2 \times 10^6$ per gram. The main aerobic spore formers were identified as *Bacillus pumilus*, *B. subtilis* and *B. megaterium*. Moulds were counted in 18 spices from $1 \times 10^2$ to $2 \times 10^4$ per gram, and consisted mainly of *Aspergillus glaucus* group, *A. restrictus* group, *A. flavus* group, *A. fumigatus*, *A. niger* and *Penicillium*.

From a study of the inactivation of microorganisms in 17 kinds of spices, doses of 5 to 15 kGy of gamma irradiation were required to reduce the total aerobic bacteria below the detectable level, while 4 to 10 kGy doses were required to decrease spore-forming bacteria below the detectable level. Coliforms in various spices were eliminated at 4 to 10 kGy. In the storage study of humidity higher than 80% at 30 to 35°C, mould counts increased up to $10^9$ per gram in many kinds of powdered spices in polyethylene pouches during one to 3 months of storage, whereas samples irradiated at 4 kGy were free from moulds.

Six spices, namely mace, sage, rosemary, clove, thyme, and oregano had high activities to inhibit the growth of *Bacillus* and *Staphylococcus*, and no changes in their antimicrobial activities were observed up to 40 kGy. The activity to prevent oxidation of fat was determined in several spices, and their anti-oxidative activities were hardly changed even at 30 kGy.
REPORTS
ON FOOD IRRADIATION DEVELOPMENTS
IN SOME REGIONS OF THE WORLD
(Session III)

Chairman

F.K. KÄFERSTEIN
WHO
ASIAN REGIONAL CO-OPERATIVE PROJECT ON FOOD IRRADIATION (RPFI)*

P. LOAHARANU
Food Preservation Section,
Joint FAO/IAEA Division of Isotope and Radiation Applications of Atomic Energy for Food and Agricultural Development,
IAEA, Vienna

Abstract

ASIAN REGIONAL CO-OPERATIVE PROJECT ON FOOD IRRADIATION (RPFI).
Activities on food irradiation in Asia and the Pacific, especially those co-ordinated by the IAEA under the Asian Regional Co-operative Project on Food Irradiation (RPFI) are reviewed. Twelve institutions in eleven Member States of the IAEA participated in the first phase of the RPFI from 1980 to 1984, with the objective of conducting research and development work, including pilot-scale studies, in the field of food irradiation, aimed at achieving commercialization of selected food items of economic importance to the region, i.e. fishery products, mangoes, onions and spices. The efficacy of irradiation for insect disinfestation of dried and cured fish, disinfestation of Oriental fruit flies (Dacus dorsalis) in and shelf-life extension of mangoes, sprout inhibition of onions and decontamination of spices is described. Results of these studies have demonstrated that the technology could be effectively transferred to relevant industries. Participating countries in the RPFI such as Bangladesh, the Republic of Korea, Pakistan, the Philippines, and Thailand are planning or are considering the construction of large multipurpose irradiation facilities for such a technology transfer. Plans to implement activities under the second phase of the RPFI on technology transfer of food irradiation as well as the prospects of commercialization of the technology in the region are discussed.

INTRODUCTION

Research on food irradiation in Asia and the Pacific started in India and Japan in the 1950s and was soon followed up in Australia, Indonesia, the Republic of Korea, Pakistan, the Philippines and Thailand in the 1960s. Since then, most other countries in the region have realized the potential benefit of this technology in reducing food losses and facilitating trade. Data generated from research and development on food irradiation in Asia and the Pacific has contributed greatly to the advance of this technology in the region and worldwide.

An important development in food irradiation occurred in Japan in 1973 when the Government, together with the Shihoro Agricultural Cooperative, located in Hokkaido, decided to build the Commercial Potato Irrad-

* This paper was presented in lieu of a review paper entitled "Food irradiation developments in Asia and the South Pacific", by P. Thomas (India), who was unable to attend.
Iator as part of the potato processing complex in Shihoro. This construction started a new era in the commercialization of food irradiation processes, which, at present, is being actively pursued and carried out in a number of countries such as Belgium, France, Hungary, Italy, the Netherlands, South Africa, USA and USSR, for specific applications.

This paper presents the summary of development on food irradiation in Asia and the Pacific, particularly relating to the co-ordinating role of the IAEA within the Asian Regional Co-operative Project on Food Irradiation in facilitating the application of the technology in the region.

REGIONAL CO-OPERATIVE AGREEMENT (RCA)

At the request of several developing Member States in Asia, the Agency initiated the Regional Co-operative Agreement for Research, Development and Training Related to Nuclear Science and Technology (RCA) to co-ordinate research and development on a number of projects related to nuclear technology in the region as early as 1972. Thirteen Member States in Asia and the Pacific eventually became party to the RCA Agreement and are actively collaborating with the Agency at present. It is important to note that, in view of the widespread interest and research activities being carried out in the field of food irradiation in Asia and the Pacific at that time, a project entitled "Radiation Preservation of Fish and Fishery Products - RPF" was selected as the first project to launch the activities of the RCA. Fourteen projects were eventually carried out under the RCA.

RADIATION PRESERVATION OF FISH AND FISHERY PRODUCTS (RPF)

Research was successfully conducted under the RPF from 1973 to 1978, with the participation of eight institutions in Bangladesh, India, Indonesia, the Republic of Korea, Pakistan, the Philippines and Thailand. The results of this work showed the technological feasibility of irradiation for shelf-life extension of fresh mackerel and milk-fish, which are common fish species in the region. The use of irradiation for insect disinfestation of dried fish appeared to be very promising. In addition, microorganisms of public health significance in fresh, dried and processed fish products can be controlled or eliminated by appropriate radiation treatment.

Results of research and development work on radiation treatment of fish and fishery products, especially from the Asian and Pacific region, were reviewed at the FAO/IAEA Advisory Group Meeting (AGM) on Radiation Treatment of Fish and Fishery Products, held in Manila, 13-16 March 1978. The AGM recommended very strongly that radiation preservation of dried and cured fishery products should be given the highest priority for Africa and Asia, where annual production of these products was 345000 and 723000 tonnes, respectively, at that time. Dried and cured fish provide the most important source of animal protein to the population in these regions, but this commodity suffers high losses, mainly due to insect infestation during storage and marketing. Often, insecticides were used to overcome the infestation problem.
The Agency therefore initiated a new co-ordinated research programme (CRP) on "Radiation Preservation of Dried Fish Indigenous to Asia - RPDF" in 1978. The CRP was in the initial stage of operation when the Japanese Government decided to join the RCA in mid-1978 with a special interest in supporting a project on food irradiation. Consequently a special mission was sent by the IAEA, under the sponsorship of the Japanese Government, in September 1979 to evaluate the status of food irradiation and to assess the interest and the need of developing Member States in the region in implementing food irradiation programmes on a practical scale. From the six countries visited by the mission, it was clear that the interest in the application of food irradiation in these countries as well as in other countries in Asia was not limited to dried and cured fish. The mission strongly recommended that the Agency should assist developing Member States of the RCA to expand the scope of the RPDF to a regional project on radiation preservation of food of economic importance to the region.

Under the sponsorship of the Japanese Government, a three-week workshop on food irradiation was convened at different institutions responsible for research and development in this field in Japan, from 22 October to 15 November 1979. The objectives of the workshop were to train senior scientists from developing Member States of RCA on methodology and research on large-scale radiation treatment of food items of interest to the region. Fourteen scientists from seven developing countries in Asia participated in the workshop. One outcome of the workshop was a proposed plan of research on radiation preservation of a number of food items to be co-ordinated by the IAEA on a regional basis.

Considering the interest of a number of countries in Asia and the Pacific in realizing the practical application of food irradiation, and based on the recommendation of the expert mission, the IAEA proposed to the Japanese Government during 1979 to consider funding a co-ordinated research programme (CRP) in this field for three years at a total cost of US$236000. After careful consideration, the Japanese Government agreed to sponsor the CRP under the title of "Asian Regional Co-operative Project on Food Irradiation (RPFI)" for three years, with the amount requested. The objective of the RPFI is to conduct research and development, including pilot-scale studies in the field of food irradiation aimed at achieving commercialization of selected food items of economic importance to the region.

A legal agreement establishing the RPFI was developed and entered into force on 28 August 1980 when the Japanese Government and the Governments of Indonesia, the Republic of Korea and the Philippines notified the Agency of their acceptance of the agreement. Eventually, eleven Governments, i.e., Bangladesh, India, Indonesia, Japan, the Republic of Korea, Malaysia, Pakistan, the Philippines, Sri Lanka, Thailand and Viet Nam became party to the agreement.
Owing to the limited financial resources available for the project and in order to concentrate efforts on studies on irradiated food items which are likely to find practical application in the near future, only fishery products, mangoes, onions and spices were selected for research under the RPFI. Consequently, fourteen research contracts and agreements were concluded with twelve institutions to carry out the work during the past four years.

Scope of work

To conduct research on the use of irradiation for:

(a) insect disinfestation and improving hygienic quality of dried and cured fishery products;
(b) insect disinfestation and shelf-life extension of tropical fruits such as mangoes;
(c) control of sprouting of onions;
(d) improving hygienic quality of spices.

Progress and achievements

Results of work conducted under the RPFI in the past four years were reviewed annually by the RPFI Project Committee which consisted of representatives of Governments party to the RPFI Agreement. These results may be summarized as follows:

(a) Dried and cured fishery products

A radiation dose of 0.3 - 0.5 kGy can effectively destroy insect species which cause infestation in dried and cured fish. Together with proper packaging, the treated products, which have a moisture content below 20% can be kept insect-free at ambient temperatures for several months. Irradiation of prepackaged dried fish having intermediate moisture content (20-40%) with a dose of 2-4 kGy together with potassium sorbate or with an oxygen absorber resulted in a shelf-life extension of the products up to 6 months at ambient conditions. Irradiation plus packaging costs for dried fish using a dose of 1 kGy were estimated to be less than 3% of the price of the product.

(b) Tropical fruits (mangoes)

A minimum dose of 0.5 kGy resulted in no adult emergence of Oriental fruit flies (Dacus dorsalis) in mangoes. A dose of 0.75 kGy together with a hot water dip treatment (55°C for 5 minutes) can extend the shelf-life of mangoes at ambient conditions from 8 to 12 days. Trial shipments of irradiated mangoes from the Philippines to the Netherlands by air and from Bangkok to Singapore by surface showed promising results.

(c) Onions

Pilot-scale studies showed that a dose of 0.1 kGy is effective for sprout inhibition and reduction of weight losses of onions stored under ambient conditions in a model storage facility with good ventilation in India. A similar dose can inhibit sprouting of onions and other crops such as potatoes and garlic in a natural low temperature storage room (2-20°C, 70-80% R.H.) which is equipped with internal forced ventilation in Korea. Similar results were achieved on sprout inhibition of shallots stored under ambient conditions in Bangladesh. All studies used tonne quantities of onions.
(d) Spices

A dose of 5 kGy could reduce the microbial load of spices (black and white pepper, nutmeg) by as much as 2–4 log cycles for the total plate count and 1–3 log cycles for the total mould and yeast counts. Packaging irradiated spices either in tin cans or in woven polypropylene bags lined with polypropylene film caused no significant change in $a_w$ values and moisture content during prolonged storage. A trial shipment by surface from Jakarta to Wageningen, the Netherlands, showed that irradiation with 5 kGy could effectively decontaminate spices without altering their chemical composition and sensory properties.

In addition, an evaluation mission consisting of experts on food irradiation from Japan, India, the USA and the IAEA was sent by the Agency to several countries participating in the RPFI in June 1983. The mission concluded that the work conducted under the RPFI has demonstrated the technological and economic feasibility of radiation treatment of fishery products (dried and cured), tropical fruits (mangoes), onions and spices. Food irradiation technology in several RPFI countries has reached the stage where it can be effectively transferred to the relevant industries. The infrastructure required for such a technology transfer is already existent in these countries. In most cases, pilot or large scale demonstration irradiators are either being constructed or are planned for this purpose in several RPFI countries (Bangladesh, India, Indonesia, the Republic of Korea, Pakistan, the Philippines and Thailand).

Based on encouraging results obtained under the RPFI, Bangladesh and Thailand have decided recently to build multipurpose irradiators to treat food and medical products. The Government of Bangladesh approved irradiated wheat, potatoes, onions, chicken, papaya, rice, strawberries and fish for human consumption on an unconditional basis while approving irradiated shrimp and frog legs on a provisional basis in December 1983. The Republic of Korea and Pakistan are considering construction of either large demonstration irradiators and/or commercial irradiators in the near future.

SECOND PHASE OF THE ASIAN REGIONAL CO-OPERATIVE PROJECT ON FOOD IRRADIATION (RPFI PHASE II)

Based on the encouraging results obtained under the original phase of the RPFI (Phase 1), it was already considered by the RPFI Project Committee at its third meeting held in Bangkok in November 1982, to plan follow-up activities for the RPFI Phase I, especially on transferring food irradiation technology to local industries. Following the positive recommendation of the evaluation mission, a proposal for a three year coordinated plan for technology transfer of food irradiation was developed by the Agency. The proposal was considered and later accepted by the RPFI Project Committee at its fourth meeting, held in Seoul in April 1984, according to the following:

Objectives

To assist national authorities in developing Member States party to the RCA to transfer food irradiation technology to local industries for the purpose of reducing malnutrition of the population and widening distribution of food in the trade and in particular to:
<table>
<thead>
<tr>
<th>Country</th>
<th>Commercial irradiator location</th>
<th>Status</th>
<th>Products treated</th>
<th>Approx. capacity</th>
</tr>
</thead>
<tbody>
<tr>
<td>BELGIUM</td>
<td>MEDIRIS A/ Fleurus</td>
<td>completed (1980)</td>
<td>spices, animal feed, frozen seafood</td>
<td>3000 t/a</td>
</tr>
<tr>
<td>BRAZIL</td>
<td>EMBRARAD A/ Sao Paulo</td>
<td>completed</td>
<td>spices</td>
<td>---</td>
</tr>
<tr>
<td>CHINA</td>
<td>Multipurpose irradiator (180 kCi) Chengdu</td>
<td>completed</td>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td></td>
<td>Multipurpose irradiator (100 kCi) Shanghai</td>
<td>completed</td>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td>ISRAEL</td>
<td>Animal Feed Irradiator (accelerator) Tel Aviv</td>
<td>completed (1984)</td>
<td>animal feed</td>
<td>---</td>
</tr>
<tr>
<td>JAPAN</td>
<td>Shihoro Potato Irradiator</td>
<td>completed (1973)</td>
<td>potatoes</td>
<td>15000 t/month</td>
</tr>
<tr>
<td></td>
<td>Shihoro, Hokkaido</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>NETHERLANDS</td>
<td>Pilot Plant for Food Irradiation Wageningen</td>
<td>completed (1968)</td>
<td>shrimp, frog legs, organic dyes, spices</td>
<td>1500 t/a</td>
</tr>
<tr>
<td></td>
<td>GAMMA MASTER-1 A/ Ede</td>
<td>completed (1972)</td>
<td>spices, frozen frog legs, shrimp</td>
<td>5000 t/a</td>
</tr>
<tr>
<td></td>
<td>GAMMA MASTER-2 Multipurpose</td>
<td>completed (1982)</td>
<td>spices, frozen frog legs, shrimp</td>
<td>5000 t/a</td>
</tr>
<tr>
<td></td>
<td>Ede</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SOUTH AFRICA</td>
<td>Fruit &amp; Vegetable Irradiator</td>
<td>completed (1982)</td>
<td>mangoes, strawberries, potatoes, onions, etc.</td>
<td>7000 t/a</td>
</tr>
<tr>
<td></td>
<td>Tzaneen</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Iso-Ster (Pty.), Ltd. A/</td>
<td>completed (1981)</td>
<td>fruits, vegetables, coconut powder</td>
<td>---</td>
</tr>
<tr>
<td></td>
<td>Kempton Park</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Multipurpose Irradiator Atomic Energy Board, Pretoria</td>
<td>completed</td>
<td>fruits, vegetables, chicken, etc.</td>
<td>---</td>
</tr>
<tr>
<td>Country</td>
<td>Facility Details</td>
<td>Completion Status</td>
<td>Processed Commodities</td>
<td>Annual Capacity (t/a)</td>
</tr>
<tr>
<td>---------</td>
<td>-----------------</td>
<td>-------------------</td>
<td>-----------------------</td>
<td>----------------------</td>
</tr>
<tr>
<td>Taiwan</td>
<td>Multipurpose irradiator</td>
<td>completed</td>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td>USA</td>
<td>Radiation Technology, Inc. a/ Rockaway, New Jersey</td>
<td>completed</td>
<td>spices, seasonings</td>
<td>500 t/a</td>
</tr>
<tr>
<td></td>
<td>Isomedix, Inc. a/ Whipany, New York</td>
<td>completed</td>
<td>spices, seasonings</td>
<td>500 t/a</td>
</tr>
<tr>
<td></td>
<td>International Nutronics a/ Irvine, California</td>
<td>completed</td>
<td>spices, seasonings</td>
<td>500 t/a</td>
</tr>
<tr>
<td>USSR</td>
<td>Grain irradiators (two electron accelerators) Port Odessa</td>
<td>completed (1981)</td>
<td>grain</td>
<td>400,000 t/a</td>
</tr>
</tbody>
</table>

a/ Mainly used for sterilizing medical supplies.
<table>
<thead>
<tr>
<th>Country</th>
<th>Commercial irradiator location</th>
<th>Status</th>
<th>Products treated</th>
<th>Approx. capacity</th>
</tr>
</thead>
<tbody>
<tr>
<td>BANGLADESH</td>
<td>Multipurpose irradiator (150 kCi) Dhaka</td>
<td>planned for 1985</td>
<td>potatoes, onions, fish</td>
<td>---</td>
</tr>
<tr>
<td>CHINA</td>
<td>Multipurpose irradiator (200 kCi) Shanghai</td>
<td>under construction</td>
<td>food in general</td>
<td>---</td>
</tr>
<tr>
<td>ECUADOR</td>
<td>Electron accelerator Quito</td>
<td>under construction</td>
<td>dried food</td>
<td>---</td>
</tr>
<tr>
<td>FRANCE</td>
<td>Pallet irradiator (2 million kCi 60Co) Marseilles</td>
<td>planned for 1985</td>
<td>food in general</td>
<td>---</td>
</tr>
<tr>
<td>HUNGARY</td>
<td>AGROSTER Joint Co. Budapest</td>
<td>planned for 1985</td>
<td>spices, potatoes, onions</td>
<td>---</td>
</tr>
<tr>
<td>IRAN</td>
<td>Multipurpose irradiator Tehran</td>
<td>planned for 1986</td>
<td>dried food</td>
<td>---</td>
</tr>
<tr>
<td>ITALY</td>
<td>Commercial Vegetable Irradiator Fucino Cooperative, Fucino</td>
<td>under construction</td>
<td>potatoes, onions, garlic</td>
<td>25000 t/season</td>
</tr>
<tr>
<td>KOREA (REPUBLIC OF)</td>
<td>Multipurpose irradiator Seoul</td>
<td>under construction</td>
<td>food in general</td>
<td>---</td>
</tr>
<tr>
<td>PAKISTAN</td>
<td>Multipurpose irradiator Karachi</td>
<td>planned for 1986</td>
<td>food in general</td>
<td>---</td>
</tr>
<tr>
<td>THAILAND</td>
<td>Multipurpose irradiator (200 kCi) Bangkok</td>
<td>planned for 1986</td>
<td>food in general</td>
<td>---</td>
</tr>
<tr>
<td>USA</td>
<td>International Nutronics Honolulu, Hawaii</td>
<td>planned for 1985</td>
<td>tropical fruit</td>
<td>---</td>
</tr>
</tbody>
</table>
(a) demonstrate the practical application of food irradiation technology with regard to insect disinfestation of fruits and stored products, improving hygiene of processed seafood to the national authorities and food industries of developing Member States party to the RCA;

(b) assist national and international agencies in their assessment of the commercial feasibility of radiation processing of food;

(c) monitor progress on research and development on food irradiation to be conducted in close collaboration with the relevant industries in RCA countries.

Scope of the project

The following general scope of work on the use of irradiation was agreed to be carried out under RPFI Phase II:

(a) disinfestation and decontamination of stored products;
(b) improvement of hygiene and storage ability of processed seafood;
(c) insect disinfestation of fruits for quarantine purposes;
(d) sprout inhibition of root crops.

Governments party to the Agreement Extension

The agreement establishing the RPFI was subsequently extended for three years starting from 28 August 1984. The following Governments are party to the Agreement Extension: Bangladesh, India, Indonesia, Malaysia, Pakistan, the Philippines, Thailand and Viet Nam. The Government of Australia has agreed to sponsor the RPFI Phase II for a duration of three years at a total cost of US$260000.

Implementation of RPFI Phase II

Activities of the RPFI Phase II will be implemented with a workshop on food irradiation, to be held at the Australian Atomic Energy Commission (AAEC), Lucas Heights, Australia from 29 April to 10 May 1985. The purpose of the workshop is to demonstrate the use of irradiation for food preservation at pilot-scale with emphasis on process control and quality assurance. Participants of the workshop are expected to be selected from scientists and representatives of food industries (industrialists), to enable them to carry out the appropriate technology transfer activities in their own countries.

PROSPECTS FOR COMMERCIALIZATION OF FOOD IRRADIATION IN ASIA AND THE PACIFIC

Japan was the first country to commercialize irradiated potatoes successfully in 1973. Up to now, Japan remains the only country in Asia and the Pacific which treats potatoes by irradiation on an industrial scale. Small-scale commercialization of irradiated food is reported in the People's Republic of China, the Philippines, Taiwan and Thailand. The commercial activities on food irradiation in different countries are summarized in Table I.
The delay in commercialization of irradiated food in the region could be partly because of the lack of legislation in this field in most countries. Only Bangladesh, Japan, the Philippines and Thailand have regulations on food irradiation. This problem should be overcome in the near future with the acceptance of the Codex Alimentarius Commission's Codex General Standard for Irradiated Foods and the Recommended Code of Practice for the Operation of Radiation Facilities used for Treatment of Food. Also, it is only recently that the food industry in the region became aware of the possible benefits of food irradiation to their products, especially those which are subject to health or quarantine inspections. In addition, most countries, especially developing ones, lack suitable irradiators to treat food on a commercial scale.

It is encouraging to note, however, that a number of countries in Asia and the Pacific, as well as those in other regions, are either constructing or are planning to build large irradiators for treating food and non-food items in their countries, according to Table II.

CONCLUSIONS

After some three decades of research and development, food irradiation is gaining recognition and acceptance in many countries. In Asia and the Pacific, where a large amount of research data on different applications of food irradiation has been accumulated, the technology could play an important role in reducing losses and facilitating wider distribution of certain food products. The RPFI has provided a strong impetus for several countries to co-ordinate their programmes effectively towards the practical application of this technology to combat the high rate of food losses and to make more food available to the population in the region.
FOOD IRRADIATION DEVELOPMENT IN AFRICA

B. CHINSMAN
Division of Technological Consulting Services,
The African Regional Centre for Technology,
Dakar, Senegal

Abstract

FOOD IRRADIATION DEVELOPMENT IN AFRICA.

The paper assesses prospects for using irradiation technology in the preservation of staple foods and in the treatment of agricultural commodities in the African region. This assessment is made in the light of the magnitude of the losses that occur, and the priority attributed by African States to ensuring that foods currently produced are better conserved to reach their consumers in edible condition with minimum loss. Estimates are presented of the cost of food losses and for the consequent food imports necessary to satisfy regional requirements. The principal causes of food loss include bacteria and insect attack, sprouting, maturation and senescence decay. A review of the literature is made which indicates that there is already some limited experience in food irradiation processing in the region. This review and other relevant studies suggest that the major causes of loss in staple foods and deterioration in other agricultural commodities can be controlled or delayed by the application of irradiation doses below the maximum levels permitted by the Codex Alimentarius. In the light of these observations and considering the high estimated cost of food losses and food imports in the region, the paper notes that a systematic assessment of the cost-benefit potential of irradiation processing in the region would be highly desirable. It is advocated that this assessment should determine the feasibility of including irradiation processing as part of the overall technological package required for the preservation of a wide range of foods and cash crops produced in the region. Attention is also drawn to a number of issues to be resolved before commercial-scale operations can be contemplated. These relate to lack of manpower and experience, financial resources and appropriate infrastructure, which may impede a rapid introduction of the technology. In conclusion, details are presented of a co-operative project which is designed to improve national capacities in food irradiation in selected institutions to start overcoming some of the barriers identified to the introduction of the process in the region.

1. INTRODUCTION

Many countries in Africa today experience problems of food shortage and famine. The situation has worsened steadily over the past decade because of the widening gap between the rates of food production and population growth. The Food and Agriculture Organization of the United Nations (FAO) has estimated that the average annual growth rate of basic food production fell from 2.7% in the 1960s to 1.3% in the
1970s, these rates being in any case less than 50% of rates recorded in other regions. On the other hand, Africa's population growth rate over these periods has steadily increased to a current level of about 3%. This imbalance between production and consumption by itself constitutes a major obstacle to the achievement of the development objectives of the region.

There is a second factor that further compounds this problem. A high proportion of the food harvested in Africa is lost to rodents, birds, insects and fungi because of poor preservation, processing and storage. Traditional methods for food preservation (sun-drying, fire, smoke, palm-oil, etc.) are inadequate, especially for long conservation. Often, they do not prevent the loss of nutritive properties or that of original flavours and even facilitate insect and microbial attack.

It is ironic that a food crisis and famine should be occurring in Africa at a time when major advances in science and technology have led to vastly improved food production and food preservation methods in other regions of the world. Few attempts have, however, been made to appraise the potential of selected new technologies systematically with a view to determining their suitability for introduction in the region. It is within this context of identifying and applying a suitable mix of viable techniques to improve the self-sufficiency in food in the African region that interest in irradiation processing should be seen.

2. SOURCES AND EXTENT OF THE FOOD LOSS PROBLEM IN AFRICA

2.1. Traditional pattern of food production

Almost all the food and agricultural commodities produced in Africa are cultivated under conditions which rely on the climate. This dependence on the weather imposes severe constraints on the whole system of production as the main periods of rainfall in most of the countries in the continent occur within a single season lasting 3 to 6 months each year. Under such conditions only one annual crop is normally cultivated and any variations in climatic patterns such as late or early rainfall, or too little or too much rainfall, can cause severe disruption and significant reductions in output.

This reliance on rain-fed agriculture also creates another set of problems. The necessity to produce a year's supply of food in a single period of each year results in enormous post-harvest problems. First, there is the problem of storage capacity and efficiency which bears directly on the magnitude of the losses which subsequently occur. The conditions in the rural areas are also adverse to long storage of food as both the nature of the staple foods and the warm climate and high humidity favour the rapid growth of organisms which cause spoilage and accelerate chemical and physical deterioration. Food therefore tends to be relatively abundant, and prices are consequently lower, immediately after harvest, and to become progressively scarcer and more expensive over the rest of the year. This scarcity and
the accompanying rise in prices are the result of both the pattern of production and the high levels of food loss which occur after harvest.

The lack of all-year round supplies also creates problems for food processing enterprises as such activities even when conducted on a small scale cannot be assured of regular supplies of raw materials at stable prices. A number of food processing enterprises in the region have actually failed precisely for this reason.

These constraints have contributed to the steady increase of food imports into the region as the food processing sector in Africa has largely remained underdeveloped. However, with increasing urbanization this situation would need to be corrected. At the current rates of urbanization, half the African population will be living in towns and cities by the year 2000. Preservation of foods for wider marketing and distribution in the fresh state and for subsequent transformation into more stable, storable and convenient forms of utilization will therefore become increasingly necessary. Reliable data on the origins and magnitude of food losses are therefore important, first, for defining appropriate measures to reduce the losses and, secondly, for appraising the suitability of alternative preservation and processing technologies for reducing food losses.

2.2. Food loss estimates

Losses in foods can be assessed both quantitatively and in terms of the decline in quality and nutritional value which occur after harvest. Loss estimation studies have, however, concentrated on measuring quantitative losses. Data obtained from these studies for the major foods produced in the region are summarized in Table I. Although a standard method of measurement was not used in these studies, the figures are instructive in indicating that substantial losses do occur. The incidence of such high levels of losses in foods suggests that the starting point for improving the food situation in the region should be the introduction of effective preservation methods. Considering also that traditional food consumption and culinary practice in Africa often calls for the use of fresh foods, methods that preserve foods in as near to the fresh state as possible will be desirable both from the point of view of maintaining food habits and for prolonging shelf-life to facilitate marketing and distribution.

2.3. Causes of deterioration and losses in staple foods

The major causes of deterioration in staple foods in Africa are summarized in Table II. The table shows that physiological and pathological damage are the principal causes of food losses. Insect attack can occur in maturing crops in the field as well as subsequently after harvest. Fungal infestation often follows such attack giving rise to the production of toxins.

In the case of roots and tubers, their botanical entities, structures and high water content make them unsuitable for long-term storage as primary commodities.
## TABLE I. LOSSES IN STAPLE FOODS

<table>
<thead>
<tr>
<th>Staple foods</th>
<th>Reported range of losses (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Roots and tubers</strong></td>
<td></td>
</tr>
<tr>
<td>Cassava</td>
<td>20–60</td>
</tr>
<tr>
<td>Yams</td>
<td>15–60</td>
</tr>
<tr>
<td>Potatoes</td>
<td>8–95</td>
</tr>
<tr>
<td><strong>Cereals</strong></td>
<td></td>
</tr>
<tr>
<td>Maize</td>
<td>10–30</td>
</tr>
<tr>
<td>Sorghum</td>
<td>6–40</td>
</tr>
<tr>
<td>Millet</td>
<td>10–50</td>
</tr>
<tr>
<td>Rice</td>
<td>6–24</td>
</tr>
<tr>
<td><strong>Plantains and bananas</strong></td>
<td></td>
</tr>
<tr>
<td></td>
<td>35–100</td>
</tr>
<tr>
<td><strong>Fish</strong></td>
<td></td>
</tr>
<tr>
<td>Fresh</td>
<td>20–50</td>
</tr>
<tr>
<td>Dried</td>
<td>20–35</td>
</tr>
<tr>
<td><strong>Fruits</strong></td>
<td></td>
</tr>
<tr>
<td>Citrus</td>
<td>20–95</td>
</tr>
<tr>
<td>Pineapple</td>
<td>20–70</td>
</tr>
<tr>
<td>Mango</td>
<td>20–50</td>
</tr>
<tr>
<td>Papaya</td>
<td>40–100</td>
</tr>
<tr>
<td>Avocados</td>
<td>43</td>
</tr>
<tr>
<td><strong>Vegetables</strong></td>
<td></td>
</tr>
<tr>
<td>Tomatoes</td>
<td>20–50</td>
</tr>
<tr>
<td>Onions</td>
<td>16</td>
</tr>
<tr>
<td>Pepper</td>
<td>15</td>
</tr>
<tr>
<td>Lettuce</td>
<td>62</td>
</tr>
<tr>
<td>Cauliflower</td>
<td>49</td>
</tr>
<tr>
<td>Cabbage</td>
<td>37</td>
</tr>
<tr>
<td>Carrots</td>
<td>44</td>
</tr>
</tbody>
</table>

Major sources Refs [1—4].

However, tubers, which are underground stems, have distinct periods of dormancy, giving a time-lag between harvest and sprouting, which makes them suitable for limited storage. Nevertheless, physiological activities such as respiration and transpiration go on throughout the dormancy period. For yams studies have shown that losses could be greatly increased by pathogenic attack even before the cessation of dormancy. The rate of respiration and, therefore, weight loss is greatly enhanced when visible pathogenic attack has occurred. Studies have shown that sprouting of yams cannot be controlled by the conventional sprout suppressants that are commonly used for stored potatoes [5, 6]. Similarly, no effective control measures
have been found to reduce nematode attack in yams [7]. Cassava, on the other hand, is a root and not an underground stem. It has no dormancy phase and undergoes senescence soon after harvest. Deterioration in cassava occurs in two stages. The first, commonly known as vascular streaking or vascular discoloration, is a purely physiological effect in which specific microorganisms cannot consistently be isolated from freshly deteriorating tissue nor can symptoms be reproduced by inoculation with isolates from the cassava. The second stage, however, is pathological and involves massive invasion of the already deteriorated roots by a wide variety of bacteria and fungi.

For fruits and vegetables losses result from physiological changes (senescence, ripening, respiration, transpiration and sprouting) and from pathological attack which is facilitated by the ease with which this produce can suffer mechanical damage. Cereals on the other hand suffer losses as a result of insects, pests and fungi.

Varying degrees of qualitative and quantitative losses occur in the various foods. Deterioration, however, tends to be relatively slow in cereals and pulses (durable products) and more rapid in roots and tubers, fruits and vegetables, and fish and sea products (perishable products). Under the conditions prevailing in the traditional system, perishable products can lose half their quality within two weeks and cannot be graded after three weeks; on a quantitative basis, half the product may be eaten after two and a half weeks and none after four weeks. On the other hand, freshly caught fish may deteriorate within hours. Durable crops can retain harvest quality during the first 8 weeks, lose half their quality after 18 to 26 weeks and are undergraded after 26 weeks. Quantitative loss is, however, slower in durable crops, of which about half the original stock will remain after one year's storage.

2.4. Cost of post-harvest food losses

For cost estimation purposes, minimum overall losses of 10 to 12% for durables and 20% for roots and tubers and 30% for fruits and vegetables can be assumed. These figures are on the conservative side when compared with the losses given in Table I. An extrapolation in monetary terms of these minimum loss estimates for 1980 is given in Table III. The table shows that a conservatively estimated minimum of 20% of the total food produced in Africa is lost after harvest. Six million tonnes of cereals are lost, while almost the same quantity of maize and rice is imported. For root and tuber crops and fruits and vegetables, losses in each case stand at over 16 million tonnes. Even at 1980 levels of production, a reduction in post-harvest food losses of 50% as called for in the Lagos Plan of Action will save an estimated $1.8 \times 10^9$ US $ worth of food annually in the region.

2.5. Cost of food imports

The average food import bill per African country between 1961 and 1965 was 37 million US $. By 1968 the figure was 64 million US $. The average annual
TABLE II. SUMMARY OF MAJOR CAUSES OF LOSS IN STAPLE FOODS

<table>
<thead>
<tr>
<th>Commodity</th>
<th>Causes of food loss</th>
<th>Mechanical damage</th>
<th>Respiration, senescence</th>
<th>Transpiration, moisture loss</th>
<th>Sprouting</th>
<th>Nematode</th>
<th>Rotting, microbes</th>
<th>Insects</th>
<th>Rodents, birds</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Roots and tubers</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cassava</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td></td>
<td>x</td>
<td></td>
<td>x</td>
<td>x</td>
<td></td>
</tr>
<tr>
<td>Yams</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td></td>
</tr>
<tr>
<td>Cocoyams</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td></td>
</tr>
<tr>
<td>Sweet potatoes</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td></td>
</tr>
<tr>
<td>Potatoes</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td></td>
</tr>
<tr>
<td><strong>Plantains and bananas</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>x</td>
<td>x</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>x</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Fruits and Vegetables</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Citrus</td>
<td>x</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>x</td>
<td></td>
<td>x</td>
</tr>
<tr>
<td>Pineapple</td>
<td>x</td>
<td>x</td>
<td></td>
<td></td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>Papaw</td>
<td>x</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>x</td>
<td></td>
<td>x</td>
</tr>
<tr>
<td>Tomatoes</td>
<td>x</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>x</td>
<td></td>
<td>x</td>
</tr>
<tr>
<td>Onions</td>
<td>x</td>
<td>x</td>
<td></td>
<td></td>
<td>x</td>
<td></td>
<td>x</td>
<td></td>
<td>x</td>
</tr>
<tr>
<td>Pepper spices</td>
<td>x</td>
<td>x</td>
<td></td>
<td></td>
<td>x</td>
<td></td>
<td>x</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>Okra</td>
<td>x</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>x</td>
<td></td>
<td>x</td>
</tr>
<tr>
<td><strong>Cereals</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>x</td>
<td>x</td>
<td></td>
</tr>
<tr>
<td><strong>Grain legumes</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>x</td>
<td>x</td>
<td>x</td>
</tr>
</tbody>
</table>
TABLE III. MAJOR STAPLE FOOD PRODUCTION AND LOSSES (1980)

<table>
<thead>
<tr>
<th>Commodity</th>
<th>Production (kt)</th>
<th>Average loss (%)</th>
<th>Estimated loss (kt)</th>
<th>Price/t (US $)</th>
<th>Estimated loss (10^9 US $)</th>
<th>Imports (kt)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rice</td>
<td>8 429</td>
<td>12</td>
<td>1 011</td>
<td>400</td>
<td>3 404</td>
<td>2 383</td>
</tr>
<tr>
<td>Maize</td>
<td>27 191</td>
<td>10</td>
<td>2 719</td>
<td>195</td>
<td>530</td>
<td>3 140</td>
</tr>
<tr>
<td>Sorghum and millet</td>
<td>20 454</td>
<td>11</td>
<td>2 250</td>
<td>310</td>
<td>697</td>
<td>-</td>
</tr>
<tr>
<td>Roots and tubers</td>
<td>83 903</td>
<td>20</td>
<td>16 718</td>
<td>25</td>
<td>419</td>
<td>-</td>
</tr>
<tr>
<td>Fruits and vegetables</td>
<td>56 323</td>
<td>30</td>
<td>16 897</td>
<td>100</td>
<td>1 690</td>
<td>135</td>
</tr>
</tbody>
</table>

TOTAL 196 300 39 650 3 740 5 658

Data based on Refs [9, 10].

The food import bill per country in 1982 stood at about 100 million US$. More recent figures for total food imports in the region are even more striking: 25 million tonnes for 1982 and 29 million tonnes for 1983 and forecasts show that average food imports per African country may exceed 125 million US$ by 1990 and 216 million US$ by the turn of the century if present trends continue [8].

For the ECOWAS subregion, annual food imports between 1962 and 1964 were estimated at about 200 million US$. By 1972–76 this figure had increased by over 300% to some 648 million US$ in current value. Although exports also increased, this was only by 157% thereby widening the food gap.

In Nigeria $5.26 \times 10^9$ Naira ($6.5 \times 10^9$ US$) was spent on food imports between 1970 and 1980. From 1978 to 1980 food imports alone amounted to $1.85 \times 10^9$ Naira ($2.3 \times 10^9$ US$). In Sierra Leone 21 million US$ representing 75% of earnings from exports of agricultural crops was spent on rice imports alone in 1981/82.

A considerable part of these food imports is necessitated by food losses after harvest that arise from pathogenic deterioration, insect attack as well as by physiological and metabolic changes, such as ripening, senescence and sprouting. Most of these food-loss creating factors can be controlled by irradiation. It is against this background that the investments necessary for the safe and effective introduction of food irradiation processing in Africa should be viewed.

3. SCOPE OF THE APPLICATION OF IRRADIATION TECHNOLOGY IN STAPLE FOOD PRESERVATION

The reduction of post-harvest losses in staple foods is now a central part of national strategies for alleviating the food crisis in the African region. The
Lagos Plan of Action accords high priority to the reduction of food losses and stipulates that measures should be introduced to reduce such losses by 50% in the short term. The major part of the effort to reduce food losses has been directed towards the upgrading of traditional techniques and adaptation of classical methods of food preservation and processing such as drying, canning, freezing, fermenting and milling of foods into flours and other stable forms of storage. Few attempts have been made to explore the possibilities of other techniques such as irradiation processing which could be considered in the comprehensive programme for reducing food losses in the region.

Apart from the limited access to the necessary facilities in the region, lack of information has been a major drawback in generating interest in food irradiation. This has made it difficult to convince national health authorities and consumers that foods processed by irradiation are wholesome and safe for consumption. The recent decision in 1983 by the Codex Alimentarius Commission to adopt the recommendation of the Joint FAO/IAEA/WHO Expert Committee on the Wholesomeness of Irradiated Food (JECFI) will serve to alleviate the fears and anxieties that the method had evoked and will serve to promote the practical applications of food irradiation.

A further development that will generate interest in food irradiation in the African region is the growing realization that some chemical additives that have for long been used in food preservation in the region are unsafe and can have an adverse effect on public health and the environment. Furthermore, many African countries continually lose a large share of their potential earnings from international trade in agricultural produce because of the poor state of these products, necessitating quarantine measures and lower prices. Whereas chemical treatment was generally permitted in the past, there is now a growing trend to restrict such treatment of agricultural commodities in international trade.

3.1. General principles

Irradiation of foods can render inactive or destroy the biological alteration agents found in foods, such as bacteria, yeasts and moulds, and which effect food deterioration. The process can be applied in several ways. Foods can be pasteurized to extend conservation duration; however, similar precautions to those taken for products pasteurized by heating (e.g. refrigeration) must be taken after such processing. Pasteurization by irradiation can be used to preserve fish and sea products, which are major sources of protein in many African countries. Large quantities of fish caught in the coastal areas are lost or destroyed during transport to the hinterland. The possibility of improving the shelf-life economically by only a few days will not only change this situation but will also open up new markets for surplus production. Pasteurization is equally effective for the preservation of meat and poultry, particularly against contamination by salmonella, as well as in limiting the extensive spread of fungi in fruits.
Sterilization, which is more often used for medical instruments and equipment, can equally be applied to foods. The method has been shown to be applicable to various types of food such as meat, poultry, fish and some vegetables but not to others such as milk and dairy products because of the unpleasant flavour changes that may occur. Just as in the case of sterilization by heating, foods sterilized by irradiation can be conserved for long periods provided the packaging remains intact. The advantage of irradiation over thermic processing lies in the fact that the products can be processed in the dry state in large capacity containers without introducing any alteration in the flavour, texture or colour of the original product.

Disinfestation of foods can be achieved at low doses of irradiation which can destroy parasites and insects found in grains, flour, fruits and other stored products. The method is therefore useful as it can be an effective alternative to chemical fumigation, which has the disadvantage of being toxic.

3.2. Experience in specific applications

3.2.1. Disinfestation treatment in Ghana

Trials with gamma irradiation [11] have been conducted in Ghana for the disinfestation of maize, cocoa beans and cowpeas. Cowpeas are leguminous grains and are important sources of protein in Africa. The traditional preservation of cowpeas involves repeated sun-drying and, apart from being laborious, it is ineffective as the grains are exposed to insect and beetle attack resulting in high losses. Preservation by chemicals leaves harmful residues in the grains and constitutes a danger to public health.

Experiments to establish the technological feasibility of gamma irradiation of red and white varieties of cowpeas [11] indicated that at doses between 0.1 and 0.5 kGy the irradiated cowpeas showed no loss in weight over a period of 11 months. Visual inspection of the irradiated white cowpeas after 11 months showed that they maintained their original colour and texture. In contrast, the non-irradiated red peas lost 4% of dry weight and experienced at 3.8% rise in spoilage due to insect attack. No mouldiness was, however, detected even though the moisture content had changed from 11 to 14% during the period. In the case of the non-irradiated white cowpeas, there was significant moisture increase from 9.5 to 18% and an increase in spoilage of about 30% over the 11 month period. The untreated peas were mouldy and had deteriorated into a sticky mass.

3.2.2. Treatment of spices in Egypt

In Egypt spices are widely used in food preparation at the domestic level and by the food industry. Spice consumption is rapidly increasing because of the steady growth of the food industry and the production of processed foods. Results of preliminary studies [12] indicated that irradiation with 10 kGy decreased
essential oils in caraway by 10%, had no effect on the pigment content of paprika, nor on the content of total and reducing sugars of caraway, coriander and black pepper. No significant differences were found in the contents of 10 different fractions of volatile oils in coriander as a result of irradiation with 10 kGy. Pilot trials have also been successfully conducted on potatoes, onions and garlic.

3.2.3. Germination and budding inhibition in Nigeria

Utilization of low irradiation doses inhibits the germination or budding of roots and tubers (carrots, sweet potatoes, potatoes, yams) or bulbs (onions, garlic) and thus extends their conservation period. This process offers considerable advantages over the use of chemical substances for the same purpose. From experiments performed in Nigeria with gamma radiation doses of 0.075 kGy and above have been reported to completely inhibit sprouting in yams for periods of up to eight months without adverse effects on physical appearance and palatability [13]. Doses of 0.2 to 0.3 kGy eliminated 70 to 80% of the nematode population in yam peels infected with Soutellonema bradyi [14]. Studies have also been successfully conducted on the possible use of ionizing radiation to inhibit sprouting in Nigerian onion cultivars and to extend the shelf-life and improve the rehydration properties of dehydrated vegetables. It therefore seems that, on the basis of available evidence, irradiation could be a useful tool for extending the storage life of perishable foods.

3.2.4. Maturation and senescence delays

Maturation in fruits such as banana, mango, papaw, guava, pear, some of which are already important commodities in international trade, can be considerably delayed by low-dose irradiation (0.25 to 0.35 kGy). The advantage of this process for tropical fruits lies mainly in the fact that these products display extensive sensitivity to physiological effects (chilling injury) when they are stored at temperatures below 10—15°C [15].

3.2.5. Other applications

Irradiation of meat products (ham, bacon, corned beef, sausage) helps to reduce or eliminate the utilization of some food additives such as nitrites. These substances are needed for the retention of flavour and colour and equally play a role in inhibiting the development of some pathogens such as Clostridium botulinum, thus preventing the production of toxin. However, under some conditions, the nitrites can combine with other chemical constituents to form nitrosamines which may lead to health problems [16]. It is thus possible, through irradiation, to maintain the nitrite content at a minimum level that is sufficient to guarantee the retention of the products' flavour.
3.3. Nutritional aspects

The effects of irradiation on food nutritional quality have been considered from two approaches. The first involved the determination of the chemical composition of the processed foodstuffs, while in the second experiments were conducted on animals fed with irradiated food. The large volume of data obtained from these studies on various foodstuffs such as fruits, vegetables, cereals, meat, poultry, fish, shrimps, and spices, revealed that foods irradiated with the prescribed doses do not change in any way their nutritional quality [17].

In some specific cases, minor losses of vitamin C and carotene were, however, noted in some fruits such as mango [18]. These losses were insignificant compared with those occurring under freezing or processing by heating [19]. Irradiation with a dose of 3 kGy was found to lead to a 15% loss of thiamine and a 26% loss of pyridoxine in some fishes such as mackerel [20].

Further studies are, however, required under the conditions prevailing in the African region to determine maximum safe doses both from the point of view of public health and safety and the increased risks due to manpower and infrastructural limitations. In addition, further studies will be required on the effects of shelf-life extension and decay control. These results are expected to be different from those obtained in studies in other regions because of varietal changes and composition, physiological response to radiation treatment and post-irradiation storage conditions especially arising from the higher ambient temperature and humidity in Africa, and the type and degree of infestation or contamination of produce before irradiation.

3.4. Economic and financial aspects

Few studies have been conducted on the economic feasibility of food irradiation in developing countries. The available studies suggest that costs will vary with the type and quantities of produce processed. Estimates made in 1982 indicated that costs will range from US $ 3 to 6/t of rice, US $ 2 to 6/t of fruits and US $ 40 to 70/t of fish [21]. The FAO/IAEA Consultants Group on the use of irradiation as a quarantine treatment of agricultural commodities [22] estimates that processing costs for irradiation disinfestation of fruits are less than US $ 60/t and could be as low as US $ 20—30/t depending on capitalization requirements and minimum treatment dose.

Preliminary assessments in the Ivory Coast [23] indicate that, provided sufficient quantities of produce can be treated, inhibition of germination in roots and tubers using low doses of 0.1 kGy, and disinfestation of agricultural produce using radiation doses of 10 kGy will be economically feasible. These assessments confirm that irradiation processing can be economically feasible where there is a large concentration of urban consumers with sufficient resources for purchasing
the preserved foods. However, where these conditions are not satisfied, the tech­
nique could in addition be utilized for the treatment of export crops, such as
chocolate and certain exotic fruits.

On the basis of this experience, the economic feasibility of food irradiation
in Africa will depend on the quantity of produce to be treated, the plant location,
and infrastructural requirements and the capital and operating cost of the plant.
The magnitude in monetary terms of losses caused by insects and other food-
deteriorating agents indicated in Table III suggests that serious consideration
should be given to studying in greater detail the economic feasibility of irradiation
processing as part of the strategic technological package for reducing food losses
and enhancing exports of agricultural produce in the African region.

3.5. Problems and perspectives for Africa

The application of food irradiation in Africa will be confronted with problems
relating to investment costs, lack of qualified staff, lack of maintenance structures
as well as some geographical constraints. The lack of an adequate transport net­
work linking the centres of food and agricultural production with urban centres
will create problems in collection and distribution. In most cases, food irradiation
may be economically feasible only where there is a concentration of production or
storage. Furthermore, the technique is associated with a number of problems
that must be overcome first if it is to be used widely and effectively. By far the
greatest of these is the difficult task of convincing national health authorities and
consumers that foods processed by irradiation are wholesome, i.e. safe for con­
sumption. Food irradiation still evokes fears and anxieties even in developed
countries. In the African context the technique will obviously require even greater
cautions.

Quite apart from the problem of safety, food irradiation also poses problems
of an infrastructural nature. This has to do with the establishment of the required
facilities or, where they already exist, with the strengthening of such facilities.
Irradiation techniques require laboratories and other physical facilities that are
specially designed and that meet certain safety standards. Food treatment by irra­
diation is no exception. Basic infrastructure is required for the handling,
distribution and storage. Irradiated foods often also require sustained levels of
cold storage and hermetic packaging to prevent deterioration. In most African
countries facilities for grading foods are either lacking or non-existent and energy and
electricity supplies pose serious problems for industry both from the standpoint
of cost and reliability of supplies.

There is also the problem of resources. Most African countries may not have
the resources that would enable them to exploit on a significant scale the potential
that irradiation offers as a technique for food treatment. The resources required
fall into three broad categories: (1) trained manpower, (2) equipment and radio-
chemicals, and (3) information and literature.
Sizeable investment will be required to train technical and financial manpower and for research and development activities. The introduction of food irradiation processing will require a multidisciplinary approach demanding co-ordination and interaction between policy-makers, scientists, technologists, and industrialists in the agro-food sectors, trade and industries, and in the public health, safety, standards and legislative sectors. Most of these are either in their infancy or non-existent and many African countries will experience difficulty in marshalling the necessary resources for developing them.

At the level of technology choice, the entire plant for irradiation processing will have to be imported. Contemporary designs of food irradiation plants are more suited to conditions in the developed countries. It may be necessary to determine parameters for more suitable designs that economize on capital and increase the labour component.

Many items required in the irradiation process such as plastic packaging material, process/handling equipment and special building materials will also have to be imported at greatly increased prices into the African region. At the same time food prices are generally kept low and may make investment costs relatively high in relation to the value of the products preserved. There may thus be a need to develop smaller, reliable and simple irradiators for use in the African region.

African countries can best be assisted to overcome these obstacles through a comprehensive programme of international co-operation. It is in the light of this realization that the African Regional Centre for Technology, ARCT, has initiated a co-operative project for reinforcing selected African institutions that already have some of the basic facilities necessary for conducting irradiation trials on staple foods and training manpower for such activities. A list of institutions that already have some basic facilities is given in Appendix 1. The project is being elaborated in co-operation with the IAEA.

4. OBJECTIVES OF THE CO-OPERATIVE PROJECT ON FOOD IRRADIATION FOR THE AFRICAN REGION

The project seeks to address the problems identified in food irradiation processing in the region with the primary aim of increasing food supplies, and enlarging the potential earnings from exports of foods and cash crops. The specific objectives include:

(i) In collaboration with African national health standards and legislative authorities and with relevant subregional, regional and international bodies, to define norms, practices and legislation appropriate for food irradiation in African environments;

(ii) To establish and/or strengthen selected laboratories in Africa for food processing by means of radiation techniques;
(iii) To train for such laboratories 'seed' staff capable of using radiation techniques in food treatment and of training others to employ such techniques;
(iv) To train technicians in the use, maintenance and servicing of equipment used in the treatment of food by radiation and of other relevant nuclear instruments;
(v) To provide advisory services to African countries with regard to the application of radiation to food treatment and the formulation of appropriate legislation;
(vi) To establish an information system aimed at disseminating knowledge about the scientific, health, legal and commercial aspects of irradiation as a food-processing technique.

The objectives would be achieved primarily through a programme of activities involving strengthening selected national institutions for carrying out irradiation trials on food, and exchange and fellowship schemes that will enable African researchers to work in relevant institutions in developed and other developing countries. The research activities would involve trials to determine parameters for the safe irradiation of common staple foods and other agricultural commodities. The exchange and fellowship scheme will be designed to promote technical co-operation between African and non-African institutions working or irradiation of foods. Training courses will be directed not only towards researchers but also other technical personnel who will be responsible for the operation and maintenance of the equipment. A reference manual will be developed on the activities of African institutions engaged in work on food irradiation which will indicate the capacity, activities and potential of each institution.

To carry out the co-operative activities in the project, three types of resources will be required: (i) personnel, (ii) equipment, and (iii) funds for direct costs. It is estimated that the resources required for all three categories will amount to US $2.5 million over a period of five years. Of these, about US $0.5 million will be contributed by ARCT in the forms of staff who will work on the project and support services and facilities that the Centre will make available. It is anticipated that when the project is finalized, the funds for its implementation will be sought from donors and institutions wishing to participate in the project.

5. CONCLUSIONS

The potential of food irradiation in Africa will depend on a number of factors. First, it will be necessary to demonstrate the technical feasibility of the process and that the food processed are nutritionally adequate and safe for human consumption. Furthermore, and perhaps more importantly at the present stage of development,
the economic feasibility of the process under African conditions would need to be established both in terms of capital and operating cost including energy demand and the improved organizational and infrastructural requirements that would have to be set up to ensure the proper and efficient use of the technique.

The potential for using an established facility as extensively as possible for the treatment of a variety of foods and export crops should be investigated to ensure maximum utility of the equipment. The seasonality of production of food and agricultural commodities would require that the equipment be adapted for treating different types of foods and produce at different times of the year. Certain produce may also require special or combined treatment for the process to be effective.

The assessment of the economic feasibility of the food irradiation process in Africa should be conducted by comparing the technique with other food processing methods. However, the objective should not be to present food irradiation as an alternative replacement for existing traditional and other new techniques of preservation. Rather, the study should be in the context of seeking to determine the optimal conditions under which a variety of technologies could be applied and to define an integrated system by which the most appropriate technologies could be used for addressing different post-harvest requirements in the region. Food irradiation technologies should therefore be considered as a part of the spectrum of technological options from which solutions to Africa's post-harvest problems could be derived.

A number of problems which may impede a rapid introduction of food irradiation processing in the African region have been identified. It is, however, relevant to note that even the well-established classic preservation technologies in the industrialized countries have several limitations when transferred in their entirety to the African region. Some of these constraints are within the same domain as those identified for food irradiation such as infrastructure, management, costs and energy inputs. The classic food preservation systems have developed in response to the needs in the industrialized countries and are as a result often energy intensive. Moreover, cans and packages often needed in these processes have to be imported at costs that are several times higher than the value of the processed food. The resulting distortion in the price of the processed food, arising from the disproportionately high cost of the packaging, has often been a deterrent to the development of the food processing sector in the continent.

There is therefore some justification for modifying and adapting existing technologies to suit conditions in Africa. These conditions would need to take into account the highly dispersed nature of agricultural production and that total production levels within individual countries are much lower than those of the developed countries. Highly skilled-manpower is also very scarce. Under these conditions, food irradiators would need to be small, simple to operate and maintain, of low cost and low energy consumption and low sensitivity to dust, high ambient temperatures and humidity and wide electric voltage fluctuations.
The positive conclusion of the Joint FAO/WHO/IAEA Commission entrusted with the study of irradiated foods marks a significant advance which would facilitate increased utilization of irradiation processing in food preservation. Furthermore, the adoption of the recommendation by the Codex Alimentarius Commission should serve to increase confidence and interest in the technique as a means of solving a wide range of food-preservation problems.

The utilization of the technique in Africa would, however, require that appropriate standards be developed and legislation enacted based on the Codex Alimentarius. The training of specialist staff for plant operation and maintenance will also be an a priori requirement. A careful assessment of the economic and financial viability of the process, given the constraints that often exist in the region, will also be necessary. Pilot trials should therefore be conducted in the region to provide the parameters that will enable the cost-effectiveness of the method to be appraised.

Appendix 1

INSTITUTIONS WITH RADIATION FACILITIES IN AFRICA

The Centre for Nuclear Studies, University of Dakar, Senegal.
The University of Nairobi, Kenya.
The University of Ife, Nigeria.
The University of Ibadan, Nigeria.
The University of Tanzania, Tanzania.
The National Centre for Radiation Research Technology, Cairo, Egypt.
The University of Sierra Leone, Freetown, Sierra Leone.
The Centre for Nuclear Studies, Zaire.
The Faculty of Science, University of Morocco, Morocco.
The National School for Mineral Industries, Rabat, Morocco.
The Centre for Nuclear Science and Technology, Algiers, Algeria.
The National Institute for Agronomic Research, Algiers, Algeria.

REFERENCES


Invited Paper

FOOD IRRADIATION ACTIVITIES IN LATIN AMERICAN COUNTRIES

T. RUBIO
Comisión Chilena de Energía Nuclear,
Santiago de Chile, Chile

Abstract

FOOD IRRADIATION ACTIVITIES IN LATIN AMERICAN COUNTRIES. The paper gives general information on the status of food irradiation in Latin American countries, considering research activities and the concomitant aspects, such as economic feasibility studies, irradiation facilities, legislation, etc. This general survey shows that the development of this technology varies between Latin American countries and that some problems need to be solved before this technology can be established in the region. The desirability of co-ordination at regional level is pointed out.

INTRODUCTION

During the last three decades extensive work on food irradiation has been conducted. As a result of this work, at present a wide variety of feasible applications are available in many countries of different socio- and techno-economic development.

In relation to Latin American countries, food irradiation can be a real solution to such large problems as the huge post-harvest losses, which sometimes represent more than 30–50%, especially where the climate conditions are adverse and/or the commercial practices are not adequate. Also, food irradiation can be very important for the Latin American countries in solving some public health problems and/or in improving the quality of the products they export. It is necessary to take into account that Latin American countries export enormous quantities of agricultural and sea products, so their economies depend heavily on the currency these products can generate.

This paper summarizes the main activities of the Latin American countries in the field of food irradiation. This survey cannot be considered a complete review but it gives a general idea of the present stage of development of this technology in the region.

Most of the information collected is based on national reports, scientific publications and especially on the trainees' reports of Latin American countries participating in the IFFIT's courses.
According to these sources of information, ten Latin American countries have been or are working in this field: Argentine, Brazil, Colombia, Cuba, Chile, Ecuador, Mexico, Peru, Uruguay and Venezuela.

The main institutions involved in food irradiation research in these countries have been the national nuclear commissions, universities and other research institutes related with food technology.

To simplify this survey the information was classified into two groups: research activities and other concomitant aspects such as economic feasibility studies, irradiation facilities, legislation, and information activities.

1. RESEARCH ACTIVITIES

The research activities were grouped according to the main technological effects.

1.1. Sprout inhibition

Table I illustrates the activity on the technological feasibility of sprout inhibition by irradiation. It shows that this application is of common interest to the majority of Latin American countries, especially as applied to potatoes and onions [1–10].

On the other hand, this situation shows an unnecessary duplication of work. Sometimes two countries have carried out studies on the same product and variety, obtaining the same results.

The research and pilot-scale studies have shown that it is possible to apply this technology at the commercial or semi-commercial scale on these products with
TABLE II. RESEARCH ON THE DISINFESTATION OF SOME PRODUCTS
BY IONIZING RADIATION

<table>
<thead>
<tr>
<th>Product</th>
<th>Argentina</th>
<th>Brazil</th>
<th>Colombia</th>
<th>Cuba</th>
<th>Chile</th>
<th>Ecuador</th>
<th>Mexico</th>
<th>Peru</th>
<th>Uruguay</th>
<th>Venezuela</th>
</tr>
</thead>
<tbody>
<tr>
<td>Barley</td>
<td></td>
<td>+</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>+</td>
</tr>
<tr>
<td>Black beans</td>
<td>+</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>+</td>
</tr>
<tr>
<td>Beans</td>
<td>+</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>+</td>
</tr>
<tr>
<td>Citrus fruits</td>
<td>+</td>
<td>+</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>+</td>
</tr>
<tr>
<td>Cocoa beans</td>
<td>+</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>+</td>
</tr>
<tr>
<td>Coffee beans</td>
<td></td>
<td>+</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>+</td>
</tr>
<tr>
<td>Corn/corn products</td>
<td>+</td>
<td>+</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>+</td>
</tr>
<tr>
<td>Oat flour</td>
<td></td>
<td>+</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>+</td>
</tr>
<tr>
<td>Papayas</td>
<td></td>
<td>+</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>+</td>
</tr>
<tr>
<td>Rice/rice products</td>
<td>+</td>
<td>+</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>+</td>
</tr>
<tr>
<td>Soja flour</td>
<td>+</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>+</td>
</tr>
<tr>
<td>Wheat/wheat flour</td>
<td>+</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>+</td>
</tr>
</tbody>
</table>

benefit to the countries of the region. Thus, for instance, in Chile potatoes, onions and garlic are being irradiated on a semi-commercial scale.

1.2. Disinfestation

Table II shows the spread of activities in the radiation-disinfestation of food. This application has acquired great importance, as an alternative to chemical pesticides, not only for the internal market, but also for the exports from the Latin American countries.

In this application Brazil and Mexico have carried out several studies in this field [2, 11, 12]. Corn, rice and wheat are the products that have been studied most, so it can be deduced that they are among the most important products for the region.
TABLE III. RESEARCH ON THE DELAY OF RIPENING

<table>
<thead>
<tr>
<th>Product</th>
<th>Argentina</th>
<th>Brazil</th>
<th>Colombia</th>
<th>Cuba</th>
<th>Chile</th>
<th>Ecuador</th>
<th>Mexico</th>
<th>Peru</th>
<th>Uruguay</th>
<th>Venezuela</th>
</tr>
</thead>
<tbody>
<tr>
<td>Avocado</td>
<td></td>
<td></td>
<td></td>
<td>+</td>
<td>+</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Babaco</td>
<td>+</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Banana</td>
<td>+</td>
<td>+</td>
<td></td>
<td></td>
<td>+</td>
<td></td>
<td></td>
<td></td>
<td>+</td>
<td></td>
</tr>
<tr>
<td>Mangoes</td>
<td>+</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>+</td>
<td></td>
<td></td>
<td>+</td>
<td></td>
</tr>
<tr>
<td>Papaya</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pineapple</td>
<td></td>
<td></td>
<td></td>
<td>+</td>
<td></td>
<td>+</td>
<td></td>
<td></td>
<td>+</td>
<td></td>
</tr>
<tr>
<td>Tomatoes</td>
<td></td>
<td></td>
<td></td>
<td>+</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>+</td>
<td></td>
</tr>
</tbody>
</table>

On the other hand, this situation again reflects that there are some products and insects of common interest to some Latin American countries. Thus, for instance, rice and corn infested by Tribolium sp. is a common problem to Cuba and Peru. Beans infested by Zabrotes sp. is a problem for Brazil and Peru [2, 12, 13].

Not so many studies have been carried out on disinfestation of fruits, but it is possible that this application will acquire importance if any chemical products in common use are banned in the near future.

1.3. Delay of ripening

Table III illustrates the research done in the Latin American countries in delay of ripening and/or senescence of some fruits and vegetables, in order to extend their shelf-life, using a combined treatment (heat plus irradiation) [14] or only ionizing radiation.

According to the information available, Venezuela and Mexico are the countries with the most studies in this field and bananas and mangoes appear to be the most important products [2, 13, 15].

1.4. Delay of microbial spoilage

Table IV illustrates the research done in Latin America to delay microbial spoilage [1, 2, 5, 8, 11, 15–21].

This application is of interest to all countries analysed and for a wide variety of products, including sea foods. Among the fruits, strawberries have had the
TABLE IV. RESEARCH ON THE DELAY OF MICROBIAL SPOILAGE

<table>
<thead>
<tr>
<th>Product</th>
<th>Argentina</th>
<th>Brazil</th>
<th>Colombia</th>
<th>Cuba</th>
<th>Chile</th>
<th>Ecuador</th>
<th>Mexico</th>
<th>Peru</th>
<th>Uruguay</th>
<th>Venezuela</th>
</tr>
</thead>
<tbody>
<tr>
<td>Apples</td>
<td>+</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bakery products</td>
<td></td>
<td>+</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Beans</td>
<td></td>
<td></td>
<td>+</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Citrus fruits</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>+</td>
<td>+</td>
<td></td>
</tr>
<tr>
<td>Cocoa beans</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>±</td>
</tr>
<tr>
<td>Corn</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cheese</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>+</td>
</tr>
<tr>
<td>Fish (fresh)</td>
<td>+</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>+</td>
</tr>
<tr>
<td>Fruit juice</td>
<td>+</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>+</td>
<td>+</td>
<td></td>
<td></td>
<td>+</td>
</tr>
<tr>
<td>Meat</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mangoes</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Melons</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>±</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Papayas</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Peaches</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pears</td>
<td>+</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Raspberries</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Rice/rice products</td>
<td>+</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Shrimps</td>
<td>+</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>+</td>
<td>+</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sugar cane</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>+</td>
</tr>
<tr>
<td>Strawberries</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td></td>
<td></td>
<td>+</td>
<td>+</td>
<td></td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td>Tomatoes</td>
<td></td>
<td>+</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>+</td>
<td></td>
</tr>
</tbody>
</table>

± = Objective not clear.

most attention, probably because they are very perishable. Citrus fruits and fruit juices have also been studied in several Latin American countries. Among the sea foods, fish, specially hake and shrimps, appear to be the most important.
TABLE V. RESEARCH ON THE DECONTAMINATION OF FOOD AND FEED

<table>
<thead>
<tr>
<th>Product</th>
<th>Argentina</th>
<th>Brazil</th>
<th>Colombia</th>
<th>Cuba</th>
<th>Chile</th>
<th>Ecuador</th>
<th>Mexico</th>
<th>Peru</th>
<th>Uruguay</th>
<th>Venezuela</th>
</tr>
</thead>
<tbody>
<tr>
<td>Animal feed</td>
<td></td>
<td>+</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Dried vegetables</td>
<td></td>
<td>+</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fish meal</td>
<td></td>
<td></td>
<td></td>
<td>+</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>+</td>
<td></td>
</tr>
<tr>
<td>Gelatine</td>
<td>+</td>
<td></td>
<td></td>
<td>+</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Spices</td>
<td>+</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

1.5. Control of pathogenic bacteria

The use of ionizing radiation to control pathogenic bacteria is another potential application for Latin American countries. However, it has not drawn enough attention up to now. Table V shows this situation.

In relation to this it would seem that Chile has carried out more studies [22] and as a result of this research dried vegetables and sometimes spices and animal feeds are being irradiated on a semi-commercial scale.

According to the information available, the control of helminths and parasitic protozoa are not of much interest to Latin American countries.

Perhaps an additional point of interest are wholesomeness studies. Brazil is the only Latin American country where some studies of this type have been carried out. Thus, nutritional studies, animal feeding and mutagenicity surveys were carried out with irradiated potatoes, corn, coffee and beans [2].

2. CONCOMITANT ASPECTS

2.1. Economic feasibility studies

The introduction of this technology depends not only on the technological studies, but also on the economic feasibility. Both aspects must be very closely linked in food irradiation plans.
Table VI shows that this is not the case for Latin American countries [2, 6, 8, 23]. Because the economic feasibility may be greatly affected by local circumstances, it is necessary to carry out these studies in different countries of the region. This is one of the weak points in the development of this technology in these countries.

2.2. Irradiation facilities

The successful introduction of irradiation techniques requires technological experiments under realistic conditions.

From this point of view, Latin America does not have a sufficient number of pilot irradiation facilities to carry out the first steps in the development of this technology.

Table VII shows the irradiation facilities available in the Latin American countries, including the commercial irradiators being used for treating products such as medical supplies [6, 18, 22, 24].
TABLE VII. ENGINEERING ASPECTS IN FOOD IRRADIATION

<table>
<thead>
<tr>
<th>Topic</th>
<th>Argentina</th>
<th>Brazil</th>
<th>Colombia</th>
<th>Cuba</th>
<th>Chile</th>
<th>Ecuador</th>
<th>Mexico</th>
<th>Peru</th>
<th>Uruguay</th>
<th>Venezuela</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pilot plant</td>
<td>+</td>
<td></td>
<td></td>
<td></td>
<td>+</td>
<td></td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td>Pilot studies</td>
<td>+</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td>Commercial</td>
<td>(+)</td>
<td></td>
<td></td>
<td></td>
<td>+</td>
<td></td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td>irradiation</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

(+)= Pilot plant/Commercial purpose.

To solve this problem from a regional point of view, it would be desirable to establish a Regional Co-operation Programme as soon as possible.

2.3. Studies on public acceptance: Information activities

Table VII shows that only three Latin American countries have done studies of public acceptance [6, 25, 26]. It is necessary to take this point into account in the introduction of the technology, including specific information activities such as courses, seminars, exhibitions, press publications, TV programmes, etc.

2.4. Legislation

Another aspect of great importance is the legislation and the authorization to apply this technology in Latin America.

At present, only Argentina, Chile and Uruguay have approved the use of this technology. The first two countries have approved the consumption of irradiated potatoes and Chile has approved the consumption of all the foods evaluated or re-evaluated by the Joint FAO/IAEA/WHO Expert Committee, Geneva, 1980 [6, 22, 27].

On the other hand, some Latin American countries have taken the first steps to obtain authorization to use this technology. Ecuador and Cuba are two examples [1, 28].

Also in 1982, the Brazilian enterprise Embrarad requested permission to irradiate onions, garlic, spices and condiments and later was informed that at least one food manufacturer has already begun to use irradiated dried onions, dried garlic and some irradiated spices in processed foods.
According to the above-mentioned information, the other Latin American countries should solve this problem of legislation, taking into account the national and international recommendations of the Joint FAO/IAEA/WHO Expert Committee, Geneva, 1980 [29] and the Codex General Standard for Irradiated Foods adopted by the Codex Alimentarius Commission in 1983.

3. CONCLUSIONS

According to the information available it can be concluded that:

(1) There is a different level of development of this technology in Latin American countries. Some of them are not active in this field at all.

(2) There is duplication among some Latin American countries in the research carried out on some products, e.g. in onions, potatoes and garlic to inhibit sprouting; in rice, corn and wheat to eliminate insects; in strawberries to delay the microbial spoilage; and in bananas and mangoes to delay ripening. This situation reflects a common interest but it also shows the lack of funding and human resources.

(3) It is urgent to develop surveys on economic feasibility and to establish legislation in this field. It would be desirable to carry out information activities to facilitate the acceptance of this technology in each country.

(4) Finally, it would be desirable to consider co-ordination of research and other activities associated with food irradiation at the national and regional level in order to solve some of the problems just mentioned.

REFERENCES


Invited Paper

RECENT DEVELOPMENTS IN FOOD IRRADIATION IN EUROPE AND THE MIDDLE EAST

J. FARKAS
Central Food Research Institute,
Budapest, Hungary

Abstract

RECENT DEVELOPMENTS IN FOOD IRRADIATION IN EUROPE AND THE MIDDLE EAST.
The paper attempts to give a picture of the status of food-irradiation research and development in Europe and the Middle East. The region's involvement in international projects and co-operation is highlighted and the potential of food irradiation is noted. Current research activities of 18 European and 5 Middle-Eastern countries are reviewed in tabular form, and an overview is given on food/feed irradiation facilities in use or in construction or planning. A general survey shows public health clearances for irradiated food items already granted in various countries of the region, and emerging commercial activities in several countries are recorded.

1. INTRODUCTION

Because of the great potential of food irradiation in contributing to the improved preservation, storage and distribution of a safe food supply, this process has received the attention of scientists and governments in Europe and in some countries of the Middle East for many years. Pioneering research on food irradiation took place in the fifties mainly in the UK, the USSR, France and the Federal Republic of Germany, which were soon followed by many of the European countries. The Middle East, Egypt and Israel developed particularly extensive R&D programmes.

The region's contribution to international developments in the field of food irradiation is well illustrated by the fact that three international projects on food irradiation, namely the Seibersdorf Project in the late sixties, the Karlsruhe Project (IFIP) in the seventies, and the still active International Facility for Food Irradiation Technology (IFFIT) in Wageningen, were all hosted by European countries.

The majority of the members of the International Food Irradiation Project (IFIP) were European and Middle-Eastern nations. The IFIP project, which was hosted by the Federal Research Centre for Nutrition, Karlsruhe, greatly contributed to the scientific basis of the historic conclusion of the Joint FAO/IAEA/WHO Expert Committee on Wholesomeness of Irradiated Food (JECFI) in November
1980 that irradiation of any food commodity up to an overall average dose of 10 kGy presents no toxicological hazard and irradiation of foods does not pose specific microbiological and nutritional problems [1]. The Karlsruhe Project was concluded in 1981 because during a decade of extremely valuable co-operative activity it has achieved its primary objective, the acquisition of data from a large number of wholesomeness and chemistry studies of irradiated foods and food components, which were evaluated by the JECFI [2].

The State Institute for Quality Control of Agricultural Products (RIKILT) and the Pilot Plant of Food Irradiation, Wageningen, are host institutions to the International Facility for Food Irradiation Technology, an international project jointly sponsored by the International Atomic Energy Agency (IAEA), the Food and Agriculture Organization of the United Nations (FAO) and the Dutch Ministry of Agriculture and Fisheries. Since 1979 IFFIT has successfully organized seven training courses on food irradiation for scientists and officials from developing countries. A total number of 141 participants from 45 countries have attended these 3- to 6-week courses. To date 31 persons from 23 developing countries have received longer term (3—15 months) applied research training in the laboratories of IFFIT and performed food-irradiation feasibility studies. IFFIT is also involved in evaluating the quality of trial shipments of irradiated mangoes, papayas, avocados, spices, shrimps, onions, garlic and dates from various developing countries, and it provides food irradiation services for those countries that have not yet established radiation facilities large enough for meaningful technological experiments [3].

Half of the 20 member countries of the recently formed International Consultative Group on Food Irradiation are in Europe and the Middle East. This Consultative Group under the aegis of the FAO, the IAEA and WHO offers through its meetings the means of jointly evaluating global developments in the field, of exchanging information and experience gained by members, and of determining priorities and objectives in the light of international developments [4, 5].

The present report attempts to give a brief overview of development in implementation of the food irradiation process in the region during recent years, i.e. after the 1980 JECFI meeting and since the last FAO/IAEA Symposium on Combination Processes in Food Preservation by Irradiation, held in November 1980 in Colombo [6].

2. POTENTIAL ROLES OF FOOD IRRADIATION IN THE REGION

As the technical and socio-economical conditions that provide the framework for technical development differ greatly in the region under consideration, it is understandable that any new technique combatting post-harvest food losses and preventing food-borne diseases could meet different needs and may play a different role in the individual nations discussed in this review.
In the highly industrialized countries of northern and western Europe with a temperate or cool climate and a well-established food preservation sector further reduction of post-harvest losses is needed less than in those areas of the region where the climatic conditions are more adverse to food storage, and refrigeration and/or controlled chemical treatment of food cannot be easily provided. Although extensive food processing is not yet as developed in some of the Middle-Eastern countries as in Europe, as urbanization increases, processed and/or preserved food becomes more and more important. In Europe the potential of food irradiation lies mainly in reducing the use of suspicious chemicals such as certain fumigants posing both occupational hazards and problems of toxic residues. The other main benefits are here the improvement of food hygiene and energy savings in the food industry and food distribution. No wonder that the major commercial applications, which have been emerged already, are in the field of radiation decontamination of food. The relative low dose treatment needed to control pathogenic non-sporeforming bacteria such as Salmonella could be of immense benefit to public health protection. More and more experts of food-borne diseases in the region realize that radiation pasteurization (radicidation) may well become as important in improving the hygienic status of solid foods of animal origin or dry feeds as the heat pasteurization of liquid food like milk already is.

Particularly in the Middle East, special importance can be assigned to radiation disinfection as a residue-free treatment of some agricultural commodities, e.g. dried dates. The microbiological action of ionizing radiation has been shown to improve remarkably the microbiological quality of spices, herbs and other natural vegetable ingredients, also that of frozen seafood and poultry, all of which are important items of the international food trade in the whole region.

3. CURRENT RESEARCH ACTIVITIES

According to a literature survey mainly based on information provided by the last four issues of the Bibliography on Irradiation of Foods [7], jointly published by the Bundesforschungsanstalt für Ernährung and IFIP in Karlsruhe, as well as on additional reports collected by the IFFIT office, research papers and research reports on food irradiation appeared since 1981 at least in eighteen European and five Middle-Eastern countries. Tables I—IV summarize these current research activities and show also the neglected areas of research. To facilitate comparison with an earlier survey made by Prof. K. Vas in 1977 [8], the research activities are recorded here in a form similar to that of his excellent review. These tables show that in spite of current economic difficulties and diminishing research funds in many countries, food irradiation research is still quite widespread in the region. This is confirmed by the fact that an increasing number of scientists participate from year to year in the annual meetings of the Food Irradiation Working Group of the European Society of Nuclear Methods in Agriculture (ESNA) [9—11].

(Text cont. on p. 225)
### TABLE I. CURRENT RESEARCH ACTIVITIES IN THE FIELD OF FOOD IRRADIATION IN EUROPE AND THE MIDDLE EAST

(A) Studies on chemical and biological effects

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Chemical effects</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Amino acids, protein/enzymes</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Carbohydrates</td>
<td></td>
<td></td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lipids</td>
<td></td>
<td></td>
<td></td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Vitamins</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>X</td>
<td></td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Aroma, colour</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Whole foods</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Packaging materials</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Biological effects</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Viruses</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bacteria, yeasts, moulds</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Protozoa</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Helminths</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Arthropods</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Plant tissues</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Animal tissues</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Enzymes</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Toxins</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

FARKAS
TABLE II. CURRENT RESEARCH ACTIVITIES IN THE FIELD OF FOOD IRRADIATION IN EUROPE AND THE MIDDLE EAST

(B) Studies on technological aspects

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Technological aspects</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Radiation, radicidation</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Meat and products</td>
<td></td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Poultry and products</td>
<td></td>
<td></td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Animal feed</td>
<td></td>
<td></td>
<td>X</td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fish, shellfish</td>
<td></td>
<td></td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Dairy products</td>
<td></td>
<td></td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fruits, vegetables &amp; products</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>X</td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Grain and products</td>
<td></td>
<td></td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Spices and herbs</td>
<td></td>
<td></td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cocoa</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Insect disinfection</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fish - dried, salted</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fruits, vegetables</td>
<td></td>
<td></td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Grain</td>
<td></td>
<td></td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cocoa, coffee</td>
<td></td>
<td></td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Retardation of ripening</td>
<td></td>
<td></td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sprout inhibition</td>
<td></td>
<td></td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Potatoes</td>
<td></td>
<td></td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Onions</td>
<td></td>
<td></td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Garlic</td>
<td></td>
<td></td>
<td>X</td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Yams</td>
<td></td>
<td></td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Control of barley germination</td>
<td></td>
<td></td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Packaging</td>
<td></td>
<td></td>
<td>X</td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Processing aids, additives</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
| Research item                        | Austria | Belgium | Bulgaria | Czecho- 
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Engineering aspects</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Irradiation facilities &amp; equipment</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pilot-plant studies</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Commercial irradiators</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Process dosimetry</td>
<td></td>
<td></td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>X</td>
<td></td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Economic aspects</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Meat, poultry</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fish, shellfish</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Animal feed</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fruits, vegetables</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Grain</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tubers, bulbs</td>
<td></td>
<td></td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>-------------------------------------------</td>
<td>---------</td>
<td>---------</td>
<td>----------</td>
<td>---------------</td>
<td>---------</td>
<td>-------</td>
<td>-----------------</td>
<td>-----------------</td>
<td>---------</td>
<td>------</td>
<td>-------------</td>
<td>--------</td>
<td>--------</td>
<td>----------</td>
<td>-------------</td>
<td>----------------</td>
<td>------</td>
<td>------------</td>
<td>-------</td>
<td>-----</td>
<td>------</td>
<td>-------------</td>
<td>--------</td>
</tr>
<tr>
<td><strong>Wholesomeness</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Effects on nutrients</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Induced radioactivity</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Microbiological safety</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Toxicology, animal testing</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Metagenesis</td>
<td>X</td>
<td></td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Teratogenesis</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Carcinogenesis</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Detection of radiation treatment</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Physical methods</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Chemical, physico-chem. meth.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Microbiological methods</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Plant physiological methods</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Enzymological methods</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Acceptability, consumer tests</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Country</td>
<td>Location</td>
<td>Type of irradiator</td>
<td>Estimated source strength</td>
<td>Completed</td>
<td>Purpose/Product</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>------------------</td>
<td>-----------------------------------------------</td>
<td>----------------------------------</td>
<td>---------------------------</td>
<td>-----------</td>
<td>-------------------------</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Nominal</td>
<td>Actual</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bulgaria</td>
<td>Novi Krichim</td>
<td>$^{60}$Co (Bulgarian des.)</td>
<td>10 kCi</td>
<td></td>
<td>Multi-purpose</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Sofia</td>
<td>$^{60}$Co</td>
<td>12 kCi</td>
<td></td>
<td>Multi-purpose</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Egypt</td>
<td>National Centre for Rad. Res. &amp; Technol., Cairo</td>
<td>$^{60}$Co, AECL JS 6500 with additional loop for food</td>
<td>1000 kCi</td>
<td>270 kCi</td>
<td>Multi-purpose</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>France</td>
<td>CEA/Cadarache</td>
<td>$^{60}$Co</td>
<td>15 kCi</td>
<td>6 kCi</td>
<td>1964</td>
<td>Multi-purpose</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>CONSERVATOME, Dagneux, Lyon</td>
<td>$^{60}$Co D$_{2}$-facility</td>
<td>300 kCi</td>
<td>60 kCi</td>
<td></td>
<td>Multi-purpose (mainly non-food)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>German Democratic Republic</td>
<td>Agricultural coop. Weideroda, Nr. Leipzig</td>
<td>$^{60}$Co, 'bulk irradiator' Central Inst. of Isotopes and Radiation Research, Leipzig</td>
<td>40 kCi</td>
<td>1981</td>
<td>Onions</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Germany, Fed. Rep.</td>
<td>Bundesanstalt für Ernährung, Karlsruhe</td>
<td>LINAC, 10 MeV Varian V-7703</td>
<td>6 kW</td>
<td>6 kW</td>
<td></td>
<td>Multi-purpose</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hungary</td>
<td>AGROSTER, Budapest</td>
<td>$^{60}$Co, 'Pilot Food Irradiator' IPARTERV/Inst. of Isot.</td>
<td>300 kCi</td>
<td>100 kCi</td>
<td>1971</td>
<td>Multi-purpose</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Institute of Isotopes, Budapest</td>
<td>$^{60}$Co, 'K-120' panoramic batch. irrad.</td>
<td>200 kCi</td>
<td>120 kCi</td>
<td>1968</td>
<td>Multi-purpose</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>$^{60}$Co, 'bulk irradiation'</td>
<td>42 kCi</td>
<td></td>
<td>1979</td>
<td>Onions</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Country</td>
<td>Institution/Location</td>
<td>Type/Description</td>
<td>Activity (Ci)</td>
<td>Year</td>
<td>Purpose</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>---------</td>
<td>----------------------</td>
<td>------------------</td>
<td>---------------</td>
<td>------</td>
<td>---------</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Iraq</td>
<td>Nuclear Res. Centre, Tuwaitha, Baghdad</td>
<td>$^{60}$Co, 'Gammabeam-650' AECL</td>
<td>50 kCi</td>
<td>Dates, onions</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Israel</td>
<td>$^{60}$Co shipboard irradiator NUMEC field irradiator</td>
<td>22 kCi</td>
<td>Multi-purpose potatoes, onions</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Italy</td>
<td>Cassacia, Rome</td>
<td>$^{60}$Co</td>
<td>Multi-purpose</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Netherlands</td>
<td>Pilot Plant of Food Irradiation, Wageningen</td>
<td>$^{60}$Co, panoramic batch irradiator, plaque source IFFIT</td>
<td>100 kCi</td>
<td>25 kCi</td>
<td>1979</td>
<td>Multi-purpose</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Poland</td>
<td>Technical University, Łódź</td>
<td>$^{60}$Co Polish design</td>
<td>25 kCi</td>
<td>20 kCi</td>
<td>Multi-purpose</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Switzerland</td>
<td>Eidgenöss. Forschungsanstalt, Wädenswil</td>
<td>$^{60}$Co</td>
<td>Multi-purpose</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>USSR</td>
<td>VNIIRT</td>
<td>$^{137}$Cs, 'Stavrida' RPP-100</td>
<td>91.2 kCi</td>
<td>1969</td>
<td>Multi-purpose (fish)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Yugoslavia</td>
<td>'Ruder Bošković' Institute, Zagreb</td>
<td>$^{60}$Co</td>
<td>42 kCi</td>
<td>Multi-purpose</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
TABLE VI. (SEMI)COMMERCIAL IRRADIATORS IN OPERATION, USED ALSO FOR PROCESSING OF SOME FOOD/FEED IN EUROPE AND THE MIDDLE EAST (AS OF JANUARY 1985)

<table>
<thead>
<tr>
<th>Country</th>
<th>Location</th>
<th>Type of irradiator</th>
<th>Estimated source strength</th>
<th>Completed in</th>
<th>Purpose/Product</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>Nominal Actual</td>
<td></td>
<td></td>
</tr>
<tr>
<td>France</td>
<td>CONSERVATOME, Dagneux, Lyon</td>
<td>$^{60}$Co, D$_1$-unit</td>
<td>1000 kCi 600 kCi</td>
<td>1962</td>
<td>Multi-purpose (mainly non-food)</td>
</tr>
<tr>
<td></td>
<td>SODETEG, Paris</td>
<td>LINAC, 6 MeV 'Circe'</td>
<td>7 kW 7 kW</td>
<td></td>
<td>Multi-purpose (mainly non-food)</td>
</tr>
<tr>
<td>Israel</td>
<td>SORVAN, Yavne</td>
<td>$^{60}$Co, AECL JS 6500</td>
<td>1000 kCi 150 kCi</td>
<td>1971</td>
<td>Multi-purpose</td>
</tr>
<tr>
<td>Netherlands</td>
<td>Pilot Plant of Food Irradiation, Wageningen</td>
<td>$^{60}$Co, continuous plant Marsh Ltd.</td>
<td>250 kCi 160 kCi</td>
<td>1967</td>
<td>Multi-purpose</td>
</tr>
<tr>
<td></td>
<td>GAMMASTER, b.v., Ede</td>
<td>$^{60}$Co, AECL JS 6500</td>
<td>1000 kCi 800 kCi</td>
<td>1971</td>
<td>Multi-purpose</td>
</tr>
<tr>
<td></td>
<td>GAMMASTER, b.v., Ede</td>
<td>$^{60}$Co, AECL JS 9000 pallet irradiator</td>
<td>3000 kCi 1200 kCi</td>
<td>1982</td>
<td>Multi-purpose</td>
</tr>
<tr>
<td>Norway</td>
<td></td>
<td>$^{60}$Co</td>
<td></td>
<td></td>
<td>Spices (mainly non-food)</td>
</tr>
<tr>
<td>United Kingdom</td>
<td>ISOTRON, Swindon</td>
<td>$^{60}$Co, package irradiation (twin plants)</td>
<td>3000 kCi 1300 kCi</td>
<td>1971</td>
<td>Multi-purpose (animal feed)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>$^{60}$Co</td>
<td>1000 kCi 600 kCi</td>
<td>1972</td>
<td>Multi-purpose (animal feed)</td>
</tr>
<tr>
<td>Yugoslavia</td>
<td>'Boris Kidrič' Institute, Belgrad</td>
<td>$^{60}$Co</td>
<td>1000 kCi 220 kCi</td>
<td>1978</td>
<td>Multi-purpose (mainly non-food)</td>
</tr>
</tbody>
</table>
4. IRRADIATORS AVAILABLE FOR FOOD IRRADIATION

Since larger radiation sources are prerequisites for the implementation of the process, the progress towards practical application can be illustrated by reviewing the radiation facilities in operation or in construction. Larger experimental food/feed irradiation facilities exist in a considerable number of countries in the region (Table V), and several multi-purpose (semi) industrial irradiators, which are used partly also for processing some food or feed, are in operation in France, Israel, the Netherlands, Norway, the United Kingdom and Yugoslavia (Table VI). To the author's knowledge only two facilities are used in the region on a commercial level entirely for the treatment of food commodities, namely the batch irradiator of the MEDIRIS plant in Fleurus, Belgium, and the grain disinfection plant at the Odessa Port Elevator RDU, USSR (Table VII) [12, 13]. The growing or renewed interest in the process is shown by the increasing number of demonstration or (semi)commercial food/feed irradiation facilities that are in the planning, design or construction stage in several countries (Table VIII).

A more detailed review on recent developments in a number of countries was recently issued as an IFFIT Report [14].

5. TRENDS OF LEGISLATION AND ACCEPTANCE OF THE PROCESS

There is a great variety of legislative attitudes to food irradiation among the countries of the region. Although the first clearances were already issued in the late fifties in the USSR and a lot of effort was also devoted in the region to wholesomeness testing of irradiated food, particularly in the Federal Republic of Germany, the United Kingdom, France, the Netherlands and Hungary, only a limited number of countries issued unconditional or provisional clearances of irradiated foods in the past decades. However, in recent years an increasing number of approvals were granted to individual irradiated foods or groups of products, e.g. spices, usually considered as one class of food, under specific conditions. A survey of the 'unconditional' and 'provisional' approvals in the region is given in Table IX, which also shows whether the clearances were issued before or since 1980. In addition, some countries have provided restricted clearances for experimental batches and/or for limited marketing tests. Such recent clearances are listed in Table X.

Except in Israel, the clearance situation of irradiated food in the Middle-Eastern countries lags behind that of the most progressive European countries.

It is hoped that both the Codex General Standard for Irradiated Foods, adopted by the Codex Alimentarius Commission in 1983, and the work of the International Consultative Group on Food Irradiation will reduce the disharmony between countries in their acceptance of irradiated foods.
TABLE VII. (SEM)COMMERCIAL FOOD/FEED IRRADIATORS IN OPERATION IN EUROPE (AS OF JANUARY 1985)

<table>
<thead>
<tr>
<th>Country</th>
<th>Location</th>
<th>Type of irradiator</th>
<th>Estimated source strength (kCi)</th>
<th>Purpose/Product</th>
</tr>
</thead>
<tbody>
<tr>
<td>Belgium</td>
<td>IRE-MEDIRIS, Fleurus</td>
<td>$^{60}$Co, 'Canmir-II'</td>
<td>Nominal 1000, Actual 450</td>
<td>Multi-purpose (mainly dry ingredients)</td>
</tr>
<tr>
<td>USSR</td>
<td>Odessa Port Elevator, RDU, Odessa</td>
<td>Electron accelerator plant, two ELV-2 type accelerators, 1.4 MeV</td>
<td>20 kW each</td>
<td>Grain disinfection</td>
</tr>
</tbody>
</table>


TABLE VIII. DEMONSTRATION/PILOT-SCALE OR (SEMI)COMMERCIAL FOOD/FEED IRRADIATION FACILITIES IN THE PLANNING, DESIGN OR CONSTRUCTION STAGE IN EUROPE AND THE MIDDLE EAST (AS OF JANUARY 1985)

<table>
<thead>
<tr>
<th>Country</th>
<th>Location</th>
<th>Type of irradiator</th>
<th>Estimated source strength</th>
<th>Status/Operation in</th>
<th>Purpose/Product</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>$^{60}$Co, 'pilot-scale food irradiator'</td>
<td>100 kCi</td>
<td>1986</td>
<td>Multi-purpose</td>
</tr>
<tr>
<td>France</td>
<td>Amavaux Market, Marseilles</td>
<td>$^{60}$Co, pallet irradiator</td>
<td>2000 kCi</td>
<td>1986</td>
<td>Multi-purpose</td>
</tr>
<tr>
<td></td>
<td>Société GUYOMARCH' Britanny, Western Fr.</td>
<td>LINAC, 'CASSITRON' CGR-MeV, 10 MeV</td>
<td>10 kW</td>
<td>1985</td>
<td>Frozen deboned poultry</td>
</tr>
<tr>
<td>German</td>
<td>Leipzig</td>
<td>$^{60}$Co, pallet irradiator</td>
<td>300 kCi</td>
<td>1985</td>
<td>Multi-purpose</td>
</tr>
<tr>
<td>Democratic</td>
<td></td>
<td>electron accelerator</td>
<td>planning</td>
<td></td>
<td>Multi-purpose</td>
</tr>
<tr>
<td>Republic</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hungary</td>
<td>AGROSTER, Budapest</td>
<td>$^{60}$Co, 'mobile gamma irradiator'</td>
<td>18 kCi</td>
<td>1985</td>
<td>Multi-purpose</td>
</tr>
<tr>
<td>Israel</td>
<td>Soreq Nuclear Research Center, Yavne</td>
<td>$^{60}$Co, 'Commercial Vegetable Irradiator'</td>
<td>300 kCi</td>
<td>1985</td>
<td>Potatoes, onions, garlic</td>
</tr>
<tr>
<td></td>
<td>Matmor Feed-Mill, Asdod</td>
<td>electron accelerator plant High Voltage Engng. Corp., 1.5 MeV</td>
<td>75 kW</td>
<td>1985</td>
<td>Poultry feed</td>
</tr>
</tbody>
</table>
### TABLE IX. UNCONDITIONAL AND PROVISIONAL CLEARANCES IN EUROPE AND THE MIDDLE EAST (AS OF JANUARY 1985)

<table>
<thead>
<tr>
<th>Foods</th>
<th>Purpose of radiation treatment</th>
<th>Belgium</th>
<th>Denmark</th>
<th>France</th>
<th>Hungary</th>
<th>Italy</th>
<th>Netherlands</th>
<th>Norway</th>
<th>Spain</th>
<th>USSR</th>
<th>Israel</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dried fruits</td>
<td>Disinfestation</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Dried vegetables</td>
<td>Decontamination</td>
<td></td>
<td>•</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Dry blood protein</td>
<td>Decontamination</td>
<td>•</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Dry food concentr.</td>
<td>Disinfestation</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Egg powder</td>
<td>Decontamination</td>
<td></td>
<td>•</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fish &amp; fish prod.</td>
<td>Raduriz. &amp; radicid.</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Frozen fish</td>
<td>Radicidation</td>
<td>•</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Frozen froglegs</td>
<td>Radicidation</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Garlic</td>
<td>Sprout inhibition</td>
<td>•</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>•</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Grains</td>
<td>Disinfestation</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Gum arabic</td>
<td>Decontamination</td>
<td>•</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Malt</td>
<td>Decontamination</td>
<td>•</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mushrooms</td>
<td>Radurization</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Onions</td>
<td>Sprout inhibition</td>
<td>•</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Potatoes</td>
<td>Sprout inhibition</td>
<td>•</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Poultry</td>
<td>Radicidation</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td>•</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Rice &amp; ground rice</td>
<td>Disinfestation</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Rye bread</td>
<td>Radurization</td>
<td>•</td>
<td></td>
<td></td>
<td></td>
<td>•</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Shallots</td>
<td>Sprout inhibition</td>
<td>•</td>
<td>X</td>
<td>X</td>
<td>x</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Shrimps, boiled</td>
<td>Radicidation</td>
<td>•</td>
<td></td>
<td></td>
<td></td>
<td>•</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Shrimps, frozen</td>
<td>Radicidation</td>
<td>•</td>
<td></td>
<td></td>
<td></td>
<td>•</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Spices (condiments)</td>
<td>Decontamination</td>
<td>•</td>
<td>•</td>
<td>•</td>
<td>X</td>
<td>•</td>
<td>•</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Strawberries</td>
<td>Radurization</td>
<td>•</td>
<td></td>
<td></td>
<td></td>
<td>•</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

X : clearances issued before 1981.

• : clearances issued since 1981.

---

6. STEPS TOWARDS COMMERCIALIZATION

On the basis of national regulatory systems, growing quantities of irradiated foods are being produced in several European countries. Wheat in the USSR, frozen fishery products and dry ingredients in the Netherlands and Belgium, spices and dry vegetable seasonings in Norway and France are such products. Smaller scale applications for test marketing or for other purposes are in progress in the German Democratic Republic, Hungary, Israel, Italy, and Yugoslavia. However,
TABLE X. CLEARANCES ISSUED FOR EXPERIMENTAL BATCHES OR LIMITED TEST MARKETING OF IRRADIATED FOOD SINCE 1981 IN SOME EUROPEAN COUNTRIES

<table>
<thead>
<tr>
<th>Food</th>
<th>German Democratic Republic</th>
<th>Hungary</th>
<th>Netherlands</th>
<th>Poland</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cherries</td>
<td>*</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Frozen chicken</td>
<td>*</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Grapes</td>
<td>*</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mushrooms</td>
<td>*</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Onions</td>
<td>*</td>
<td></td>
<td>*</td>
<td></td>
</tr>
<tr>
<td>Pears</td>
<td>*</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Potatoes</td>
<td>*</td>
<td></td>
<td>*</td>
<td></td>
</tr>
<tr>
<td>Red currant</td>
<td>*</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Refrigerated snacks</td>
<td>*</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>from minced meat</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sour cherries</td>
<td>*</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Spices</td>
<td>*</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Strawberries</td>
<td>*</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

at present the large-scale use of radiation processing is still hampered by the lack of world-wide legal acceptance of irradiated food commodities. It is not possible to utilize irradiation facilities economically when only a few commodities may be irradiated and even these may not be exported. Therefore, not all countries that have already granted clearances can actually use the process in practice.

An important task is now to transfer the technology to the food producers, processors and distributors, and to convince consumer organizations and consumers of the safety of the process. Because of misinformation, and the fact that in the mind of most people the word 'radiation' is associated with danger, and with the controversy over nuclear energy, a long-term policy of information and education is required to overcome these misapprehensions. It is confidently expected, however, that within the next few years many countries will allow the process, and ultimately the international trade in irradiated food will be just as acceptable as the trade in irradiated medical supplies.
REFERENCES


CHEMICAL AND MICROBIOLOGICAL CHANGES IN IRRADIATED FOOD

(Poster Session II)
Poster Presentations

EFFECT OF RADIATION PASTEURIZATION OF CHICKEN CARCASSES ON THE TASTE QUALITY OF THE COOKED MEAT

D. BASKER
Agricultural Research Organization,
The Volcani Center,
Bet-Dagan

Y. KLINGER
Kimron Veterinary Institute,
Bet-Dagan

M. LAPIDOT, E. EISENBERG
Soreq Nuclear Research Center,
Yavne

Israel

In Israel poultry carcasses may now be γ-irradiated with up to 7 kGy. The effect of irradiation within this limit on the shelf-life of chilled but unfrozen chicken was examined, as measured by the taste quality of the cooked meat. Leg meat and breast meat were prepared separately and packed commercially on the bone, treated with 3.7 ± 0.5 kGy, and stored at 1 to 2°C. Frozen meat from the same batches was used for comparison, as well as untreated meat from fresh batches on each occasion.

After each storage period, up to 23 days for leg meat and 28 days for breast meat, samples were cooked in water with the addition of mild (background) spicing. Approximately 40 unpreselected assessors participated in each of four taste panel sessions for each type of meat. A trihedral taste test was used to select subpanels of discriminating assessors. On a 0-to-10 unit quality scale the subpanels found that the taste quality of the irradiated meat deteriorated as follows:

Leg meat: Quality score = 7.32 − 0.13 (days)
(r = −0.38, d.f. = 43, 0.001 < P < 0.01)

Breast meat: Quality score = 7.82 − 0.08 (days)
(r = −0.36, d.f. = −58, 0.001 < P < 0.01)

On a 13-point pictorial scale the subpanels found that the percentage of better-than-neutral ratings decreased as follows:

Leg meat: 86.3 − 2.1 (days)
(r = −0.996, d.f. = 2, 0.001 < P < 0.01)

Breast meat: 82.4 − 0.08 (days)
(r = −0.92, d.f. = 2, 0.05 < P < 0.10)
It was concluded that the taste quality of leg meat was satisfactory for about two weeks, and decreased after about three weeks. Breast meat was satisfactory for about three weeks, decreasing in quality after about four weeks.

SAFETY EVALUATION OF IRRADIATED FOOD IN CHINA

Yin DAI
Institute of Food Safety Control and Inspection,
Ministry of Public Health,
Beijing, China

A nation-wide programme directed towards extending and applying food irradiation techniques in China and to eliminate psychological barriers among the people is currently being carried out. It consists of two steps:

1. Human feeding trials and the setting up of temporary hygienic standards.

From the 1980s up to 1981 a series of animal toxicity studies were carried out; no adverse effects were observed. Based on this information and on the literature, from 1982 until 1985 human feeding trials were carried out, i.e. for a period of two to three months five foodstuffs (rice, potato, mushroom, peanut and sausage) were tested. In addition, for a period of three months studies on the human diet, mainly composed of irradiated rice, vegetables and meat products, were carried out at our Institute and the Shanghai Medical College. The studies comprised the following: acceptability, clinical symptoms, appetite and physical condition, anthropometric measurements, routine haematological examinations, serum albumin and A:G ratio, serum urea nitrogen, serum GPT, GOT, r-GT and alkaline phosphatase, serum and urinary 17 hydroxy cortisol, chromosome aberration assay of peripheral lymphocytes, ECG and ultrasonic examinations of the liver, spleen and gall bladder.

In comparing the hygienic standards of unirradiated food with those of irradiated food it was established that the latter meets the same standards.

Based on the above studies China has approved the hygienic standards of the following irradiated foods for domestic trial: rice, potato, mushroom, peanut, onion, garlic and sausage.

2. Long-term observation of human consumption and the setting up of specific hygienic standards for irradiated foods. It is our intention to carry out studies on both these points.
EFFECTS OF GAMMA RADIATION ON THE SWEET POTATO WEEVIL Cylas formicarius elegantulus (Sum.)*

M.A. DAWES, M.A. MULLEN, J.H. BROWER, R.S. SAINI, P.A. LORETAN
The Carver Research Foundation, Tuskegee Institute, Tuskegee, Alabama
and United States Department of Agriculture, Agricultural Research Service, Stored-Product Insects Research Branch, Savannah, Georgia
United States of America

The sweet potato weevil Cylas formicarius elegantulus (Summers) is the most destructive pest of sweet potatoes in the southeastern United States of America and throughout the world. It was originally described in India, in 1792, and since it was reported in New Orleans in 1875 the weevil has infested eleven southern states at one time or another. The weevils concealed feeding habit, development to the adult stage within the enlarging root, host specificity to Ipomoea sp., and ease of movement through commerce contribute to its persistence and spread. Control with conventional insecticide application is very difficult and an effective control method would be of great benefit to the sweet potato industry.

The effects of gamma radiation on all metamorphic stages of the weevil were studied to find an alternative control procedure. All stages were treated with a series of doses between 5 and 100 krad from a $^{60}$Co source having a strength of about 260 Ci and a dose rate of 300 rad/min. The irradiator was calibrated by using a lithium fluoride thermoluminescence dosimetry system. Eggs (ages 1, 3 and 5 days) irradiated at 5—20 krad were unable to develop to the larval stage at any treatment level. Twelve-day old larvae irradiated at 5—50 krad, were unable to develop to pupae above 10 krad and no adults emerged at any treatment level. When 5-day old pupae were irradiated at 5—50 krad, adult emergence occurred with doses as high as 20 krad but not at 35 krad. Some adults that emerged after irradiation at all levels had abnormal elytra. A dose of 5 krad in the pupal stage was enough to cause sterility in the emerged adults. Adults were irradiated at 10—100 krad and maintained at 32°C (normal curing temperature for

* Study performed at Stored-Product Insects Research Branch, Agricultural Research Service, United States Department of Agriculture, Savannah, Georgia, with support from the United States Department of Energy, USA.
sweet potatoes) and 27°C (optimal rearing temperature for the sweet potato weevil post treatment. At 100 krad all the adults died within 7 days at 32°C and 11 days at 27°C. The higher temperature accelerated mortality at all doses and survival time of irradiated adults decreased with increasing dose at both temperatures. The reproductive ability of irradiated adults was considerably reduced at doses as low as 5 krad and complete sterility occurred at doses of 25 krad and above.

**IAEA-SM-271/9P**

**RADIATION DEACTIVATION OF BACTERIAL FLORA IN SOME EGYPTIAN POULTRY FEED**

Y.A. EL-ZAWAHRY*, Y.A. YOUSSEF, H.M. ROUSHDY, N.H. AZIZ

National Centre for Radiation Research and Technology, and
Faculty of Science, Ain Sham University, Cairo, Egypt

The bacterial flora of poultry feeds sampled from three different companies and the possible role of gamma radiation in the elimination of these pathogenic bacteria to ensure the hygienic safety for man and poultry were studied. The common bacteria isolated from the poultry feed samples were classified in the families of Pseudomonadaceae, Micrococcaceae, Bacillaceae and Enterobacteriaceae. These species of bacteria were identified as 10 Gram-negative and 13 Gram-positive species. The radiation dose required to inhibit completely the natural bacterial flora in tested samples of poultry feed was 20 kGy. The most radioresistant bacterial isolates subjected to a sublethal dose of 15 kGy were identified as *Bacillus cereus*, *B. polymxa* and *B. megaterium*. The dose response curves of *B. cereus* and *B. polymxa* started with shoulder portion followed by an exponential death, whereas *B. megaterium* exhibited a straight-line relationship directly. The D₁₀-value of *B. megaterium* spores (3.30 kGy) was about 1.5 and 1.7 fold the D₁₀-value of *B. polymxa* and *B. cereus*, respectively. The present work indicated also that the exposure of poultry feeds to an irradiation dose of 10 kGy (1 Mrad) reduced the number of bacteria considerably and destroyed all spoilage and pathogenic bacteria, especially *Salmonella*, and finally increased the shelf-life during storage periods. A higher radiation dose of 15 kGy failed to show any greater reduction of viable bacterial counts.

* Present address: Faculty of Science, Zagazig University, Zagazig, Egypt.
MEAT IRRADIATION TECHNOLOGY CENTER (MITC) FOR RESEARCH IN THE IRRADIATION PROCESSING OF MEAT

N. FERRELL, D.P. SLOAN
CH2M HILL,
Albuquerque, New Mexico,
United States of America

As an important facet of the United States Department of Energy's Byproducts Utilization Program, and in keeping with their commitment to transfer technology to industry, a demonstration and research irradiator is being developed to transfer caesium-137 irradiator technology to the meat industry. The facility will be located at or near an existing meat handling system to allow integration of the system into the process flow.

The MITC will be sited within a region characterized by high meat production, where interest in new developments and innovative technology is essential to market position. This will stimulate industry to participate in the research and to supply parameters for scale-up of research data to commercial application.

The major design objective is to assist the pork industry to develop the data base for FSIS\(^1\) regulations regarding irradiation certification of pork as trichina-safe and free of toxoplasmosis and other parasites.

Secondary objectives are the development of new meat products, market and consumer research, and other related meat irradiation research.

Facility design and programme management is discussed in detail in the paper along with the roles of the institution and industry participation.

\(^{1}\) FSIS = Food Safety Inspection Service.
OBSERVATIONS ON THE USE OF GAMMA IRRADIATION TO CONTROL NITROSAMINE FORMATION IN BACON

United States Department of Agriculture, Agricultural Research Service, Eastern Regional Research Center, Philadelphia, Pennsylvania, United States of America

After N-nitrosopyrrolidine (NPYR) and to a lesser extent N-nitrosodimethylamine were found in the fried edible portion of bacon and its drippings, the United States of America passed regulations reducing the ingoing \( \text{NaNO}_2 \) level from 156 to 120 mg/kg and also required the addition of 550 mg/kg sodium ascorbate/erythorbate (NaAsc/Ery) [1]. As a result of the continuing concern about the possible adverse health effect of consuming cured meats containing nitrosamines, particularly fried bacon, considerable research was carried out on developing alternatives to the use of nitrite [2]. In one of the alternatives we developed, bacon was prepared with 120 mg/kg \( \text{NaNO}_2 \) and 550 mg/kg NaAsc and then irradiated with \( ^{60}\text{Co} \) (30 kGy at \(-40^\circ\text{C})\). Residual \( \text{NaNO}_2 \) was reduced to almost non-detectable levels (<1 mg/kg) before frying. This resulted in less than the 10 \( \mu\text{g/kg} \) violative level of NPYR after frying compared with the non-irradiated controls which had higher values [3].

Initial studies with bacon prepared in the same manner and subjected to \( ^{137}\text{Cs} \) irradiation at 0, 10, 20 and 30 kGy, indicated that 30 kGy \( ^{137}\text{Cs} \) might not be as effective as 30 kGy \( ^{60}\text{Co} \) in reducing residual \( \text{NaNO}_2 \) and NPYR. An apparent elevation of NPYR values in fried bacon was observed in the 10 kGy samples. To determine if this observation was real, we conducted three experiments in which sixteen bacon bellies were cured with and without NaAsc, then irradiated at 5\(^\circ\text{C}\) with \( ^{137}\text{Cs} \) (0 to 15 kGy in 2.5 kGy increments). Subsequent to frying and analysis, in duplicate, all the sample sets indicated elevated NPYR in the edible portion between 2.5 and 7.5 kGy. The non-irradiated controls (0 kGy) were typically >10 \( \mu\text{g/kg} \) NPYR and the concentrations were lowered by doses greater than 10 kGy. In the earlier study, where bacon was irradiated with \( ^{137}\text{Cs} \) or \( ^{60}\text{Co} \) at 0, 10, 20 and 30 kGy, this elevation of NPYR in fried bacon was not observed in the \( ^{60}\text{Co} \) samples — only a dose related decrease.

These findings suggest that dose rate and/or the energy of the gamma rays may be an important determinant in nitrite destruction and nitrosamine formation-
destruction. Therefore, direct comparison between the same isotopes (\(^{137}\)Cs or \(^{60}\)Co) at different source strengths and \(^{137}\)Cs versus \(^{60}\)Co studies are warranted. These same factors may have important implications for the formation-destruction of radiolytic compounds, heretofore not observed.

Gamma irradiation at the higher than 15 kGy dose levels still significantly reduces the NPYR in fried bacon compared with non-irradiated bacon and offers the best opportunity for nitrosamine and microbiological control with maintenance of quality attributes when low (20–40 mg/kg) NaNO\(_2\) is employed.

REFERENCES

[1] UNITED STATES DEPARTMENT OF AGRICULTURE, Nitrates, Nitrites and Ascorbates (or Isoascorbates) in Bacon, Federal Register 4:20992.

THE ROLE OF LACTOBACILLI AND OTHER BACTERIA IN RADURIZED MEAT

W.H. HOLZAPFEL,
Department of Microbiology,
University of Pretoria,
Pretoria

J.G. NIEMAND
Iso-Ster (Pty) Ltd,
Kempton Park

South Africa

The shelf-life of vacuum-packaged ground beef can be trebled by a radurization dose of 3 kGy and consecutive storage at 4°C. Whilst most typical meat spoilage bacteria are effectively eliminated by radurization, several factors seem to favour the survival and growth of lactobacilli in vacuum-packaged radurized meat. Although lactobacilli constituted <1% of the initial microbial population, this relationship changed to 5.5% directly after radurization, and to
>90% within 5 days of refrigerated storage. The dominant lactobacilli were classified as *L. sake* and *L. curvatus*. These organisms seem to have a relatively high survival rate after radurization. On average, lactobacilli seem to be slightly more resistant to radiation than other non-sporeforming bacteria. D$_{10}$-values ranging from 0.30 to 0.88 kGy (average 0.59 kGy) were found for eleven *Lactobacillus* isolates. Contrary to expectations, a higher radiation resistance was found for actively growing (logarithmic) cultures of *L. curvatus*, as compared to stationary cultures.

D$_{10}$-values for nine *Salmonella* isolates (identified as *S. typhimurium* and *S. brandenburg*) ranged from 0.35 to 0.55 kGy in nutrient broth, but were lower in VE broth and higher in meat. D$_{10}$-values ranging from 0.40 to 0.63 were found for *Brochothrix thermosphacta*, whilst pseudomonads appeared to be extremely sensitive to radiation, with average values of 0.1 kGy. For *Staphylococcus sciuri* isolates a higher radiation resistance ($D_{10} = 0.64$ to $0.71$ kGy) was found than for any other meat-associated staphylococci ($D_{10} = 0.27$ to $0.38$ kGy). The latter were represented by *S. aureus*, *S. intermedius* and *S. simulans*.

It can be concluded that, although lactobacilli survive a radiation dose of 3 kGy, all potentially harmful bacteria are effectively eliminated in vacuum-packaged ground beef by radurization.

---

VE = veal extract.
DEPURATION OF BACTERIALLY CONTAMINATED LIVE AND SHUCKED SOFT SHELL CLAMS, *Mya arenaria*, BY GAMMA IRRADIATION

J.C. MALLET
Department of Biological Sciences,
University of Lowell,
Lowell, Massachusetts

J.D. KAYLOR, J.J. LICCIARDELLO
United States Department of Commerce,
Northeast Fisheries Center,
Gloucester Laboratory,
Gloucester, Massachusetts

United States of America

Bacterial decontamination of shellfish from polluted waters by the conventional depuration process is limited by the time constraint required for treatment and the variability among individual specimens to purge themselves. Soft shell clams are marketed either live, in the shell, or as shucked meats. No adverse effect on survival of clams was observed at treatments below 100 krad, but above this dose level a significant increase in mortality occurred (Fig.1). Treatment of inoculated clam meats with 100 krad, the proposed limit in the United

![Graph showing cumulative mortality of irradiated Mya arenaria at 6 days post-irradiation. Control mortality equals 2.6%. (1 rad = 1.00 X 10^-2 Gy)](image)
States of America, was calculated to effect a 2–3 log reduction in numbers of *E. coli* \((D_{10} = 37 \text{ krad})\), *S. typhimurium* \((D_{10} = 51 \text{ krad})\) and *Staphylococcus aureus* \((D_{10} = 42 \text{ krad})\) (Fig. 2). In countries where higher dose levels are permitted, a greater degree of decontamination is feasible since treatment with doses up to 330 krad did not effect any change in sensory characteristics when evaluated fried.
INTERACTION PHENOMENA IN THE RADURIZATION OF MEAT

J.G. NIEMAND
Iso-Ster (Pty) Ltd,
Kempton Park

H.J. VAN DER LINDE
Nuclear Development Corporation
of South Africa (Pty) Ltd,
Pretoria

W.H. HOLZAPFEL
Department of Microbiology,
University of Pretoria,
Pretoria

South Africa

The final quality and shelf-life of radurized meat and meat products are affected by various intrinsic and extrinsic factors. The initial microbial population determines the radurization dose as well as the type of interaction between radiation survivors. The importance of oxygen exclusion through application of correct packaging materials is highlighted by the fact that radurized meat was overgrown with fungus within seven days because of the elimination of bacterial competition and availability of oxygen. Vacuum-packaging solved this problem. Most meat and meat products developed detectable off-odours when radurized at ambient temperatures or above. However, meaningful improvements in the organoleptic properties could be achieved when radurization was carried out at temperatures of between 0 and 2°C. Post-radurization storage temperatures had the greatest single effect on the shelf-life and quality of meat and meat products. Combination treatments with radurization such as lactic acid and nitrogen gas-packaging hold much promise and are being pursued for commercial application.
The paper presents preliminary consumer acceptance tests performed on a popular Ghanaian kenkey made from combined-treated corn dough and presented to twenty adult panelists.

Krammer's Quick Rank Test showed that there was no significant difference (P = 0.05) in colour, flavour and taste between the control and combined-treated maize grains. Starch viscosity measurements of samples also showed that the decrease in intrinsic viscosity was not directly related to the combined heat and radiation treatments.

Heat-treated and combined-treated maize grains yielded more reducing sugars (as mg·L⁻¹ dextrose) than the unheated controls.
MICROBIOLOGICAL QUALITY AND PRODUCTION  
OF AFLATOXIN B₁ BY Aspergillus flavus LINK NRRL 5906 
DURING STORAGE OF ARTIFICIALLY INOCULATED 
MAIZE GRAINS TREATED BY A COMBINATION 
OF HEAT AND GAMMA RADIATION 

G.T. ODAMTTEN 
Department of Botany, 
University of Ghana, 
Legon, Accra 

V. APPIAH 
Department of Biology, Food and Agriculture, 
Ghana Atomic Energy Commission, 
Legon, Accra 

Ghana 

D.I. LANGERAK 
International Facility for Food Irradiation Technology (IFFIT), 
Wageningen, Netherlands 

Maize grains artificially inoculated with 1.3 × 10⁶ c.f.u.-g⁻¹ of spores of Aspergillus flavus Link NRRL 5906 were kept in open containers either unheated (20°C) or heat-treated (60°C for 30 min) under low (<45% r.h.) or high (>85% r.h.) humidity conditions. Part of the grains, in woven polypropylene sacks, remained unirradiated; the rest was irradiated with 3.5 and 4.0 kGy, respectively, for 30 minutes. The grain samples were stored at 65% r.h. and 28°C for one month and then at 80% r.h. for the following three months. 

Moist heat treatment (60°C for 30 min, >85% r.h.) did not increase (P = 0.05) the initial moisture content of maize grains (above 13% m.c.) significantly but reduced the initial mould and yeast count by 0.9 log cycles and the total aerobic bacteria count by 0.3 log cycles. A combination of moist heat and gamma irradiation with 4.0 kGy, however, lowered the initial mould and yeast count by 5.1 log cycles and the total aerobic bacteria count by 4.2 log cycles. Incubation at 65% r.h. and 28°C for one month augmented the killing effect of the radiation treatment. After three months’ storage at 80% r.h. the 

₁ c.f.u.-g⁻¹ = colony forming units per gram.
population of mould and yeast as well as the total aerobic bacteria of the combined-treated grains (60°C, 4.0 kGy) remained nearly the same (i.e. 5.0 and 4.3 log cycles reduction, respectively). The control of the moist heat-treated grains, however, had mould and yeast and total aerobic bacteria counts lowered by 1.5 and 1.3 log cycles, respectively, after three months’ storage at 80% r.h. The grains did not become rancid.

Triplicate samples showed that only control grains (20L and 20H) and the grains (20H) irradiated with 4.0 kGy contained 0.8—4.0 μg/kg of aflatoxin B\textsubscript{1} after three months’ storage at 80% r.h. and 28°C.

DETERMINATION OF IRRADIATION D-VALUES FOR
\textit{Aeromonas hydrophila} IN GROWTH MEDIUM, BUFFER AND FISH

United States Department of Agriculture, Agricultural Research Service, Eastern Regional Research Center, Philadelphia, Pennsylvania, United States of America

To assess the potential of irradiation processing as a means of controlling the presence of \textit{Aeromonas hydrophila} in marine products [1] three clinical isolates (K144, BA2 and BW83) and two food isolates (F6-10 and B2-10) were used in these studies. The cultures were irradiated in a caesium-137 source at doses up to 125 krad. Cultures were irradiated directly at 2 or 22°C in BHI growth medium, in potassium phosphate buffer (0.1M, pH 7.2), or in ground blue fish (Table I)\textsuperscript{1}. The number of survivors after exposure to various irradiation doses was determined by plating appropriate dilutions on duplicate plates of phenol red starch agar with 10 mg/L ampicillin, and enumerating amylase\textsuperscript{+} colonies after 24 h incubation at 28°C. Survivor plots (log\textsubscript{10} number of survivors versus dose) were determined by regression analysis of the data; correlation coefficients ≥0.96 were obtained for all strains and variables. Decimal reduction doses (D values in krad)\textsuperscript{2} were calculated as the reciprocal of the slope obtained from the regression analysis.

The D-values observed with the different strains were determined (Tables II—IV). Comparison of our data with those of Tarkowski et al. [2]

\textsuperscript{1} BHI = Brain, heart, infusion.

\textsuperscript{2} 1 rad = 1.00 × 10\textsuperscript{-2} Gy.
### TABLE I. EFFECT OF GROWTH PHASE ON D-VALUES FOR *A. hydrophila*
(irradiated in culture broth and plated on nutrient agar)

<table>
<thead>
<tr>
<th>Strain</th>
<th>Stationary phase cells</th>
<th>log phase cells</th>
</tr>
</thead>
<tbody>
<tr>
<td>K144</td>
<td>18.1</td>
<td>18.0</td>
</tr>
<tr>
<td>BA2</td>
<td>19.0</td>
<td>19.5</td>
</tr>
<tr>
<td>BW83</td>
<td>16.5</td>
<td>18.3</td>
</tr>
<tr>
<td>F6-10</td>
<td>17.6</td>
<td>16.9</td>
</tr>
<tr>
<td>B2-10</td>
<td>17.8</td>
<td>21.6</td>
</tr>
</tbody>
</table>

### TABLE II. EFFECT OF PLATING MEDIUM AND IRRADIATION MEDIUM ON D-VALUES FOR *A. hydrophila*

<table>
<thead>
<tr>
<th>Strain</th>
<th>Starch ampicillin agar</th>
<th>Nutrient agar</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Growth medium</td>
<td>Phosphate buffer</td>
</tr>
<tr>
<td>K144</td>
<td>16.2</td>
<td>15.5</td>
</tr>
<tr>
<td>BA2</td>
<td>18.7</td>
<td>18.1</td>
</tr>
<tr>
<td>BW83</td>
<td>16.8</td>
<td>15.9</td>
</tr>
<tr>
<td>F6-10</td>
<td>15.7</td>
<td>15.7</td>
</tr>
<tr>
<td>B2-10</td>
<td>15.5</td>
<td>13.7</td>
</tr>
</tbody>
</table>

### TABLE III. EFFECT OF TEMPERATURE OF IRRADIATION ON D-VALUES OF *A. hydrophila* IN FISH (plated on starch ampicillin agar)

<table>
<thead>
<tr>
<th>Strain</th>
<th>Temperature of irradiation (°C)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>22</td>
</tr>
<tr>
<td>K144</td>
<td>13.7</td>
</tr>
<tr>
<td>BA2</td>
<td>15.2</td>
</tr>
<tr>
<td>BW83</td>
<td>14.5</td>
</tr>
<tr>
<td>F6-10</td>
<td>11.0</td>
</tr>
<tr>
<td>B2-10</td>
<td>11.3</td>
</tr>
</tbody>
</table>
TABLE IV. D-VALUES OF *A. hydrophila* IRRADIATED IN GROUND BEEF AT 2°C (plated on starch ampicillin agar)

<table>
<thead>
<tr>
<th>Strain</th>
<th>D-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>K144</td>
<td>14.0</td>
</tr>
<tr>
<td>BA2</td>
<td>14.3</td>
</tr>
<tr>
<td>BW83</td>
<td>18.9</td>
</tr>
<tr>
<td>F6-10</td>
<td>15.1</td>
</tr>
<tr>
<td>B2-10</td>
<td>15.0</td>
</tr>
</tbody>
</table>

indicate that *A. hydrophila* is slightly more radiation resistant than *Yersinia enterocolitica* and *Campylobacter jejuni*, but not as resistant as *Salmonella* when these pathogens were irradiated in raw beef. However, our D-values for *A. hydrophila* in fish at 2°C are similar to those reported by Lambert and Maxey [3] for *C. jejuni* in ground beef and turkey. Overall, the results of our study indicate that a dose of 100 krad should be efficacious for the elimination of the levels of *A. hydrophila* encountered in retail fresh foods.

REFERENCES

IRRADIATION FOR FOOD SAFETY

(Session IV)

Chairman

T. RUBIO
Chile
Invited Paper

IRRADIATION: AN EFFECTIVE MODE OF PROCESSING FOOD FOR SAFETY

D.A.A. MOSSEL
Department of the Science of Food
of Animal Origin,
Faculty of Veterinary Medicine,
The University of Utrecht,
Utrecht, Netherlands

Abstract

IRRADIATION: AN EFFECTIVE MODE OF PROCESSING FOOD FOR SAFETY.

Foods of animal origin, particularly chicken and pork, continue to transmit febrile enteritis, including salmonellosis and campylobacteriosis, either subsequent to their consumption ('direct transmission') or after eating food that was initially wholesome but cross-contaminated off catering equipment, in turn infected by raw food of animal origin ('indirect transmission'). Moreover, precooked frozen shrimps imported from areas of production in the Orient have transmitted shigellosis in the Netherlands. These events result from heavy contamination pressure. In the case of meats this originates from intestinal infection of healthy animals; as far as shrimps are concerned, infectious pressure stems from the severely contaminated environment. Markedly improved measures of hygiene, including those attaining generally accepted GMP, are effective in reducing the contamination rate markedly, without completely eliminating the pathogens concerned though. Attempts to identify contaminated consignments by sampling examination were demonstrated to be unsuccessful, even when linked to certification by producing countries. The only practicable solution of this serious health problem has to rely on terminal processing for safety, as introduced in the twenties in the dairy industry and somewhat later in the manufacture of egg products. Gamma irradiation (radicidation) at a level of \( \leq 4 \text{ kGy} \) was found to be most effective for a more than adequate degree of elimination of pathogens as judged by Risk Analysis. Radicidation for this purpose did not entail immediate flora changes or even shifts in the microbial community structure secondary to slight temperature abuse, that presented any health risk. Neither were organisms isolated that could not be identified with types customarily encountered in fresh or processed food. Consequently, health authorities and the food industry alike henceforth have means available to protect consumers against the perennial food-transmitted enteric infectious diseases by the application of low amounts of ionizing energy. They should not postpone these or similar measures of intervention unnecessarily because otherwise they risk being blamed by history for being reprehensibly over-anxious.

PRECEPTS

Food-transmitted infections and intoxications remain serious health problems in nearly all parts of the world. Even advanced countries suffer from such diseases, particularly those spread by food of...
animal origin [1-4]. Reported incidents constitute only a minor part of the really occurring morbidity, even when an advanced Public Health infrastructure prevails [5,6]. The reasons for this high degree of underreporting are: (i) only approximately one third of the patients will consult a doctor at all; (ii) in turn, only about one third of the physicians consulted will ever send a specimen to a bacteriological laboratory; (iii) the incriminated food is only rarely reliably identified [7]. It is indeed striking that suffering from febrile food-transmitted gastroenteritis is nowadays considered to be as trivial and unavoidable as a spell of common cold, victims not seeming to bother calling for medical attention.

The financial impact of outbreaks transmitted by foods is considerable[2,8]. The primary costs are direct losses due to decreased productivity, medical expenses and foods having to be destroyed. In addition, significant reductions in demand for incriminated commodities are often observed after an outbreak. Finally the financial impact of law suits being made is often dramatic [9].

Four epidemiological groups of disease may be distinguished [6]; (i) the "big four", almost world-wide, including salmonellosis, campylobacteriosis and intoxications due to Staphylococcus aureus and Bacillus cereus; (ii) the "minor culprits": febrile gastro-enteritis caused by Shigella, Yersinia enterocolitica, Vibrio parahaemolyticus, various enteropathogenic and enterotoxigenic types of Escherichia coli, Clostridium perfringens, Aeromonas hydrophila, Edwardsiella tarda, the enteric parasites of helminthic and protozoan nature and the enteric viruses, particularly hepatitis A and the Norwalk group [10]; (iii) the very aggressive, but fortunately less frequently involved organisms, including *C. botulinum*; (iv) organisms whose aetiological rôle in food-transmitted diseases has only recently or not definitely been established, so that no estimate of their frequency can be made at present; cf Table I.

In approximately 90% of outbreaks, foods of animal origin are the aetiological agent [31,2]. The outbreaks usually result from what is called the 'dual failure' [6]: contamination of a food, followed by proliferation of the contaminant to colonization levels, exceeding the minimal infectious or minimal toxic dose for the most sensitive consumer.
Table I. Less common pathogenic and toxinogenic agents which may be transmitted by food

<table>
<thead>
<tr>
<th>Organism</th>
<th>References</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aeromonas hydrophila</td>
<td>[11-14]</td>
</tr>
<tr>
<td>Cryptosporidium parvum</td>
<td>[15,16]</td>
</tr>
<tr>
<td>Edwardsiella tarda</td>
<td>[17-19]</td>
</tr>
<tr>
<td>Escherichia coli, non-invasive and non-enterotoxinogenic; serotype O 157:H7</td>
<td>[20-22]</td>
</tr>
<tr>
<td>Lancefield group D streptococci</td>
<td>[23,24]</td>
</tr>
<tr>
<td>Norwalk virus</td>
<td>[25,10]</td>
</tr>
<tr>
<td>Pseudomonas aeruginosa</td>
<td>[26,27]</td>
</tr>
<tr>
<td>&quot;Small round&quot; viruses</td>
<td>[28-29]</td>
</tr>
<tr>
<td>Vibrio vulnificus</td>
<td>[30]</td>
</tr>
</tbody>
</table>

In viroses and parasitic diseases mere contamination of food will trigger the disease, so that only strict measures of food hygiene will result in their control. On the other hand, in food intoxications caused by S. aureus, sporeforming bacilli and clostridia, contamination is hard to avoid completely and consequently prevention has to rely on inhibition of microbial growth or arrest of spore germination.
Table II. Intervention Triad of Wilson

1. Safety assurance of the raw material by careful application of good practices.

2. Processing for safety to eliminate the pathogens occurring despite the control measures indicated under 1.

3. Avoiding recontamination and recolonization which would nullify the protection afforded by the measures indicated under 1 and 2.

After [6]

As indicated before, the main causes of food-transmitted infectious diseases are by far salmonellosis and campylobacteriosis. Their aetiology has been well established. The environment wherein, particularly swine and poultry, are fattened, is severely contaminated from sources like contaminated feed ingredients, surface water, soil, birds and insects [32].

The food animals mentioned so become carriers of Salmonella and Campylobacter, organisms harmless to the animals though causing enteric disease in man.

There is no hope for controlling these diseases unless by intervention as emphasized in 1955 by Wilson [33]. This includes a terminal decontamination procedure such as heat pasteurization of milk and egg products [34] without at the least neglecting the other elements of longitudinally integrated processing for safety; cf Table II.

Various procedures have been developed for terminal processing for safety of raw meat and poultry, leading to a high degree of elimination of enteric pathogens. These include surface heat treatments [35,36], surface decontamination with lactic acid [37-39] and irradiation with gamma rays at the ca. 5 kGy level [40-42]. All three processes are effective in the sense that they lead to significant lethality of the nonsporing pathogens involved. However, heat treatment may change the organoleptic characteristic of red meats and poultry, and moreover, requires large amounts of energy.
A promising alternative is the application of surface decontamination of fresh meat and poultry with lactic acid. This will achieve ca. 2 log₁₀ reductions of colony forming units of enteropathogenic Enterobacteriaceae and Campylobacter jejuni without any impairment of organoleptic attributes [43,38,39].

A most attractive decontamination method is radicidation [44], defined as a treatment with ionizing radiation at doses up to approximately 5 kGy adequate for the elimination of nonsporing pathogenic micro-organisms in fresh foods [45,40,46-51]. Radicidation can also successfully be applied to e.g. frequently dangerously recontaminated precooked food of animal origin, such as precooked frozen shrimps imported from oriental production areas [52].

Radicidation as used for these purposes has the following advantages; (i) there is no induced toxicity, teratogenicity or mutagenicity [53]; (ii) the fresh, frozen or dried character of the foods is not jeopardized; (iii) there is no significant loss of organoleptic properties of foods so treated; (iv) this treatment allows decontamination of foods after packaging, which, in view of the frequency of cross-contamination in the food industry [31,6] is of paramount importance; (v) due to elimination of mostly Gram negative spoilage agents the keeping quality of radicidized foods at refrigeration temperatures is markedly increased [43,54,55].

ESSENTIALS OF RADIATION PROCESSING FOR SAFETY

Radiation sensitivity of micro-organisms differs with genera and even species, all extrinsic conditions (medium, temperature, pO₂, pH₂O etc.) being equal. Gram-negative bacteria, including pathogens such as Salmonella and Shigella are generally more sensitive than Gram-positive bacteria: cf Table III. Bacterial spores are markedly more resistant, and Micrococcus radiodurans is exceptionally refractory to radiation. Moulds and yeasts are of intermediate resistance. In practical terms radicidation in doses between 3 and 6 kGy can be used to markedly reduce non-sporeforming pathogens such as Salmonella, Shigella, Campylobacter, Yersinia, Vibrio parahaemolyticus, E.coli and Staphylococcus aureus in different kinds of fresh or frozen foods [57].
### Table III. Radiation sensitivity of some organisms

<table>
<thead>
<tr>
<th>Organisms</th>
<th>Medium</th>
<th>Temperature</th>
<th>Dose for 10⁶ inactivation (kGy)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Salm. paratyphi</td>
<td>Beef liver</td>
<td>5°C</td>
<td>1.8</td>
</tr>
<tr>
<td>Salm. senftenberg</td>
<td>Fish meal</td>
<td></td>
<td>7.2</td>
</tr>
<tr>
<td>Shigella sonnei</td>
<td>Crabmeat</td>
<td></td>
<td>1.6</td>
</tr>
<tr>
<td>Shigella dysenteriae</td>
<td>Oysters</td>
<td></td>
<td>2.4</td>
</tr>
<tr>
<td>Yersinia enterocolitica</td>
<td>Ground Beef</td>
<td>0°C</td>
<td>1.2</td>
</tr>
<tr>
<td>Yersinia enterocolitica</td>
<td>Ground Beef</td>
<td>-30°C</td>
<td>2.3</td>
</tr>
<tr>
<td>Staphylococcus aureus</td>
<td>Beef</td>
<td></td>
<td>1.9-3.4</td>
</tr>
<tr>
<td>Vibrio parahaemolyticus</td>
<td>Crabmeat</td>
<td></td>
<td>0.5-1.0</td>
</tr>
<tr>
<td>Streptococcus faecalis</td>
<td>Broth</td>
<td></td>
<td>5.5</td>
</tr>
<tr>
<td>Aspergillus flavus (spores)</td>
<td>Water</td>
<td></td>
<td>2.5</td>
</tr>
<tr>
<td>Cl. botulinum 62 A (spores) (most resistant)</td>
<td>Ham</td>
<td>15°C</td>
<td>15.5</td>
</tr>
<tr>
<td>Micrococcus radiodurans</td>
<td>Broth</td>
<td></td>
<td>&lt;60</td>
</tr>
<tr>
<td>Foot and mouth disease virus</td>
<td>Calf kidney cells</td>
<td></td>
<td>36</td>
</tr>
</tbody>
</table>

Data from [56]

The exact dose required in every instance can only be determined by the procedure called Risk Analysis [58], because it is affected by the initial contamination rate of the food to be treated. In essence risk assessment includes estimating the hazard to the consumer of the final extent of contamination of a food with various pathogenic agents. This hazard approaches asymptotically, but does never actually attain zero. It is rather depending on a very low survival rate of pathogens \( (N_R) \) expressed by the formula

\[
N_R = N_0 \cdot \Lambda^{-1} \cdot \Delta \quad \text{where}
\]

- \( N_0 \) = initial load of the pathogen in cfu·g⁻¹;
- \( \Lambda \) = lethality of the process, defined as \( N_f/N_o \);
\( N_f = \text{cfu count immediately after processing;} \)
\( \Delta = \text{increase or decrease in cfu-g}^{-1} \text{ resulting from manufacturing steps, storage, distribution and culinary preparation} \)

\( N_r \) values have, ultimately to be gauged against the minimal infectious dose of the organism under study.

It is essential to note that in some instances survival curves obtained by irradiation are not rectilinear [45]. Consequently lethality has to be expressed in an integrated parameter, i.e. the dose required to reduce \( N_0 \) by e.g. six \( \log_{10} \) cycles within the usual confidence limits [59].

Concern has been expressed repeatedly that radicidation of foods may lead to a flora shift in the direction of reducing the foods' original colonization resistance. This might entail a risk of the food becoming dangerously recolonized upon recontamination after processing. Though such hazards have never been advanced in the case of heat processing of foods, they yet prompted extensive studies on radicidized foods. The detailed results of the studies will be presented in the following section. It may be useful to indicate already at this stage that in these surveys no indication whatsoever was obtained that immediate flora changes or population shifts during storage were such that they markedly decreased resistance against post-process recolonization as it existed prior to irradiation.

RESULTS OF PRACTICAL ASSAYS IN THREE AREAS

Frozen poultry

Poultry and poultry products are very frequently identified as the source of food-transmitted disease of microbial aetiology. The main pathogens involved are *Salmonella*, *Campylobacter* and *Staphylococcus aureus* [48,60,61]. It has been demonstrated that pre-packaging of poultry, freezing and subsequent irradiation with low doses of 2-5 kGy is effective in eliminating these pathogens [48,62]. Our own experiments [63] have shown that irradiation of frozen chicken with 4 kGy resulted in 3 \( \log_{10} \) cycles reduction of the aerobic mesophilic colony count and over 4 \( \log_{10} \) cycles reduction of the psychrotrophic colony.
Table IV. Effect of irradiation on the microbial quality of frozen chicken

<table>
<thead>
<tr>
<th>Organisms</th>
<th>0 kGy</th>
<th>1 kGy</th>
<th>2 kGy</th>
<th>3 kGy</th>
<th>4 kGy</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mesophilic colony count</td>
<td>6.8</td>
<td>5.8</td>
<td>4.6</td>
<td>4.1</td>
<td>3.6</td>
</tr>
<tr>
<td>Psychrotrophic colony count</td>
<td>5.8</td>
<td>5.7</td>
<td>4.0</td>
<td>&lt;2.8</td>
<td>&lt;1.8</td>
</tr>
<tr>
<td>Enterobacteriaceae</td>
<td>5.5</td>
<td>&lt;2.8</td>
<td>1.0a</td>
<td>0.4</td>
<td>-0.4</td>
</tr>
<tr>
<td>Lactobacillus</td>
<td>6.0</td>
<td>4.1</td>
<td>4.2</td>
<td>3.1</td>
<td>&lt;2.8</td>
</tr>
<tr>
<td>Lancefield D streptococci</td>
<td>5.1</td>
<td>3.7</td>
<td>3.9</td>
<td>3.2</td>
<td>&gt;2.0</td>
</tr>
<tr>
<td>Staph. aureus</td>
<td>4.6</td>
<td>2.2</td>
<td>&lt;0.5a</td>
<td>&lt;-0.5</td>
<td>&lt;-0.5</td>
</tr>
</tbody>
</table>

Data from [63]

The effect on the mesophilic and psychrotrophic microflora of frozen chicken surviving irradiation with 2 and 4 kGy was found to be, as expected, that the percentage of Gram-positive cocci increased whereas Gram-negative rods decreased. In irradiated chicken Micrococcus spp. and yeasts were the most prevalent organisms amongst the psychrotrophic flora, with Streptococcus spp. and Micrococcus spp. predominating in the mesophilic flora; cf Table V. These data are in agreement with the results of Welch and Maxcy [64] with regard to radiation-resistant Micrococcus spp. also isolated from irradiated chicken.

Mulder [65] observed that during storage at 7°C of poultry irradiated at 2.5 kGy total colony counts increased about 3 \( \log_{10} \) cycles more rapidly than Gram-negative counts.

Frozen precooked and peeled shrimps of tropical origin

Many opportunities exist for mishandling precooked frozen shrimps [66]. In view of the frequency with which they are consumed without further heating, pathogens occurring in shrimps are a perpetually
Table V. Effect of irradiation on the mesophilic and psychrotrophic microflora of frozen chicken (in % of total colony count)+.

<table>
<thead>
<tr>
<th>Organisms</th>
<th>mesophilic</th>
<th></th>
<th></th>
<th>psychrotrophic</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0 kGy</td>
<td>2 kGy</td>
<td>4 kGy</td>
<td>0 kGy</td>
<td>2 kGy</td>
<td></td>
</tr>
<tr>
<td>Aerococcus</td>
<td>-</td>
<td>10</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>Micrococcus</td>
<td>28</td>
<td>39</td>
<td>43</td>
<td>-</td>
<td>83</td>
<td></td>
</tr>
<tr>
<td>Staphylococcus</td>
<td>10</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>Streptococcus, Lancefield D</td>
<td>3</td>
<td>43</td>
<td>50</td>
<td>-</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>Corynebacterium</td>
<td>19</td>
<td>3</td>
<td>-</td>
<td>19</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td>Lactobacillus</td>
<td>22</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>Acinetobacter</td>
<td>2</td>
<td>-</td>
<td>-</td>
<td>8</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>Xanthomonas</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>4</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>Pseudomonas</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>46</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>Kluyvera</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>5</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>Hafnia</td>
<td>10</td>
<td>-</td>
<td>-</td>
<td>7</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>Klebsiella</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>11</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>E. coli</td>
<td>4</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>Yeasts</td>
<td>2</td>
<td>5</td>
<td>7</td>
<td>-</td>
<td>14</td>
<td></td>
</tr>
</tbody>
</table>

+ Limit of significance 2-5%. Data from [63]

imminent public health hazard. Recently 59 cases of bacterial dysentery caused by Shigella flexneri type 2 occurred in The Netherlands [3]. The epidemic caused death in 14 patients, all aged over 70. A shrimp cocktail served at the Christmas dinner was demonstrated to be epidemiologically related to the outbreak. The incriminated shrimps were imported in a peeled frozen condition from the Far East. Because the epidemic strain showed the same antibiotic resistance and plasmid
### Table VI. Effect of irradiation on the microbial quality of frozen Malaysian shrimps

<table>
<thead>
<tr>
<th>Organisms</th>
<th>$\log_{10}$ cfu.g$^{-1}$</th>
<th>Dose of radiation (kGy)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>0</td>
</tr>
<tr>
<td>Mesophlic colony count</td>
<td>6.8</td>
<td>4.8</td>
</tr>
<tr>
<td>Psychrotrophic colony count</td>
<td>6.2</td>
<td>4.2</td>
</tr>
<tr>
<td>Enterobacteriaceae</td>
<td>3.2</td>
<td>&lt;-0.5</td>
</tr>
<tr>
<td>Lactobacillus</td>
<td>5.2</td>
<td>&lt;2.8</td>
</tr>
<tr>
<td>Lancefield D streptococci</td>
<td>4.9</td>
<td>1.0</td>
</tr>
<tr>
<td>Staph. aureus</td>
<td>3.5</td>
<td>&lt;-0.5</td>
</tr>
</tbody>
</table>

Data from [63]

### Table VII. Radiation sensitivity of some strains of Shigella and Salmonella in frozen precooked, peeled tropical shrimps

<table>
<thead>
<tr>
<th>Bacteria</th>
<th>$D_{10}$ (kGy)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Shigella dysenteriae</td>
<td>0.22</td>
</tr>
<tr>
<td>Shigella sonnei</td>
<td>0.25</td>
</tr>
<tr>
<td>Shigella boydii</td>
<td>0.26</td>
</tr>
<tr>
<td>Shigella flexneri 2</td>
<td>0.41</td>
</tr>
<tr>
<td>Salmonella typhimurium</td>
<td>0.88</td>
</tr>
</tbody>
</table>

Data from [52]
Table VIII. Immediate microbial flora change (in %) in frozen shrimps as a result of irradiation

<table>
<thead>
<tr>
<th>Organisms</th>
<th>mesophilic</th>
<th>psychrotrophic</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0 kGy</td>
<td>4 kGy</td>
</tr>
<tr>
<td>Gram-positive cocci</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Micrococcus</td>
<td>4</td>
<td>84</td>
</tr>
<tr>
<td>Staphylococcus</td>
<td>82</td>
<td>16</td>
</tr>
<tr>
<td>Streptococcus</td>
<td>9</td>
<td></td>
</tr>
<tr>
<td>Gram-positive rods</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Corynebacterium</td>
<td>5</td>
<td></td>
</tr>
</tbody>
</table>

Data from [63]

profile as endemic Malaysian types, it is most likely that the incriminated shrimps had been recontaminated off the severely contaminated local environment, after previous decontamination by cooking.

Post-processing recontamination bears a sporadic and most erratic character [6]. Therefore sample examination of consignments of food upon importation in attempts to separate safe lots from unsafe ones, is totally unreliable. Rather should shrimp be systematically processed for safety before it reaches the consumer. This can, in principle, be achieved by radicidation at doses of 4-6 kGy.

We found that a radiation dose of 4 kGy resulted in 3 log\(^10\) cycles reduction of the aerobic psychrotrophic and mesophilic colony counts of Malaysian shrimps [63]. In addition, Enterobacteriaceae, Lactobacillus, Lancefield D streptococci and Staph. aureus could not be detected in 1 g aliquots, after doses between 2 and 4 kGy had been applied (Table VI). Subsequently inoculated pack studies with 4 strains of Shigella and 1 strain of Salmonella were carried out. As illustrated by Table VII Shigella was more radiation sensitive in frozen shrimps than Salmonella; a dose of 2.5 kGy was found to result in a lethality of more than 6 log\(^10\) cycles of any Shigella serotype [52].
Table IX. Flora shift (in %) as a result of post-irradiation storage at 12°C for 84 hours

<table>
<thead>
<tr>
<th>Organisms</th>
<th>mesophilic 0 kGy</th>
<th>mesophilic 4 kGy</th>
<th>psychrotrophic 0 kGy</th>
<th>psychrotrophic 4 kGy</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Gram-positive cocci</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Micrococcus</td>
<td>9</td>
<td>-</td>
<td>2</td>
<td>-</td>
</tr>
<tr>
<td>Staphylococcus</td>
<td>14</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td><strong>Gram-positive rods</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Corynebacterium</td>
<td>34</td>
<td>-</td>
<td>23</td>
<td>-</td>
</tr>
<tr>
<td>Lactobacillus</td>
<td>9</td>
<td>-</td>
<td>6</td>
<td>-</td>
</tr>
<tr>
<td><strong>Gram-negative rods</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Moraxella</td>
<td>25</td>
<td>93</td>
<td>46</td>
<td>88</td>
</tr>
<tr>
<td>Pseudomonas</td>
<td>-</td>
<td>7</td>
<td>2</td>
<td>12</td>
</tr>
<tr>
<td>Enterobacteriaceae</td>
<td>-</td>
<td>-</td>
<td>8</td>
<td>-</td>
</tr>
<tr>
<td><strong>Other</strong></td>
<td>9</td>
<td>-</td>
<td>13</td>
<td>-</td>
</tr>
</tbody>
</table>

Data from [51]

Table VIII shows the immediate effect of irradiation on the microbial association of frozen precooked shrimps originating from Malaysia. In the initial flora mesophilic coagulase negative Staphylococcus and psychrotrophic Micrococcus were predominant; however, after a radiation treatment up to 4 kGy the mesophilic and psychrotrophic association comprised mostly Micrococcus spp.

Subsequently storage studies were carried out at 12 and 21°C [51]. The dominant spoilage flora developing on control shrimps stored at 12°C consisted mainly of psychrotrophic and mesophilic Moraxella spp. and the coryneform group, followed by mesophilic coagulase-negative Staphylococcus spp. After irradiation at 4 kGy Moraxella spp. became the predominant organism within psychrotrophic and mesophilic association (Table IX).
Table X. Flora shift (in %) as a result of post-irradiation storage at 21°C for 36 hours.

<table>
<thead>
<tr>
<th>Organisms</th>
<th>mesophilic</th>
<th>psychrotrophic</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0 kGy 4 kGy</td>
<td>0 kGy 4 kGy</td>
</tr>
</tbody>
</table>

**Gram-positive cocci**
- Micrococcus: 13 - 5
- Staphylococcus: 2 - 3

**Gram-positive rods**
- Corynebacterium: 23 4 22
- Lactobacillus: 13 - 13
- Leuconostoc: 4 - -

**Gram-negative rods**
- Moraxella: 17 72 30 62
- Pseudomonas: 4 - 3 2
- Enterobacteriaceae: 6 - 3
- Acinetobacter: 4 24 18 36
- Other: 14 - 3 -

Data from [51]

The spoilage flora of non-irradiated shrimps developing at 21°C was more heterogeneous than the association at 12°C. It consisted of psychrotrophic and mesophilic Moraxella spp., the coryneform group, Lactobacillus spp., mesophilic Micrococcus spp. and psychrotrophic Acinetobacter spp. In irradiated shrimps stored at 21°C Moraxella spp., followed by Acinetobacter spp. were the most prevalent organisms amongst the psychrotrophic and mesophilic flora (Table X).

Our data corroborate earlier findings of Welch and Maxcy [64,67] who also observed a predominance of Moraxella-Acinetobacter spp. and catalase-positive cocci in food of animal origin irradiated at radiication doses.
Table XI. Microbial community structure of ground black pepper. Counts expressed in log_{10} cfu·g^{-1}.

<table>
<thead>
<tr>
<th></th>
<th>Microorganism</th>
<th>Count</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aerobic mesophilic colony count</td>
<td><em>Clostridium</em> spp.</td>
<td>2.7</td>
</tr>
<tr>
<td>Aerobic mesophilic spore count</td>
<td><em>Enterobacteriaceae</em></td>
<td>4.7</td>
</tr>
<tr>
<td>Surviving 1 min at 80°C</td>
<td>Coli aerogenes</td>
<td>7.7</td>
</tr>
<tr>
<td>Surviving 20 min at 100°C</td>
<td><em>bacteria</em></td>
<td>6.0</td>
</tr>
<tr>
<td>Surviving 20 min at 115°C</td>
<td>Lancefield group D</td>
<td>&lt;1.8</td>
</tr>
<tr>
<td>Anaerobic mesophilic spore count</td>
<td>Streptococci</td>
<td>4.9</td>
</tr>
<tr>
<td>Surviving 1 min at 80°C</td>
<td><em>Yeasts</em></td>
<td>&lt;1.8</td>
</tr>
<tr>
<td>Aerobic thermophilic spore count</td>
<td>Moulds</td>
<td>4.6</td>
</tr>
<tr>
<td>Surviving 1 min at 80°C</td>
<td></td>
<td>&lt;1.8</td>
</tr>
</tbody>
</table>

Data from [70]

These results substantiate the views that low dose (< 4 kGy) irradiation of shrimps: (1) effectively eliminates enteropathogens frequently occurring in such product; (ii) does not present a potential hazard resulting from a shift in the microflora, even when radi-cized shrimps are stored at temperatures up to 21°C. Concurrently it had been established that radicidation at < 4 kGy does not significantly impair the sensory acceptability of shrimps.

**Spices**

Spices reach the trade in severely contaminated condition, with moulds and heat resistant bacterial spores dominating [68-70]; cf Table XI. Sometimes spices contain in addition micro-organisms of health significance such as *Bacillus cereus*, *Clostridium perfringens*, mycotoxin-producing moulds and *Salmonella* spp. Black pepper contaminated with *Salmonella weltevreden* was responsible for several incidents of human salmonellosis over a wide area [71]. In 1981/82 *Salmonella oranienburg* in black pepper caused an outbreak in Norway in which over 120 patients were recorded [72].
Table XII. Effect of irradiation on the aerobic mesophilic colony count and aerobic and anaerobic mesophilic spore counts of black pepper

<table>
<thead>
<tr>
<th>Group</th>
<th>log$_{10}$ cfu.g$^{-1}$</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0 kGy</td>
</tr>
<tr>
<td>aerobic mesophilic colony count</td>
<td>8.0</td>
</tr>
<tr>
<td>aerobic mesophilic spore count</td>
<td></td>
</tr>
<tr>
<td>- surviving 1 min at 80°C</td>
<td>7.7</td>
</tr>
<tr>
<td>- surviving 20 min at 100°C</td>
<td>6.0</td>
</tr>
<tr>
<td>anaerobic mesophilic spore count</td>
<td></td>
</tr>
<tr>
<td>- surviving 1 min at 80°C</td>
<td>7.5</td>
</tr>
<tr>
<td>- surviving 20 min at 100°C</td>
<td>5.9</td>
</tr>
<tr>
<td>Enterobacteriaceae</td>
<td>4.7</td>
</tr>
<tr>
<td>Lancefield D streptococci</td>
<td>4.9</td>
</tr>
<tr>
<td>Moulds</td>
<td>4.6</td>
</tr>
</tbody>
</table>

Data from [70]

A promising physical decontamination method for spices is a "hygienization" treatment with ionizing radiation, which was already used successfully for many years in practice in The Netherlands [73].

In our study with black pepper [70], one of the most highly contaminated spices, a radiation dose of 6 kGy resulted in 4 log$_{10}$ cycles reduction of the aerobic mesophilic colony count. The aerobic mesophilic bacterial spore count, surviving a heat treatment of 1 minute at 80°C and the heat resistant fraction of the aerobic mesophilic bacterial spores, surviving a heat treatment of 20 minutes at 100°C, were reduced by 3, and 6 log$_{10}$ cycles, respectively, at a dose of 4 kGy. Moulds were reduced from 4.1 x 10$^4$ to below 50 c.f.u per gram by a dose of 4 kGy. Lancefield D streptococci and Enterobacteriaceae were reduced by a factor of 10$^4$ to 10$^5$ at a dose of 4 kGy; cf Table XII.

The microbiological quality of customarily marketed spices can, hence, be improved by a treatment with ionizing radiation at a level of 4 to 6 kGy. This also applies to elimination of Enterobacteriaceae, suggesting possibilities for Salmonella-ridicitation. At the doses
indicated the flavour integrity of spices is not changed by the process [71-75].

MONITORING THE MICROBIAL EFFICIENCY OF RADIATION

Principles

In assessing the lethality of any technique for processing for safety it is vital to determine the real numbers of survivors and not a fictitious, arbitrary fraction of their colony forming units [76]. It has been recognized for a long time that a marked proportion of the vegetative microbial cells occurring in foods processed for safety and

![Diagram](image)

*FIG. 1. Solid medium repair (SMR) procedure as applied to damaged, facultatively and strictly aerobic bacteria.*
in those stored under conditions restricting microbial proliferation, particularly chilling and freezing, carry sublethal lesions. Sublethally stressed cells preserve their pathogenetic traits. However, it leads to slower growth, but particularly to incompetence to develop on the customarily used selective media that do not inhibit undamaged populations of the same taxon. Failure to allow for this effect can lead to marked underestimation, i.e. up to six log10 cycles, of the numbers of colony forming units present in a sample and consequently to dramatic overestimation of lethality [76,38]. Therefore monitoring of processing for safety calls for a deliberate repair process ("resuscitation") of stressed cells, before attempts are made to assess their number of colony forming units by selective procedures.

Two different approaches have been elaborated to restore the natural vitality of damaged populations, viz. repair in a suitable liquid medium [79] and resuscitation on a solid medium [77,79]. Due to the distribution of severity of damage over a stressed population, repair is generally not a synchronized process. Consequently, when liquid medium repair methods are used, growth of recovered cells occur in addition to repair, leading to falsely high results. Solid medium repair (SMR) is not affected by such occurrences and therefore the technique of choice in procedures relying on colony counting.

Our recommended procedure for this purpose is presented in Figure 1. It relies on the use of a catalase enriched tryptone soya agar [38] for recovery of impaired populations.

**Recommended simple selective enumeration techniques**

**Enterobacteriaceae.** The medium used is violet red bile glucose agar, allowing the formation of colonies with purple halos as a result of dissimilation of glucose by all Enterobacteriaceae [80]. The medium is previously tested for adequate selectivity and productivity [81] and then used to overlay the solid repair medium incubated for 4-6 hours at laboratory temperature. The temperature of incubation of the overlayed plates depends on the types sought. Taxonomic grouping of isolates relies on subculturing onto MacConkey agar for the assessment of the mode of attack on lactose and subsequent stabbing into the three layered Gram-negative diagnostic tubes
[82] allowing determination of the characteristic traits of types of health or ecological significance.

**Staph. aureus.** Resuscitation is as described for Enterobacteriaceae. Subsequently the repair plates are overlaid with Baird-Parker agar, incubated at 42°C [83] with the usual confirmation procedures.

**Lancefield group D streptococci.** Solid medium repair followed by overlaying by kanamycin aesculin azide agar and incubation at 42°C [84] has been found to allow quantitative recovery with a high degree of selectivity (over 95% of colonies with black halos being Lancefield group D strains) of D streptococci, also of those damaged by freezing or other adverse conditions.

**Spores of the genera Bacillus and Clostridium.** The choice of an optimum heat treatment, mimicking pasteurization is essential. This was found to be 1 min exposure to a temperature of 80°C in a diluent of pH = 6.9 ± 0.1, since this treatment was demonstrated to result in (i) the virtual elimination of the total nonsporing microflora: (ii) sparing the less thermoresistant spores; and (iii) dissipation of the required amount of heat activation for spore germination [85]. The enumeration of colony forming units of aerobic and anaerobic spores can successfully be carried out in poured plates of Schaedler agar under aerobic and anaerobic conditions, respectively [86]; Clostridium spp. are enumerated in poured plates of Differential Reinforced Clostridium agar in an anaerobic atmosphere [87].

**RETROSPECT**

From the experimental data presented in this paper it is evident that markedly improved protection of the public against diseases of microbial etiology transmitted by foods is within reach, reliable elimination of prevalent enteropathogens by radicidation is attainable, while the surviving flora, mainly *Moraxella* spp. and catalase-positive cocci, is not of public health significance [47].
This certainly also applies to pathogenic agents not dealt with experimentally in our investigations, such as helminths and protozoa [42, 6, 55]. The classical defence lines relying on high-level hygiene during slaughter and industrial food handling are insufficient to control in these food-transmitted enteric infections [86].

Consequently, as emphasized by Wilson since 1935 [33], a third line of defence, processing for safety, is required here, as it was in the dairy and later the egg products industry [34]. Radicidation is one of the effective modes of processing for safety of raw and pre-cooked food of animal origin.

Intervention in food manufacture, e.g. by radicidation, tends to increase cost. Consequently industry is not likely to introduce such practices unless they are legally enforced, as in pasteurization of raw milk in many countries. On the other hand, Governments are not inclined to make processing for safety compulsory, unless there are signs of strong support by consumers. Unfortunately, the majority of the consumers consider "a touch of food poisoning" as an inevitable hazard, like catching a cold and are consequently not pressing hard for measures of intervention.

Another important consideration in the adoption of processing for safety by radiation is that of perceived risks related to the process of irradiation at large and its applications to foods in particular. Part of these reservations can be refuted by referring to the wealth of published information pointing to the absence of any risk involved in the consumption of foods processed by irradiation at a level not exceeding 10 kGy [53].

Another health objection raised against food irradiation is that it does not eliminate viruses. This is no doubt true, since viruses show an elevated resistance against radiation [89]. However, at 5 kGy at least one decimal reduction of relevant viruses will occur, which is certainly better than when foods are marketed without any processing.

Another objection often levelled against food irradiation is the security risk of having "a nuclear reactor at every corner of the street". First and foremost food irradiation is not practised in a nuclear reactor. Moreover plants used for this purpose can very well be limited to a few per country of the size of e.g. the United Kingdom and then present of course a security risk that is easy to contain.
So far objections against food irradiation are rational and can be eliminated by the expert. Much more difficult to control are the emotional objections in this area. First of all there is the myth that the effects of food processing per se are detrimental to the consumer's health. These fears can rather easily be refuted by reference to the scientific literature unless holders of such views refer to traits that cannot be assessed. Fears of this nature are similar to the so-called 'Post Hiroshima radiophobia'. It is certainly not for the Health Scientist to deal with such phenomena. Rather should the assistance of Behavioural Scientists be requested, whose experience allows them to deal with phobias per se. Nonetheless the Health Scientist can contribute to the ultimate clearing away of such problems, i.e. by (i) not obsessively pressing for a particular mode of processing for safety; and (ii) continuously providing reassurance based on unbiased data from the scientific literature [43].

One final point has to be made about the attitude of Government Agencies. Their prudence with respect to authorizing food irradiation is certainly laudible. Nonetheless, they should also take into account that by not permitting the radicidation of foods, which are frequently responsible for the transmission of microbial diseases, they prevent industry from protecting the consumer against fully avoidable risks. Hence, the balancing of merely theoretical toxicological hazards against tangible health benefits should be a point of constant concern. Otherwise, history might blame our generation of Health Legislators for being reprehensibly over-anxious.

REFERENCES

Estimate of cases of food- and waterborne illness in Canada and
the United States

[2] GILBERT, R.J.
Food infections and intoxications - recent trends and prospect
for the future. In advances and prospects in food microbiology

The only valid approach to microbiological safety of food,
Intervention as the rational approach to control diseases of microbial etiology transmitted by foods

[5] MANN, J.M.
A prospective study of response error in food history questionnaires: implications for foodborne outbreak investigation

Microbiological quality control

[7] BOUWER-HERTZBERGER, S.A.
Food-transmitted disease of microbial origin. The pathogenesis of food transmitted disease, mainly of microbial etiology in the region of Haarlem, The Netherlands

An analysis of economic costs associated with an outbreak of typhoid fever

Costs resulting from foodborne disease because of mishandling in food service establishments

Foodborne Norwalk Virus

Cytotoxic enterotoxin produced by Aeromonas hydrophila: relationship of toxigenic isolates to diarrheal disease

[12] DUBEY, R.S., SANYAL, S.C.
Characterization and neutralization of Aeromonas hydrophila enterotoxin in the rabbit ileal-loop model

Biochemical characteristics of enterotoxigenic Aeromonas spp.

Phenotypic markers associated with gastrointestinal Aeromonas hydrophila isolates from symptomatic children
Cryptosporidiosis: clinical, epidemiologic and parasitologic review.

[16] SOAVE, R., MA, P.
Cryptosporidiosis: traveler's diarrhea in two families

[17] MARSH, P.K., GORBACH, S.L.
Invasive enterocolitis caused by Edwardsiella tarda

[18] NAGEL, P., SERRITELLA A., LAYDEN, T.J.
Edwardsiella tarda gastroenteritis associated with a pet turtle

Edwardsiella tarda isolated in Israel between 1961 and 1980

[20] O'BRIEN, A.D., LIVELY, T.A., CHEN, M.E., ROTHMAN, S.W., FROMAL, S.B.
Escherichia coli 0157:H7 strains associated with haemorrhagic colitis in the United States produce Shigella dysenteriae 1 (Shiga) like cytotoxin.

Hemorrhagic colitis associated with a rare Escherichia coli serotype.

[22] MARTIN, T., VAN BURGSTEDEN, R.A., POPICK, D.C.
Hemorrhagic colitis associated with Escherichia coli 0157:H7.

[23] SEDOVA, N.N., NEFEDEVA, N.P., SKIRKO, B.K.

[24] BATISH, V.K., CHANDER, H., RANGANATHAN, B.
Characterization of deoxyribonuclease-positive enterococci isolated from milk and milk products

Norwalk virus gastroenteritis in volunteers consuming depurated oysters
[26] ROKOSZEWSKA, J., SMYKAL, B., BOGDANOWICZ, E.
Mass outbreak of food poisoning by goulash contaminated with
*Pseudomonas aeruginosa*

[27] BODEY, G.P., BOLIVAR, R, FAINSTEIN, V., JADEJA, L.
Infections caused by *Pseudomonas aeruginosa*

[28] APPLETON, H, PALMER, S.R., GILBERT, R.J.
Foodborne gastroenteritis of unknown aetiology: a virus infection?

[29] APPLETON, H, BUCKLEY, M., MAWER, S.L.
Virus particles in oysters

*Vibrio vulnificus* - A gastronomic hazard

[31] BRYAN, F.L.
Hazard analysis critical point approach: epidemiological rationale and applications to food service operations.

Epidemiological studies on *Salmonella* in a certain area
I. The presence of *Salmonella* in man, pigs, insects, seagulls and in food and effluents

[33] WILSON, G.S.
Symposium on food microbiology and public health: general conclusion

[34] LEE, J.A.
Recent trends in human salmonellosis in England and Wales: the epidemiology of prevalent serotypes other than *Salmonella typhi-murium*

[35] SMITH, M.G., GRAHAM, A.
Destruction of *Escherichia coli* and salmonellae on mutton carcasses by treatment with hot water

[36] EUSTACE, I.J.
Control of bacterial contamination of meat during processing
Dekontamination schlachtwarmer Rinderkörper mit organischen
Säuren
Fleischwirtschaft 59, (1979) 656-663.

[38] VAN NETTEN, P., VAN DER ZEE, H., MOSSEL, D.A.A.
A note on catalase enhanced recovery of acid injured cells of
gram negative bacteria and its consequences for the assessment of
the lethality of L-lactic acid decontamination of raw meat sur-
faces

F.J.M.
Conditions for the use of lactic acid as a decontaminant in the
meat industry.
Veter. Quart. 7 (1985). In Press.

[40] LEY, F.J., KENNEDY, T.S., KAWASHIMA, K., ROBERTS, D., HOBBS, B.C.
The use of gamma radiation for the elimination of Salmonella from
frozen meat

[41] MOSSEL, D.A.A.
The elimination of enteric bacterial pathogens from food and feed
of animal origin by gamma irradiation with particular reference
to Salmonella radicidation
Journal of Food Quality 1, (1977) 85-104.

[42] KAMPELMACHER, E.H.
Irradiation for control of Salmonella and other pathogens in
poultry and fresh meats

[43] MOSSEL, D.A.A., VAN NETTEN, P.
Whither protection of the consumer against enteropathogenic bac-
teria on fresh meats and poultry by processing for safety
In: Food Irradiation Now. Martinus Nyhoff. The Hague and Boston,

[44] GORESLINE, H.E., INGRAM, M., MACUCH, P., MOCQUOT, G., MOSSEL,
D.A.A., NIVEN, C.F., THATCHER, F.S.
Tentative classification of food irradiation processes with
microbiological objectives.
Nature 204, (1964) 237-238.

[45] DYER, J.K., ANDERSON, A.W., DUTIYABODHI, P.
Radiation survival of food pathogens in complex media

Radiation resistance and injuring of Yersinia enterocolitica
[47] MAXCY, R.B.
Irradiation of Food for Public Health Protection

[48] MULDER, R.W.A.W.
Ionising energy treatment of poultry

Low dose gamma irradiation of raw meat. I. Bacteriological and
sensory quality effects in artificially contaminated samples

Low dose irradiation of raw meat. II. Bacteriological effects on
samples from butcheries

Radiation of precooked frozen tropical shrimp. A microbial

Elimination of Shigella from frozen precooked tropical shrimps

[53] WHO 1981
Wholesomeness of irradiated foods

Shelf-life extension of minced beef through combined treatments
involving radurization

[55] DEMPSTER, J.F.
Radiation Preservation of Meat and Meat Products: A Review

[56] BRYNJOLFSSON, A.
Food Irradiation in the United States
Proc. of the 26th Meet. European Meat Res. Workers, Colorado

[57] INGRAM, M.*, FARKAS, J.
Microbiology of foods pasteurized by ionising radiation

[58] MOSSEL, D.A.A.*, DRION, E.F.
Risk analysis. Its application to the protection of the consumer
against food-transmitted diseases of microbial aetiology
[59] MOSSEL, D.A.A., DE GROOT, A.P.
The use of pasteurizing doses of gamma radiation for the destruction of *Salmonellae* and other *Enterobacteriaceae* in some foods of low water activity.

[60] OOSTEROM, J., UYL, Ch. den, BANNFFER, J.R.J., HUISMAN, J.
Epidemiological investigations on *Campylobacter jejuni* in households with a primary infection

[61] BRYAN, F.L.
Foodborne diseases in the United States associated with meat and poultry

[62] LAMBERT, J.D., MAXCY, R.B.
Effect of gamma radiation on *Campylobacter jejuni*.

Lethality and flora shift of the psychrotrophic and mesophilic bacterial association of frozen shrimps and chicken after radiation
In: *Microbial associations and interactions in food* (Eds. I. Kiss, T. Deak, K. Incze).

[64] WELCH, A.B., MAXCY, R.B.
Characteristics of some radiation-resistant hemolytic micrococci isolated from chicken.

[65] MULDER, R.W.A.W.
*Salmonella* radicidation of poultry carcasses

Microbiological quality of frozen precooked and peeled shrimp from South East Asia and from the North Sea

[67] WELCH, A.B., MAXCY, R.B.
Characterization of radiation-resistant vegetative bacteria in beef.
[68] BAXTER, R., HOLZAPFEL, W.H.
A Microbial investigation of Selected Spices, Herbs and Additives in South Africa.

[69] SCHWAB, A.H., HARPESTAD, A.D., SWARTZENTRUBER, A., LANIER, J.M.,
WENTZ, B.A., DURAN, A.P., BARNARD, R.J., READ, J.R.
Microbiological Quality of Some Spices and Herbs in Retail Markets.

[70] SOEDARMAN, H., STEGEMAN, H., FARKAS, J., MOSSEL, D.A.A.
Decontamination of black pepper by gamma radiation
In: Microbial associations and interactions (Eds. I. Kiss, T. Deák, K. Incze).

[71] LAIDLEY, R., HANDZEL, S., SEVERS, D., BUTLER, R.
Salmonella weltevreden outbreak associated with contaminated pepper

[72] GUSTAFSEN, S., BREEN, O.
Investigation of an outbreak of Salmonella orienburg infection in Norway caused by contaminated black pepper.

[73] FARKAS, J.
Radiation processing of dry food ingredients

[74] WEBER, H.
Gewürzentkeimung: Einflüsse von Elektronen und Gammastrahlen auf die Qualität verschiedener Gewürze

[75] EISS, M.I.
Irradiation of spices and herbs

[76] MOSSEL, D.A.A., VAN NETTÈN
Harmful effects of selective media on stressed micro-organisms—nature and remedies.

[77] MOSSEL, D.A.A., RATTO, M.A.
Rapid detection of sublethally impaired cells of Enterobacteriaceae in dried foods
MOSSEL, D.A.A., VELDMAN, A., EELDERINK, I.
Comparison of the effects of liquid medium repair and the incorpo­ration of catalase in McConkey-type media on the recovery of Enterobacteriaceae sublethally stressed by freezing

SPECK, M.L., RAY, B., READ, R.B.
Repair and enumeration of injured coliforms by a plating proce­
dure

MOSSEL, D.A.A., EELDERINK, I., KOOPMANS, M.T.A.G.F., VAN ROSSEM, F.
Influence of carbon source, bile salts and incubation temperature on recovery of Enterobacteriaceae from foods, using MacConkey­
type agars

MOSSEL, D.A.A., BONANTS-VAN LAARHOVEN, T.M.G., LIGTENBERG-MERKUS, A.M.Th., WERDLER, M.E.B.
Quality assurance of selective culture media for bacteria, moulds and yeasts: An attempt at standardization at the international level

MOSSEL, D.A.A., EELDERINK, I., SUTHERLAND, J.P.
Development and use of single, 'polytropic' diagnostic tubes for the approximate taxonomic grouping of bacteria isolated from foods, water and medicinal preparations
Zentralblatt für Bakteriologie und Parasitenkunde, Abt. I, Orig.

VAN DOORNE, H., PAUWELS, H.P., MOSSEL, D.A.A.
Selective isolation and enumeration of low numbers of Staph.
aureus by a procedure that relies on elevated-temperature culturing

MOSSEL, D.A.A., BIJKER, P.G.H., EELDERINK, I.
Streptococci of lancefield groups A, B and D and those of baccal origin in foods: their Public Health significance, monitoring and control

The enumeration of "all" spore heaving cells of Bacillaceae in heat-processed foods.
Antonie van Leeuwenhoek 39, (1973) 656.

DE WAART, J., POUW, H.
Studies on the suitability of blood free media for the enumera­tion of Clostridia
[87] GIBBS, B.*M.*, HIRSCH, A.*
Spore formation by clostridium species in artificial medium

[88] GERATS, G.*E.*, SNIJDER, J.*M.*A.*, VAN LOGTESTIJN, J.*G.*
Slaughter techniques and bacterial contamination of pig
carcasses
Proceedings of the 27th European Meeting of Meat Research

[89] SULLIVAN, R.*, FASSOLITIS, A.*C.*, LARKIN, E.*P.*, READ, R.*B.*, PEELER,
J.*T.*
Inactivation of thirty viruses by gamma radiation
THE INTEREST OF THE PORK INDUSTRY IN THE UNITED STATES OF AMERICA IN IRRADIATION

C.D. VAN HOEWELING
National Pork Producers Council,
Washington, D.C.

D. MEISINGER
National Pork Producers Council,
Des Moines, Iowa

United States of America

Abstract

THE INTEREST OF THE PORK INDUSTRY IN THE UNITED STATES OF AMERICA IN IRRADIATION.

Trichinosis is a disease caused by a microscopic parasite, Trichinella spiralis, which becomes encysted in the muscle after migrating from the intestine. The migration of heavy infestations can result in a painful, debilitating disease. Pork is one of the sources of this parasite. The potential hazard of trichinosis is a reason some people do not eat pork. Various attempts have been made to quantify how much of a deterrent trichinosis is to pork consumption. The pork producers in the United States of America are convinced that eliminating this disease would substantially increase pork consumption and thereby increase the profitability of producing pork. The pork producers in the USA want to assure American consumers and those in other countries that American pork is safe. The National Pork Producers Council (NPPC) desires to use all possible methods for making pork trichina-safe. One of the processes they want to have utilized is irradiation and approval is being sought. This desire is motivated by knowledge that 30 krad or less exposure to $^{137}$Ce has been shown to be effective in inactivating the trichina. Further encouragement was received by the WHO/FAO/IAEA expert committee’s conclusion relative to the safety or irradiation at doses of mrad or less. The Food and Drug Administration’s (FDA) proposal to categorize irradiation at 100 krad and below as safe was also encouraging. A petition has been submitted to FDA requesting approval for pork irradiation. Research studies confirming the effectiveness of low level (15–30 krad) irradiation and the microbial and organoleptic changes in irradiated pork will be reported. The results of a consumer survey conducted by NPPC will also reveal that consumers are concerned about irradiation but less than about chemicals and pesticides. Other results of the survey will be reported and discussed. Finally, the likelihood of irradiation of pork being approved in the USA will be discussed.

Trichinosis is a parasitic disease caused by a microscopic nematode Trichinella spiralis.[1] This parasite, which becomes encysted in the muscle of swine and other carnivorous animals, has the ingestion of meat as part of the life cycle (see Fig. 1). As can be seen from the diagram, the ingestion of infested meat by a pig or other animal can result in the life cycle being completed in one animal. It is readily apparent that this cycle can
be completed in man if infested meat is ingested. Completion of the life cycle in man with the migration of the larva can cause a debilitating painful disease. The danger of contracting this disease from eating pork has long been a deterrent to pork consumption. It is likely that Moslem and Jewish laws prohibiting the eating of pork were based on illnesses associated with pork consumption and continue until the present time.

The pork producing industry of the United States of America (USA) has long suspected that this threat of trichinosis has reduced the consumption of pork in the USA.

A pork irradiation feasibility study projected a two per cent increase in the demand for pork in the short term if trichinosis elimination resulted in a positive demand shift.[2] If the increased demand occurred, this study projected US$402 million increased profit to the pork producers. In the longer term they projected an increase of pork exports by one-third which would be equal to one percent of the domestic demand.

The same study emphasized the importance of consumer acceptance of the irradiation process and the elimination of trichinosis. If there were in fact a two per cent reduction in demand for pork these figures projecting increased profit would be reversed and could result in an equal loss to pork producers.

This emphasizes the importance of consumer awareness of the benefit from eliminating any threat from trichinosis and accepting irradiation as 'safe.'

There have been questions raised in the USA relative to cooking of pork in microwave ovens.[3] These questions arise because of the unequal temperatures that can occur during microwave cooking and the possibility of trichina cysts surviving the cooking process.

Consumer surveys conducted by the National Pork Producers Council have revealed that the longer cooking pork requires, a means of reducing the potential of contracting trichinosis, detracts from the desirability of pork meat. As many as 80 to 90 per cent of consumers surveyed considered the longer cooking to be undesirable. Added to this is the fact that the longer cooking at higher temperatures reduces the succulence of the pork meat and thereby reduces its palatability. This is also confirmed by the response of 40 to 50 per cent of the consumers surveyed who felt that pork was drier than other meats after cooking.

Admittedly, the actual impact of trichinosis on pork consumption is difficult to assess because conclusive evidence at this point is virtually impossible to obtain. These figures do suggest that the elimination of the threat of this parasite in pork supply would significantly increase pork consumption and, therefore, the profitability of pork production.
Various estimates have been made in regard to the incidence of *Trichina spiralis* infestation in swine raised in the USA. There is general agreement that perhaps less than one-tenth of one per cent of the hogs raised are infected by this parasite. Even at this low level there may be over 100,000 trichina-infected hogs slaughtered each year in the USA.

Because of the infestation of various undomesticated animals, the likelihood of completely eliminating the disease from swine
seems very remote. With more and more swine in the USA being raised in what is referred to as 'confinement rearing,' that is, enclosed in buildings and without contact with 'wild' animals that normally habitate farm environs, the incidence of trichinosis has decreased. Also, in recent years, strict regulation of feeding of food-waste to swine has further reduced the incidence of this parasite in USA swine.\[5\]

Fortunately, the reported outbreaks of this disease in human beings has also decreased.\[6\] This reduction coincided with the careful regulation of the feeding of food-waste to swine. In more recent years, the incidence has been reduced to between 100 to 200 reported cases per year. However, because of the potential threat of this disease, there is still a percentage of the population who do not eat pork. Unfortunately, as long as some pork or pork products contain a relatively heavy infestation of trichina there will continue to be some human trichinosis.

There are recognized methods for reducing the hazard of trichinosis by testing swine at slaughter. In Europe, for many years, there has been a microscopic examination for the cysts in a portion of the tissue, usually from the diaphragm. This procedure is known as trichinoscopy.\[7\] This system, admittedly, only detects the most heavily infected animals, but seems to have been almost completely successful in preventing the human disease in countries where it is used.

In the USA, the United States Department of Agriculture Food and Safety Inspection Service has regulations covering the heating, freezing, or drying of pork products which will render the parasite inactive.\[8\] These are requirements for pork products that are sold 'ready-to-eat.' Fresh pork in the USA is sold with the knowledge that it must be heated to a temperature of at least 170°F or 77°C. This practice has been very effective in controlling the occurrence of the disease in the USA, as evidenced by the very few cases that occur as referred to earlier.

In 1982, for the reasons outlined above, the National Pork Producers Council established a task force to study and recommend how trichinosis could be further reduced or eliminated in the USA. This task force set the goal of having all the retail pork in the USA safe from trichinosis by 1987.

The task force recognized from the outset that total elimination of this parasite from swine was not practical. It was aware that other testing and treatment methods would be required in addition to the established methods of heating, freezing, and drying of pork and pork products. Methods used to detect infection in addition to the trichinoscopy would have to be developed and utilized. The pooled-digestion methods have been employed on a trial basis in the USA. A modification of this pooled-digestion procedure is the stomacher method, which is used widely...
in Denmark. Recently the enzyme-linked immunosorbent assay method (ELISA)\(^\text{[10]}\) has been undergoing stages of testing leading up to recognition in the USA. The purpose of all these methods and tests is to identify those animals that are infested with Trichina spiralis. Food from animals shown to be infected would have to be treated to inactivate the parasite before the meat was released for consumption.

One procedure which the NPPC Task Force anticipated utilizing from the beginning was the irradiation of pork.

Experimental work has been conducted over the years to determine the irradiation of pork could render the trichina parasite sterile.\(^\text{[11,12]}\) Additional experimental data were developed by a co-operative research project.\(^\text{[13]}\) These studies confirmed the efficacy of gamma radiation at a dose of 15 to 30 krad for the sterilization of Trichina spiralis in pork. Pigs were heavily infected and irradiated in another facility located at the Scandia National Laboratory in Albuquerque, New Mexico.\(^1\) The effectiveness of the irradiation level was tested by means of a rat bio-assay described previously by Kotula, et al.\(^\text{[14]}\) The results show that there is a complete inhibition of the trichina development at an irradiation of 15 krad. Studies using different cuts of infected pork show there is no variability in the radio-sensitivity of the trichina in different muscles. Irradiation is effective regardless of whether the whole carcass or ground pork are irradiated. The age of the cyst was shown not to be a variable for radio-sensitivity. The data clearly indicate that 30 krad caesium-137 gamma radiation can be delivered to split market weight hog carcasses with acceptable uniformity, and that such a dose can provide a substantial margin of safety for human consumption of even heavily infected meat.

With the recognition of the World Health Organization in 1981, that foods irradiated at doses up to 10 kGy or 1 mrad presents no toxicological hazard,\(^\text{[15]}\) there was a new enthusiasm for irradiation of pork. Furthermore, the Food & Drug Administration's published proposal in the Federal Register on 14 February 1984 \(^\text{[16]}\) that food treated at levels of 100 krad or less were considered safe for human consumption, appeared to increase the possibility of securing approval for irradiating pork. The knowledge that the irradiation of pork for the elimination of the infectiveness of trichina parasite can be accomplished with an adequate margin of safety at 30 krad exposure was also reassuring. All of these factors provide encouragement for the possibility of the use of irradiation in the USA for the treatment of pork.

It was recognized that there should be additional data in regard to the effect of even a low dose of radiation on the palatability of pork. Mattison, et al.,\(^\text{[17]}\) investigated the effect

\(^1\) 1 rad = 1.00 \times 10^{-2} \text{ Gy.}\)
of 100 krad irradiation on the microflora, sensory characteristics, and the development of oxidative rancidity of vacuum-packed pork loins, after irradiation and during low temperature (4°C) storage up to 21 days. The conclusions were that irradiation significantly reduced the number of mesophiles, the psychrotrophs, anaerobic bacteria and staphylococci with the effect on mesophiles and psychrotrophic supported organisms being the greatest. As the increased storage progressed up to 21 days, the difference between the irradiated and non-irradiated pork became greater indicating a potential for increased beneficial effect of low doses of irradiation with longer holding of the product after treatment. The effect of irradiation on the sensory characteristics was minimal. Taste panelists could significantly detect differences between irradiated and non-irradiated pork only during early storage (2 days) and no significant differences were observed thereafter up to 14 days of storage. The irradiated pork had less cooking loss and lower thiobarbituric acids (TBA) values than non-irradiated samples. The differences were not significant nor were the rancidity TBA levels approached for either treatment.

It is reassuring that these studies have shown that the irradiation of pork at the low levels necessary to inactivate the trichina parasite does not affect the organoleptic characteristics or microbial populations adversely. Because of these data, and the reaffirming of earlier studies in regard to the effectiveness of irradiation, the pork industry is anxious to have this irradiation procedure recognized and approved.

Since the present requirements of the Food, Drug & Cosmetic Act require the submission of a food additive petition for the application of irradiation to food,[18] petitions have been submitted to the Food and Drug Administration (FDA) for approval. Irradiation Technology, Inc. has submitted a petition to the FDA to approve the irradiation of pork.[19] The NPPC is also preparing a food additive petition seeking this same approval. There is no information available from FDA about the status of the application submitted.

One of the major obstacles to irradiation in the USA is the acceptance by consumers of the process. In an effort to determine what knowledge consumers in the USA had about irradiation and how they regarded the procedure, the NPPC with the co-operation of the Department of Energy conducted a survey of consumers.[20] This was a nationwide telephone survey of 1000 households. The sample was carefully stratified and objectively selected according to the various population characteristics of the various geographic areas.

One of the questions asked was: How carefully do you read labels on food? Fig. 2 reflects the response to this question. The most striking fact is that 16 per cent or almost one-sixth of the respondents said they never read a label and another 30
30\% said only occasionally. This infers that only 54 per cent of the people read labels most of the time or all of the time.

Another question asked pertained to their level of concern about food treatments and effectiveness. Fig. 3 reveals the results of this question. It is apparent from reviewing this graph that without question the current treatment methods of sprays and preservatives, the risk of disease, and concern about waste or spillage are problems that the consumers considered to be a major concern to them.

Another question asked was their awareness of the irradiation process. It was described as gamma waves, irradiation, ionization, and combined. Fig. 4 shows that approximately one out of four respondents were at least aware of one of the terms as a possible method of sterilization or preserving foods. Fig. 5 shows the relative concerns when each of the descriptions is evaluated. It is apparent that the term ionization is of least concern and that the term irradiation was of somewhat more concern but there is not a great deal of difference.

Fig. 6 is an illustration of their concern about irradiation when compared with other food treatments. What is perhaps disturbing is that almost 40 per cent of the respondents did list irradiation as a major concern. It is significant however, to note that the percentage that list chemical sprays and preservatives is higher than irradiation. When major and minor concerns are combined, irradiation is currently clearly of lower concern than either of the other treatment alternatives tested.
**FIG. 3. Level of personal concern about current food treatment and effectiveness.**

**FIG. 4. Awareness of 'irradiation' processing using three different descriptions.**
FIG. 5. Initial level of concern for process using three different descriptions.

FIG. 6. Comparison of personal concern levels. Irradiation versus current methods.
Fig. 7 is an illustration of what respondents felt was the most persuasive of the attributes that they would consider to be favouring irradiation. It can be seen from this figure that the information that there was no radiation in the food and that no chemicals would be used was most persuasive to 40 per cent of the respondents. Also a significant per cent were influenced by the fact that radiation was utilized for food for patients whose immune responses are impaired. It is noteworthy too that FDA approval would also be a significant attribute.

Another attempt to determine what is considered to be the most persuasive reasons to irradiate food in addition to attributes already discussed is reflected in Fig. 8. Again the reduction in the use of chemicals and preservatives is a very significant factor, but not as great as the belief it would ease world hunger.

Finally, Fig. 9 reveals the influence on the respondents both initially and after the attributes had been presented to dispel the notion of some disadvantage to the process. It is interesting to note that the level of concern after all the facts and attributes had been presented is essentially the same as after the initial presentation. The only significant change after the attribute presentation would be a slight increase in the number of people that hold no concern about the process and a reduction in the number of people undecided.
Reduce spoilage (6%)
Lower cost (8%)
Remove preservatives (11%)
Reduce chemicals (17%)
Extend shelf life (5%)
No nutrition loss (4%)
Not frozen (2%)
Taste same/cook less (3%)
Don’t know (9%)
Ease world hunger (35%)

100% represents those respondents with at least one factor rated as at least a "minor advantage" for the process. (N = 988)

**FIG. 8.** Most persuasive of additional attributes in favour of the process.

**FIG. 9.** Comparison of consumer concern before and after attribute presentation.
As you can readily see, there are formidable obstacles to be overcome if pork is to be irradiated in the USA. For many years, the effectiveness of irradiation for the sterilizing of parasites has been known. The obstacle to the use of irradiation has been the recognition of the process as a safe procedure. It was hoped more recently that such approvals would be forthcoming with the WHO/FAO/IAEA expert committee report recognizing the safety of the process at regulated doses. The FDA publication of a proposal to recognize low-level irradiation as safe added to this optimism. Unfortunately, the assurances of these authorities have not overcome the hysteria that this food preservative process occasions among those who claim to represent the consumers in the USA.

The reports of positive actions taken by Canada and the acceptance of the process in many other countries of the world does not seem to be convincing to these vocal opponents of moving positively in the USA. Therefore, it is doubtful that the irradiation of pork will be a reality in the USA any time soon. This will not deter the NPPC in its quest to have the irradiation of pork be approved and utilized in the USA.

REFERENCES


[6] Ibid.


LEGISLATION AND ACCEPTANCE
OF IRRADIATED FOOD

(Session V)

Chairman

L. SAINT-LÈBE
France
THE REGULATORY INVOLVEMENT OF THE FOOD SAFETY AND INSPECTION SERVICE IN FOOD IRRADIATION

R.E. ENGEL
Food Safety and Inspection Service,
United States Department of Agriculture,
Washington, D.C.,
United States of America

Abstract

THE REGULATORY INVOLVEMENT OF THE FOOD SAFETY AND INSPECTION SERVICE IN FOOD IRRADIATION.

As part of its responsibility for ensuring that meat and poultry products are safe and wholesome, the Food Safety and Inspection Service (FSIS) is currently considering the implications of food irradiation as a preservative technique for meat and poultry. In the United States of America, food irradiation is regulated by the United States Food and Drug Administration (FDA), which regards irradiation as a food additive; FSIS is required to act in agreement with FDA guidelines for its use. FDA has recently solicited comments on its proposal of February 1984, to allow the use of low levels of ionizing radiation for preserving food products and higher levels for the disinfestation of spices. Although meat and poultry products are not included in the current proposal, it is possible that applications for these products will be approved in the future. At low levels, for example, the shelf-life of fresh meat and poultry could be extended. In addition, Trichina infestation in fresh pork can be controlled effectively at 30 krad. At higher levels, meat and poultry products could be sterilized and thus safely stored for years without refrigeration. If FDA approves the use of food irradiation for meat and poultry products, FSIS must be ready to change its regulatory procedures to meet the demands presented by a newly implemented technology. FSIS is particularly concerned about the impact of irradiation on regulatory issues such as labelling, nutritional quality, public health, and plant and equipment design. If irradiation is approved by FDA, FSIS will issue regulations governing its application in meat and poultry processing establishments. Whether irradiation officially remains an additive or is redefined as a process, certain generic procedures would have to be completed before the technology could be put in place. In preparing a regulation, FSIS must meet the requirements of the Administrative Procedure Act, which opens the process to consumer comment. Furthermore, FSIS would need to train its inspectors to deal with the new technology. In sum, FSIS would have to address a large complex of factors before irradiation could become a standard application in meat and poultry production. If timeliness is important, early involvement on the part of FSIS appears to be essential.

INTRODUCTION

As part of its responsibility for ensuring that meat and poultry products are safe and wholesome, the Food Safety and Inspection Service (FSIS) of the U.S. Department of
Agriculture (USDA) is currently considering the implications of food irradiation as a preservative technique for meat and poultry. In the United States, food irradiation is regulated by the U.S. Food and Drug Administration (FDA), which by law regards irradiation as a food additive; FSIS is required to act in agreement with FDA guidelines for its use. FDA is now evaluating comments on its February 1984 [1] proposal to allow the use of low levels of ionizing radiation for preserving food products and higher levels for the disinfection of spices. Although meat and poultry products are not included in the current proposal, it is possible that applications for these products will be approved in the future. If FDA approves the use of food irradiation for meat and poultry products, FSIS must be ready to change its regulatory procedures to meet the demands presented by a newly implemented technology.

There is, of course, nothing new about radiation in itself: it is a purely natural phenomenon, always potentially available to man, that he has learned to harness. The scientific conception of radiation as a physical event within an atom — statistical, predictable, and measurable — is now nearly a century old. The concept and basic technology of food irradiation dates back almost 40 years.

The process incorporates the use of cobalt-60 (60Co) or cesium-137 (137Cs) to produce an energy field that is used to inactivate unwanted bacteria within the foods being processed. This technique is used today to sterilize pharmaceutical products and medical supplies, as well as to process the food that our astronauts have been consuming for the last decade. Since 1959 some 40 irradiated food products have been approved in over 20 countries; irradiation has proved especially popular in developing countries, where refrigeration is not widely available and spoilage is a significant problem. Commercial irradiation in the United States, however, is limited to only a few products: potatoes, wheat and wheat flour, and spices. It has not been extensively pursued because of several factors: the availability of alternative preservatives and fumigants, regulatory barriers, questions about its practicality and cost advantages, and concern over consumer acceptance.

Current Status and Regulatory Aspects of Food Irradiation

Significant radiation studies in the United States began in the early 1950's, when both irradiation techniques and processing equipment were developed. The U.S. Atomic Energy Commission (AEC) and the U.S. Department of the Army (DA) sponsored most of the early studies.
The past 3 decades have shown advances and reversals in the evolutionary process from the laboratory to industry. There were two major setbacks in the 1960's when FDA denied a DA petition for approval of irradiated ham and revoked approval of irradiated bacon in accordance with the 1958 amendment to the Federal Food, Drug and Cosmetic Act (FD&C). Food irradiation was redefined in the legislation as a food additive and, thus, is not permitted for human consumption until approval is granted by FDA. The law also requires FDA approval for packaging materials in contact with the food during radiation processing [2].

In 1976 the Food and Agriculture Organization, International Atomic Energy Agency, World Health Organization (FAO/IAEA/WHO) Joint Expert Committee on the Wholesomeness of Irradiated Food (JECFI) evaluated the experimental evidence for the wholesomeness of nine foods. The meeting produced the following results: 1) recognition of food irradiation as a process (controverting the 1958 FD&C Act); 2) recognition of the importance of the radiation-chemistry approach to wholesomeness evaluation, in tandem with animal feeding and cytotoxicity studies; 3) unconditional acceptance of irradiation of wheat and wheat products (15-100 krad for sprout inhibition), chicken (200-700 krad for refrigerated life extension and pathogen elimination), papaya (50-100 krad for prolongation of fresh market life by partial elimination of spoilage organisms); and 4) provisional (pending unconditional) acceptance of irradiation of onions (2-15 krad for sprout inhibition), fresh cod, and redfish (100-200 krad to reduce numbers of spoilage and pathogenic microorganisms and to extend refrigerated life at or below 3° C), and rice (10-100 krad for insect disinfestation).!

In 1977 the Codex Alimentarius Commission (CAC) issued two publications for comment: General Standards for Irradiated Foods and a Code of Practice for the Operation of Irradiation Facilities Used in the Treatment of Foods. The draft reports embodied the conclusions and recommendations of the 1976 JECFI meeting; they became the Recommended Standard and Code of Practice at the 1979 Commission session.

In 1979 FDA, which is represented on both the JECFI and the CAC, established an inhouse committee to develop criteria for evaluating the safety of irradiated foods. The criteria, however, stopped short of a comprehensive evaluation of

\[ 1 \text{ rad} = 1.00 \times 10^{-2} \text{ Gy}. \]
existing toxicological data to determine whether any irradiated food had been demonstrated as safe. The FDA committee submitted its final report, Recommendations for Evaluating the Safety of Irradiated Foods, in 1980. After considering projected levels of human exposure, qualitative and quantitative estimates of unidentified radiolytic products, and sensitive toxicological tests, the committee stated the following:

1. Foods irradiated to doses not exceeding 100 krad are wholesome and safe for human consumption (and require no safety testing to market).

2. Foods composing no more than 0.01% of the daily diet and irradiated to 5000 krad (e.g., spices) are also considered safe for human consumption, with no toxicological testing required.

3. When foods composing more than 0.01% of the daily diet are irradiated at doses above 100 krad, short-term mutagenicity tests must be conducted, plus 90-day feeding studies with one rodent species and one nonrodent species. For the animal feeding studies, the food may be lyophilized (freeze-dried) and incorporated into the animal diet at the highest concentration that does not compromise the nutritional requirement of the test species. Unequivocal negative responses in the required test are sufficient to establish the safety of the irradiated food under test.

In 1980 meetings, the Joint IAEA/FAO/WHO JECFI committee reviewed all available toxicological and radiation chemistry data and evaluated the wholesomeness of irradiated foods. The JECFI concluded that "the irradiation of any food commodity up to an overall average dose of 10 kGy or 1 Mrad presents no toxicological hazard; hence, toxicological testing of foods so treated is no longer required." Further, it stated that "1 Mrad introduces no special nutritional or microbiological problems." It called for further wholesomeness studies of the sterilizing dose range of 5 Mrad. In effect, the JECFI put to rest the toxicological questions regarding food irradiation (to the interim overall average dose limit of 10 kGy), urging that "the technological and economic feasibility of food irradiation on an industrial scale should be established" [3].

The FDA responded to petitions in 1983 and approved the use of $^{60}\text{Co}$ and $^{137}\text{Cs}$ for applying radiation doses of up to 1 Mrad to reduce or control microbial contamination of spices, natural flavorings, and dehydrated seasonings [5]. On February 14, 1984, FDA published in the Federal Register a notice of proposed rulemaking for the use of ionizing radiation to treat food. The proposed regulations would permit food to be irradiated to inhibit the growth and maturation of fresh fruits and vegetables to disinfect food of insects at doses not to exceed 100 krad, and to disinfect spices of microbes at doses not to exceed 3 Mrad. The proposed regulation, in addition, would require that records be kept for 1 year past the expected shelf-life of the product and that these records be available for FDA inspection. In June 1984, the use of ionizing radiation at the 1 Mrad level to control insect infestation of spices was approved.

As of this writing there are six irradiation petitions pending at FDA, dealing with a variety of irradiation issues [6]. It appears from all indications that food irradiation will be approved for use on agricultural food commodities by mid-summer of this year. FSIS has recognized the potential benefits of this technology as a way of reducing pathogens on meat and poultry products and eliminating helminths from pork.

A possible sign of things to come is the legislation introduced during the last session of the United States Congress that would have reclassified irradiation as a process rather than an additive. The legislation was endorsed by several agricultural, scientific, and industrial organizations, including the American Medical Association. Although the bill was not enacted, it has been reintroduced in this year's Congressional session [7]. It would encourage commercial development and consumer education programs. The next several years could show a spiraling upward growth in this technology.

Applications for Meat and Poultry

There are numerous possible applications of irradiation in the production of meat and poultry. One important intrinsic advantage of irradiation is that the slight temperature increase during processing has little or no effect on heat-sensitive qualities of food such as flavor, texture, odor, and nutritional quality. This fact sharply distinguishes irradiation from other preservation techniques, such as canning.
One possible area for the use of irradiation that has received considerable research attention is the low-dose treatment of fresh meats to extend freshness beyond the usual period. Fresh meat products constitute the great bulk of meat consumed in the United States; those products spoil rapidly, as a result of microbiological activity. The most common preservation techniques are the maintenance of cold storage and processing areas and delaying retail preparation to minimize the exposure of surface area to aerobic bacteria. Low-dose irradiation of fresh meat products would delay microbial spoilage and extend handling life, thereby making possible a greater flexibility in distribution.

Of considerable interest at the moment is the use of irradiation to control bacteria that cause food poisoning. The most significant of these pathogens is Salmonella, which is responsible for many of the cases of food poisoning reported in the United States. It has been estimated that for every reported case there are up to 100 not reported, thus indicating that there may be as many as 2.5 million cases of salmonellosis in the United States each year [8]. The illness is responsible for approximately 20 deaths annually. It takes a major financial toll in costs from medical care and lost productivity and income, estimated to be as much as $2 billion each year [9].

A considerable amount of research has been done on the irradiation of poultry carcasses to control salmonellae. One major study found that a medium dose of 250 krad combined with a handling-environment temperature of 1.6°C (34.9°F) resulted in a product that was essentially free of salmonellae and that could be kept safely, under refrigeration, for up to 20 days [10]. This same study reported that higher doses would allow for a higher handling temperature but would result in color changes that could make the product undesirable. No regulatory action has been proposed yet on these techniques.

The Use of Low Dose Irradiation to Control Trichinosis

A number of factors have limited both domestic and international markets for U.S. pork. One of great importance is trichinosis. Trichinosis is caused by a small parasitic nematode, Trichinella spiralis, that settles in the muscles of pigs and many carnivorous animals, including man. People become infected by eating undercooked meat containing the cysts. Swine are usually infected from eating meat scraps in

\[1 \text{ US billion} = 10^9.\]
garbage that has not been properly cooked or from eating wildlife; consequently, the incidence of the disease is substantially less in areas where hogs are grain-fed in confined areas compared with those garbage-fed or that roam in woods or pastures [11]. When ingested, the infected meat is digested and the trichina larvae are released into the intestine where they rapidly mature into adults, mate, and produce large numbers of offspring. The larval offspring leave the intestine, enter the blood stream, and invade the striated skeletal muscle, where they migrate extensively before becoming encapsulated within a microscopic cyst. The encysted parasites may remain alive in a dormant state for the life of the host (the normal course in human infection), or until the second generation trichinous meat is again ingested by a carnivore [12].

Although the incidence of trichinosis in both humans and swine has declined dramatically in recent years, over the 5-year period of 1979-1983 there was an average of 116 cases and less than 1 death per year [13].

Research on the irradiation of trichina-infected meat has indicated that the parasitic disease cycle could be effectively broken by relatively low levels of radiation. Dose levels between 20 and 30 krad have been found to be effective in preventing the maturation of encysted trichinae. These dosage levels are well below the 100 krad limit expected to be set by FDA. Work currently underway by the U.S. Department of Energy (DOE) and USDA's Agricultural Research Service (ARS) and their contractors on irradiating infected market-weight split pork carcasses indicates that doses as low as 8 krad cause sterility in first generation larvae; a 15 krad dose prevents emergence of the encysted larvae [14].

The DOE study further indicates that entire sides of pork may be irradiated without concern over possible shielding effects. One must remember, though, that this dose level is substantially smaller than what is necessary for a complete kill; the objective is to inhibit reproduction of the organism in the intestine of the host.

USDA Irradiation Activities

The USDA has conducted studies of food irradiation as a quarantine treatment for fruits since the 1950's. In August of 1980, the U.S. Department of Defense and the USDA signed a Memorandum of Understanding, which transferred the lead agency role for the food irradiation program from the U.S. Army Natick Research and Development Laboratories to the ARS
The USDA indicated that it would concentrate its research on a long-range program using low levels of irradiation to prevent marketing losses and to improve the safety and quality of fruits, vegetables, and grains as an alternative to present methods used for food preservation and insect disinfection. The recent medfly crisis in California and the proposed action of the U.S. Environmental Protection Agency (EPA) to restrict the use of ethylene dibromide as a fumigant have renewed interest in the possible use of irradiation in quarantine control of insects. Also of special interest was the potential of irradiation as an alternative to the use of nitrite in preservation of meats, especially bacon.

The USDA held conferences in 1981 and participated in a workshop on low-dose radiation treatment of agricultural commodities in 1982. USDA scientists are considering the use of irradiation with caution because of the results of previous studies indicating that the irradiation rates required for insect quarantine purposes may cause phytotoxic damage to fruit. ARS is currently conducting research on the use of radiation for insect disinfection at three locations.

Toxicological studies to determine the wholesomeness of chicken parts sterilized with ionizing radiation, initiated by the U.S. Army, were continued under the auspices of ARS. These studies—some of the most exhaustive wholesomeness studies ever undertaken on any food product—were designed to provide data on toxicity, carcinogenicity, mutagenicity, teratogenicity, and anti-metabolite formation. Final reports have been accepted for a number of the wholesomeness studies, but no conclusions on the wholesomeness of irradiation sterilized chicken can be made until the information has been evaluated in its entirety by FDA.

FSIS has now initiated a program of active cooperation with DOE, the U.S. National Bureau of Standards (NBS), ARS, the industry, and consumer groups to review the regulatory policy relevant to this technology. The absence of an approved use for food irradiation is in fact a major impediment to any regulatory agency preparing for this newly relevant technology. Once an approval has been given, even at the 100 krad level, we can begin to credibly address the major issues ahead. A processor wishing to employ this technology as part of the processing operation must submit a petition for its approval, as outlined in the 1958 Food Additives Amendment to the FD&C Act. The FDA will then approve the intended use of the additive by issuing a regulation that specifies the
conditions for use. The information that must accompany the applicant petition to FDA before a food additive regulation is issued includes:

1. Identity of the food additive (radiation source)

2. Proposed conditions of use (dose, food type, and process conditions)

3. Data for intended effect (mainly microbiological)

4. Methods for determining amount of additive (Dosimetry)

5. Safety (identity and quantity of radiolytic products and/or toxicology studies)


Once the guidelines are established, the issues related to packaging, labeling, radiation sources, dose levels, dosimetry, efficacy, and specific product uses can be addressed. With this information in hand, FSIS may modify the Meat and Poultry Regulations contained in the Code of Federal Regulations (CFR)[17] to approve the use of irradiation in USDA inspected plants. Any regulation change must, of course, be in accordance with the Administrative Procedure Act.

It is conceivable that changes could result in post mortem inspection as currently performed. The purpose of post mortem inspection is to remove from human food channels carcasses and parts that are unfit for human food because of adulteration due to disease or abnormalities discernible upon examination of internal organs and tissues. The Agency's inspection programs and laboratory analyses could be altered or modified as well.

In considering how FSIS could approve the use of irradiation in post mortem inspection, the rules and regulations of other agencies must be taken into account as well as those governing FSIS. Several examples are:

1. The use of radioisotopes in commercial irradiators is governed by NRC regulations contained in 10 CFR, part 30, Rules of General Applicability to Domestic Licensing of Byproduct Material, and 10 CFR, part 20, Standards for Protection Against Radiation. These regulations define the basic licensing and radiation safety
requirements for the protection of both radiation workers and the public but do not address the quality of the products irradiated except to ensure that the products remain free of radioactive contamination.

2. The basic radiation safety considerations are the same for licenses issued by either the NRC or State Government Agencies. In the evaluation of an application for a commercial irradiator, matters such as source integrity, design of the irradiator safety systems, training and experience of personnel, and the radiation safety program for operation of the irradiator must be considered.

3. The actual design of an irradiator providing a safe environment for its operating personnel would be approved under the American Standards Institute (ANSI) criteria and the Nuclear Regulatory Commission (NRC) Licensing Guide. Food irradiation equipment designs are varied, but all models contain the following: a gamma ray source (usually $^{60}\text{Co}$); heavy concrete shielding (about 6 feet thick) and a water pool, for personnel protection; a means of transporting food products into and out of the irradiation chamber; and control electronics.

In current processing sequence in a hog-slaughter facility, the live hogs are first stunned, exsanguinated, and hung from an overhead conveyor for easy transferral throughout the plant. After being dehaired, gutted, headed, split, and cleaned, the prepared carcasses are placed in refrigerated storage for approximately 24 hours. The chilled carcasses are then ready for cutting, handling, and packaging.

An irradiation facility could be designed to treat the pork at any of several stages in the processing sequence, such as after packaging or before dehairing. After passing through the facility, the pork could be processed in the usual manner.

Meat and poultry irradiation research for dose verification and product response will also be needed. The purpose of irradiation is to achieve a desired product response to some absorbed dose. It is essential to obtain a dose that falls within the acceptable maximum and minimum dose range for a particular food. As the ionizing effect of the radiation is additive, the combined dose from both sides must fall within the product's desired maximum/minimum ratio. This will require an approved dosimetry system for following a food
product through the process. The maximum-to-minimum absorbed dose ratio and the dose actually absorbed throughout the product during exposure to a source of gamma radiation will determine the conveyor speed, conveyor configuration, and system control sequence. The dose requirements also determine whether the product must be treated individually, or can be boxed, bagged, or palleted. In addition to control of the dose profile in the product, control of desired side reactions can sometimes be achieved by use of temperature (chilled or frozen), pH, and the presence of various types of atmospheres, chemical gases, or chemical additives that can act as gamma sensitizers or protectors [18].

In conclusion, FSIS is preparing to respond to petitions for the use of irradiation in meat and poultry products. Even after the approval of use by FDA, a petition from the industry to FSIS requesting the use of irradiation in a USDA-inspected facility would have to address, at a minimum, the following points:

1. Efficacy—Data are required that establish the effective treatment of carcass sides or cuts and assure that the nutritional value is not affected.

2. Dosage and variations of the dosage that can be controlled by the system proposed.

3. A description of the flow-through system proposed (e.g., will this be an on-line system, whole carcasses, sides, or cuts?)

4. Environmental impact data.

The FSIS would take such information, review it, and, if the petition is acceptable, amend the regulations in accordance with the Administrative Procedure Act [19].

Many of these required steps can be expedited by the close cooperation of the various government, industrial, and academic groups.

REFERENCES


[13] GREEN, J., Private communication (February 11, 1985), Centers for Disease Control, Atlanta, Georgia.

[14] SIVINSKI, J.S., Meat irradiation is here but is it now? The National Provisioner, November 12, 1983.


ETAT ACTUEL DU DEVELOPPEMENT DES TRAITEMENTS IONISANTS EN FRANCE

Y. HENON
Service de radioagronomie,
Département de biologie,
CEA, Centre d'études nucléaires de Cadarache,
Saint-Paul-lez-Durance, France

Abstract—Résumé

THE PRESENT STAGE OF DEVELOPMENT OF IONIZING RADIATION TREATMENT IN FRANCE.

During the 1970s in France only the Commissariat à l'énergie atomique (CEA) continued to do research in the field of ionizing-radiation treatment of foodstuffs, with special emphasis on the radiochemistry of polysaccharides. The conclusions of the Joint FAO/IAEA/WHO Expert Committee in 1980 revived interest in this procedure. In 1982 the three committees in charge of examining the documentation relating to applications for authorization reacted favourably to the summary report on the toxicology of irradiated foodstuffs submitted by the CEA. New applications need no longer contain a new toxicological study if the dose is lower than 10 kGy. This liberalization of procedure has encouraged industrialists to prepare application documentations (five in 1983 and five in 1984) and has made for more expeditious examination thereof. Technically convincing but economically disappointing experiments have shown that the two existing radiation sterilization facilities are unsuitable for harvested agricultural products. It is therefore advisable to set up units which could meet the requirements of the food industry. In the Marseilles region it is planned to build a multipurpose commercial facility and a development facility by 1986. Moreover, a firm in western France is reported soon to be acquiring an electron accelerator for the radicidation of mechanically jointed and frozen poultry. Concurrently with these activities a large information campaign has been undertaken. However, it is too early to offer to the public products for large-scale human consumption which have been treated with ionizing radiation.

ETAT ACTUEL DU DEVELOPPEMENT DES TRAITEMENTS IONISANTS EN FRANCE.

Dans les années 70, seul le Commissariat à l'énergie atomique (CEA) maintenait encore en France une activité de recherche dans le domaine du traitement ionisant des aliments, principalement axée sur la radiochimie des polysaccharides. Les conclusions du Comité mixte OMS-FAO-AIEA d'experts en 1980 ont relancé l'intérêt pour ce procédé. En 1982, les trois commissions chargées d'instruire les dossiers de demande d'autorisation ont réagi favorablement à un rapport de synthèse présenté par le CEA sur la toxicologie des aliments irradiés. Toute nouvelle demande ne doit plus forcément comporter d'étude toxicologique nouvelle lorsque la dose est inférieure à 10 kGy. Cet allègement de procédure a encouragé les industriels à établir des dossiers (5 en 1983, 5 en 1984) et a permis d'accélérer leur examen. Des expériences convaincantes sur le plan technique mais décevantes sur le plan économique ont démontré l'inadaptation des deux installations de radiostérilisation existantes pour des produits agricoles récoltés. Cette situation rend donc opportune la création d'unités permettant de répondre aux exigences de l'industrie alimentaire. Dans la région de Marseille, il est envisagé de construire
pour 1986 une installation commerciale polyvalente et une installation de développement. Par ailleurs, une société de l’ouest de la France devrait bientôt s’équiper d’un accélérateur d’électrons pour la radicidation de viandes de volailles séparées mécaniquement et congelées. Parallèlement à ces actions, un effort important d’information a été entrepris mais il semble encore prématuré de proposer au public des produits de grande consommation qui auraient été ionisés.

En France, comme dans d’autres pays, ce sont les conclusions du Comité mixte OMS-FAO-AIEA d’experts réuni en 1980 qui ont relancé l’intérêt pour le traitement ionisant des aliments. Au début des années 70 en effet, un certain nombre d’organismes avaient cessé toute activité dans ce domaine, découragés par les multiples obstacles qui s’étaient dressés. Seul le Commissariat à l’énergie atomique a poursuivi un programme de recherches sur le sujet et a notamment participé au Projet international basé à Karlsruhe. Les études ont porté sur la radiochimie des polysaccharides, avec en particulier l’identification et le dosage des produits de radiolyse. Il a été démontré qu’aucun de ces produits ne se forme en une quantité telle qu’il pourrait être toxique, et que tous sont susceptibles d’apparaître au cours d’autres traitements. Par ailleurs, les résultats obtenus avec plusieurs variétés d’amidon se sont révélés semblables à ceux obtenus pour l’amidon de maïs. On a ainsi pu apporter une preuve supplémentaire de la validité du principe d’extrapolation d’un produit à d’autres produits de la même famille.

1. L’EVOLUTION DE LA LEGISLATION

La première autorisation sollicitée en France concernait la pomme de terre. Elle a été déposée en 1967, date à laquelle n’existait pas encore de cadre légal pour le procédé qui était simplement interdit. La première réponse de l’administration a donc été d’élaborer un décret, publié en 1970, selon lequel une autorisation est nécessaire pour chaque type de produit. Le dossier est examiné par trois commissions: le Conseil supérieur d’hygiène publique de France, l’Académie nationale de médecine et la Commission inter-ministérielle des radioéléments artificiels.

Il faut souligner que, pour les aliments destinés à l'alimentation humaine, ces autorisations n'ont été délivrées que pour une durée de cinq ans. Cette mesure, ajoutée à un contexte techno-économique peu favorable, ne pouvait que rendre plus réticentes encore les sociétés susceptibles d'être intéressées par ces applications.

En 1982, une étape importante a été franchie lorsque, s'appuyant sur les travaux du Projet international et des différents comités mixtes OMS-FAO-AIEA, le Commissariat à l'énergie atomique a rédigé un rapport général intitulé «Traitement ionisant des denrées alimentaires: efficacité et absence de risques pour l'homme» (Rapport CEA R-5162, 1982). Cette synthèse a en effet été présentée aux trois commissions compétentes et a reçu leur avis favorable. Objet de remises à jour régulières, elle constitue une caution en matière de toxicologie. Un protocole concernant les demandes d'autorisation a été élaboré: il sert de guide aux sociétés présentant des demandes. Sa caractéristique la plus remarquable est qu'il n'exige pas de nouvelles études toxicologiques lorsque la dose employée est inférieure ou égale à 10 kGy.

Cet allègement de procédure a grandement facilité le dépôt de nouveaux dossiers, ainsi que leur examen.

En 1983, la débactérisation par rayonnement gamma de 72 épices et aromates a été autorisée. Cette même année, les dossiers suivants ont été soumis aux services officiels:
- pasteurisation de la gomme arabique;
- pasteurisation des légumes déshydratés;
- pasteurisation de mélange de flocons de céréales destinés à être incorporés dans les produits laitiers;
- radicisation de viandes de volailles séparées mécaniquement et congélées;
- aseptisation d'emplaillages alimentaires.

Tous ont déjà été approuvés. Les autorisations sont, quand cela est technologiquement pertinent, délivrées à la fois pour le rayonnement gamma du cobalt 60 et du césium 137 et pour les faisceaux d'électrons accélérés d'une énergie maximale de 10 MeV.

Les sociétés utilisatrices peuvent ainsi choisir la technologie qui répond le mieux à leurs besoins et à leurs contraintes.

En 1984, quatre nouveaux dossiers ont été déposés. Ils ont pour objet:
- la pasteurisation du sang, du plasma et du cruor déshydratés;
- la désinsectisation des fruits secs et des légumes secs;
- la radicidation du blanc d'oeuf liquide, déshydraté ou congelé;
- la pasteurisation des plantes médicinales à infusion.

Comme on le voit, ce sont essentiellement des produits intermédiaires de l'industrie alimentaire qui font l'objet de demandes. Le problème de l'étiquetage obligatoire se pose en effet de façon moins aiguë. Dans les mois à venir, les dossiers concerneront les denrées animales pour lesquelles l'avantage sanitaire apporté par le traitement ionisant est indiscutable.
Le meilleur exemple semble être la diminution ou l'élimination du risque d'intoxication dû à la présence de bactéries pathogènes dans des aliments tels que les cuisses de grenouille ou les crustacés.

Par ailleurs, pour tenir compte des acquis scientifiques récents, une révision du texte de base de la réglementation (le décret du 8 mai 1970) est à l'étude. Elle devrait introduire davantage de souplesse, notamment en matière d'étiquetage, question qui sera examinée cas par cas. Il a été entre autres proposé d'introduire après la mention obligatoire une phrase facultative à connotation positive, du type «qualité microbiologique assurée par traitement ionisant».

Enfin, la possibilité d'accorder une autorisation générale jusqu'à la dose de dix kilograys est à l'étude.

2. L'UTILISATION COMMERCIALE DU PROCEDE

Les autorisations accordées de par le monde ne reflètent pas l'utilisation réelle qui est faite du procédé. Ainsi, un grand nombre de pays permettent officiellement d'inhiber la germination des pommes de terre par ionisation, mais peu nombreux sont ceux qui emploient effectivement cette méthode. La raison en est sans doute le contexte industriel existant en matière de radiotraitement, le plus souvent limité à des installations construites pour la stérilisation d'articles médico-chirurgicaux.

Il est certain que l'utilisation de telles usines à des fins agroalimentaires biaise l'évaluation technico-économique et limite les possibilités d'application rentables.

C'est ainsi qu'en France, deux sociétés de service, Conservatome et Sodeteg-Caric, ont depuis les années 60 développé leurs activités dans le domaine des plastiques et des produits pharmaceutiques, médicaux et cosmétiques. La première utilise le cobalt 60, la seconde un accélérateur d'électrons.

Situées à la périphérie de deux grandes villes, Lyon et Paris, elles se trouvent éloignées des lieux des production. Des coûts de transport doivent donc être ajoutés aux coûts de traitement, d'autant plus difficiles à supporter que les produits ont une valeur faible, comme c'est le cas des matières premières agricoles récoltées, en particulier la pomme de terre ou l'oignon. De plus, dans ces installations, les caractéristiques des convoyeurs limitent les quantités unitaires pouvant être traitées, ce qui multiplie les manutentions et accroît les coûts. Enfin, la dose minimale qui peut être délivrée en fonctionnement commercial est souvent trop élevée, ce qui écarte les possibilités d'applications aux faibles doses.

Il n'est donc pas étonnant que seules quelques centaines de tonnes de pommes de terre et d'oignons aient été traités dans notre pays. Si l'efficacité de la technique a pu être vérifiée, sa non-rentabilité économique dans les conditions décrites a également été démontrée.
Le cas de produits alimentaires comme les épices et les légumes déshydratés est différent. Leur valeur assez élevée rend en effet supportables les surcoûts qu’entraîne l’utilisation d’installations mal adaptées. Quelques centaines de tonnes d’épices destinées à l’industrie (et non vendues au public) ont ainsi été traitées en France en 1984. La quantité de produits intermédiaires ionisés croîtra au fur et à mesure que seront délivrées les autorisations.

Nombreux sont ceux qui semblent maintenant convaincus que le transfert du procédé vers l’industrie agroalimentaire nécessite une approche nouvelle. Plusieurs projets ont ainsi pris naissance au cours des derniers mois. Des associations se sont créées dans plusieurs régions, afin d’examiner la faisabilité d’un centre de traitement ionisant polyvalent, répondant en particulier aux contraintes imposées par les produits alimentaires. Le projet le plus avancé est celui d’une association dénommée Apional, qui propose de construire, près du port de Marseille, à la fois une unité gamma industrielle et une unité de recherche-développement. Conçues par la Société SGN, filiale du CEA, elles devraient commencer à fonctionner en 1986. La seconde installation régionale sera sans doute construite ultérieurement dans l’ouest de la France.

Certaines sociétés peuvent difficilement avoir recours à une installation de service, soit parce que leurs produits sont trop fragiles, soit parce que les quantités à traiter sont trop importantes. Le choix peut alors éventuellement se porter sur des accélérateurs d’électrons, dont la souplesse d’utilisation présente quelques avantages par rapport aux radioisotopes. Ainsi, une société commercialisant des viandes de volailles séparées mécaniquement et congelées devrait acquérir cette année une machine «Cassitron» développée par la société CGR — MeV, filiale du groupe Thomson. Certaines sociétés s’intéressent également à des petits irradiateurs gamma qui pourrait être intégrés.

3. L’INFORMATION

Dans les années 60, on lisait dans des publications françaises et étrangères que l’heure de l’utilisation commerciale était venue. Vingt ans après, on pourrait avoir quelque hésitation à oser encore le dire si entre-temps un effort sans précédent de recherche fondamentale, certes long et coûteux, mais absolument indispensable, n’avait été fourni.

Le développement de la technique peut donc avoir lieu dans de bonnes conditions, car il repose maintenant sur des bases scientifiques solides. Il ne faut cependant pas se leurrer : le procédé ne sera pas banalisé du jour au lendemain parce que les instances internationales l’ont reconnu sans risques toxiques. Il reste à informer les consommateurs, clairement et objectivement, tant sur les avantages que sur les limites du traitement. La première étape nous a paru être l’emploi d’un mot autre qu’«irradiation» qui égare le public plus qu’il ne l’informe. Nous avons obtenu sur ce point un certain consensus des administrations et de
l'industrie, mais il n'y a pas unanimité sur le nom de remplacement proposé, «ionisation», quoique la presse le reprenne souvent.

Après plusieurs années d'explications, de discussions et de réflexion commune avec les scientifiques, les médecins et les nutritionnistes, on peut considérer que ces milieux sont maintenant assez bien informés et que, apparaissant plus crédibles que les promoteurs du procédé, ils peuvent constituer un relais auprès des journalistes, des consommateurs et de leurs associations. Ainsi, le Conseil supérieur d'hygiène publique de France et l'Académie nationale de médecine ont-ils récemment publié des textes prenant clairement position en faveur des traitements ionisants.

La majorité des articles parus dans la grande presse sont bienveillants, comme le sont ceux qui sont parus dans les magazines des associations de consommateurs. Dans ces derniers, la non-toxicité du procédé n'est pas remise en cause, mais des garanties de contrôle sérieux et un étiquetage informatif sont demandés.

CONCLUSION

En 1930, un nommé Wurst déposait en France un brevet concernant «de la nourriture de toute sorte, conditionnée en boîtes métalliques scellées et soumise à l'action de rayons Röntgen durs, de haute intensité, pour tuer les bactéries». Un demi-siècle s'est écoulé depuis. C'est beaucoup, mais c'est peu si l'on considère que, vers 1800, plus de cinquante ans avant les découvertes de Pasteur, un autre français nommé Nicolas Appert inventait un procédé de conservation qui porterait son nom. Aujourd'hui ou demain, en France et ailleurs, l'ionisation trouvera-t-elle aussi sa place car elle permet d'offrir au consommateur des aliments plus sains et plus sûrs.
STATUS OF COMMERCIAL DEVELOPMENT OF FOOD IRRADIATION IN IRAQ

H. AUDA
Department of Biochemistry,
Faculty of Agriculture and Biology,
Nuclear Research Centre,
Baghdad, Iraq

Abstract

STATUS OF COMMERCIAL DEVELOPMENT OF FOOD IRRADIATION IN IRAQ.

After having achieved successful results in the application of atomic energy in the food irradiation programme in Iraq, a step forward was taken by the Iraqi Atomic Energy Commission (IAEC) by joining the International Food Irradiation Project (IFIP) in 1975. In view of the important results in disinfestation and the radiation chemical data on dates, IFIP approved the inclusion of wholesomeness testing of irradiated dates in the work programme for 1976. In 1980 irradiated dates were granted unconditional clearance up to 1 kGy by JECFI. There is no formal legislation yet to regulate irradiated food, and the major food legislation in the country is related to food quality, safety and trade. In the light of the 1980 JECFI approval and the available information on the safety of irradiated food, the authorities at IAEC have formed a special committee to elaborate a set of model regulations for the control of and trade in irradiated food.

INTRODUCTION

The present world demand for food supplies requires adequate effort to increase agricultural products as well as to reduce post-harvest losses. Reports show that developing countries suffer major losses up to 40% of their agricultural output. The solution to these problems lies mainly in the production plans of governments as well as in the preservation of the food produced and the reduction of spoilage. A large percentage of the spoiled food results from either insect infestation or bacterial spoilage, especially in highly perishable commodities such as fish and fishery products. For insect disinfestation methyl bromide has been used. However, its application has not produced results that meet the quarantine measures of importing countries and it imposes several limitations such as residue accumulation and incomplete kill of some stages of the insects [1–3].

Several insect species are known to infest ripe dates in Iraq. A few of these insects feed on dates and continue breeding throughout storage for several generations [3, 4]. Conventional methods of using methyl bromide to destroy insects attacking dates have not met with success because of the limited effectiveness of this fumigant to control date insects at all stages of development. Consequently,
new methods of date disinfestation have been sought and gamma radiation has been used successfully to disinfest stored dry dates [4].

Among other important and widely used crops in Iraq for which radiation was used for sprout inhibition were potatoes and onions [5].

The use of irradiation to prolong the shelf-life of fresh dates has also been investigated on a number of varieties irradiated at doses from 0.1 to 2.7 kGy. As commonly found for other fruits, a considerable difference was noted in the response of different varieties and different stages of maturity [6]. No significant difference in the sensory properties of irradiated and unirradiated dates could be detected.

ECONOMIC ASPECTS

Iraq is considered one of the date-growing countries producing annually approximately 300 000–400 000 tonnes. Dates are one of the richest sources of sugar; important nutrients such as vitamins, proteins, sodium, iron and magnesium are also present in the fruit. A large quantity of dates intended for human consumption and for industrial processing are exported annually to various countries throughout the world; the remainder is consumed locally. Dates constitute a good source of raw material and are utilized industrially in the production of syrup, liquid sugars, vinegar, ethyl alcohol, protein yeast pastry and animal feeds.

Insect infestation poses a serious problem for the production and marketing of dates; a number of factors such as the lack of mechanization, inadequate packaging and storage facilities contribute to an increased hazard of insect attack during storage and shipping. Many of the date-importing countries have set a threshold limit of permissible infestation, and in most cases this is a small percentage. However, even after fumigation large quantities of stored dates and dates ready for shipment are infested to a certain degree and therefore do not comply with the standards of the importing country. Thousands of tonnes are rejected annually because of heavy insect infestation and this causes considerable economic loss.

Insects that live on stored dates are the fig moth *Ephestia cautella* and the saw-toothed grain beetle *Oryzaephilus surinamensis*. They have been carefully studied and the radiation dose required for their disinfestation has been established [4].

One of the most important and widely cultivated vegetable crops in Iraq are onions; potatoes are less cultivated. However, an increasing demand for potatoes has been recorded in recent years. Potatoes are grown in two main seasons, the spring crop, which is harvested in April/May and the autumn crop, which is harvested in November/December. Onions are usually harvested during April/May for early varieties and June/July for the late varieties.

After harvest large quantities of both crops are stored in ordinary stores. These two crops usually suffer great losses during storage due to sprouting, shrinkage and
plant diseases. To ensure marketing of good quality potatoes and onions and to minimize losses, experiments were carried out to determine the minimum dose required for sprout inhibition during storage at ambient and under controlled temperatures. This was found to range from 0.06—0.09 and 0.05—0.1 kGy for onions and potatoes, respectively [5]. Commercial-scale experiments have not been made and need to be technically determined.

It is well established that the economics of irradiation processing depend mainly on the amount of food items or other commodities treated in the same irradiator. Irradiation is a large-scale process and a long period of operation is required to make this process competitive with conventional techniques. These conditions are necessary for the determination of the economic feasibility of radiation techniques on a commercial scale.

In Iraq investigations on food irradiation started with experiments on insect disinfestation of dry dates in 1967. Work was started at the Nuclear Research Institute (NRI) of the Iraqi Atomic Energy Commission (IAEC). This work was then supported by the International Atomic Energy Agency (IAEA) under the joint programme No.941/RB. In 1970 the IAEC requested the IAEA to send an expert to assist in planning and programming work on food irradiation with special reference to important local foodstuffs (grain, rice, dates, fish, etc.) and to assist in the work already started on the irradiation of dates [7]. Two major directions were carried out in the NRI and were mainly concerned with the irradiation of insects infesting dates and the effects of ionizing radiation on various chemical constituents of the date fruits. A small-scale experiment on sprout inhibition of potatoes and onions was started at a later date.

In the framework of this research programme technical assistance was provided by the IAEA and Dr. K. Vas was assigned for one month's planning work in 1971. As a result of Dr. Vas' mission an integrated food irradiation programme was elaborated. Dr. Vas concluded in his report that utilization of atomic energy in food and agriculture is an important proposition from the point of view of the national economy and public health in Iraq. He also stated that dates, grain, pulses and tobacco were the most likely candidates for disinfestation by irradiation. Dr. Vas also reported that the radiation-prolongation of the market life of fish and poultry could be achieved by using doses to kill spoilage-causing microorganisms and so should be introduced in Iraq [7].

In conclusion the report stated that certain other industrial uses of atomic energy could be combined with food irradiation to achieve a constant utilization of the radiation emitted by an isotope-type irradiator.

A larger radiation source is necessary to be able to carry out technologically valid experiments on the basis of which rough estimates of the economics of the process could be evaluated.

Following Dr. Vas' recommendations and to continue the IAEA's technical assistance the Iraqi Atomic Energy Commission agreed to the nomination of Dr. J. Farkas for a three month period starting on 1 October 1972. During his
mission Dr. Farkas worked on the technical feasibility of date radurization. He also carried out several experiments on the applicability of gamma irradiation in date juice manufacture [6].

REGULATION OF FOOD IRRADIATION

The food irradiation programme has achieved successful results on food items such as dates, onions and potatoes and the authorities at the Nuclear Research Institute decided on further studies on the wholesomeness of irradiated dates. In 1975 the Iraqi Atomic Energy Commission authorities signed an agreement to join the International Food Irradiation Project (IFIP) and were represented in both the Scientific Programme Committee and the Board of Management.

In view of the importance of the results on disinfestation and the radiation chemical data it was considered that wholesomeness testing of irradiated dates should be carried out. In 1976 IFIP approved the inclusion of animal studies on irradiated dried dates in its programme. To complement this animal feeding study a number of short-term test procedures such as mutagenic tests, cytogenic analyses and cellular DNA were used to detect whether dates induced any abnormality as a result of irradiation.

Based on all the studies made by the IAEC and IFIP, irradiated dates were granted unconditional clearance up to 1 kGy by the 1980 Joint FAO/IAEA/WHO Expert Committee on the Wholesomeness of Irradiated Food (JECFI).

In the light of the 1980 approval of the JECFI and the available information on the safety of irradiated food, the process should offer the national authorities the means to adapt the existing legislation, or develop proper legislation in countries without any form of legislation on food irradiation.

Although several countries have some form of legislation which regulates the marketing and commercialization of certain irradiated food items, Iraq has at present no specific legislation on this matter. On the basis of all available information on the safety of irradiated food a total of 73 approvals (unconditional and provisional) covering 26 different foods have been issued in 19 countries [8].

While there is no formal legislation yet in Iraq to regulate irradiated food, act No. 99 on radiation protection was signed in 1980 to regulate the use of isotopes and the importation and storage of irradiated food in the country. The major food legislation in this country is related to food quality, safety and trade. As a consequence of the JECFI recommendations and the Codex Alimentarius Commission, the IAEC, in co-operation with the Ministries of Health, Industry and Agriculture, has taken the first steps to establish legislation for the control of irradiation facilities and irradiated food. The authorities on food irradiation at the IAEC are aware that the stage has been reached in many countries where they are on the brink of the industrial application of this technique and legislation should, if possible, not fall behind in this country. As a first step, the authorities have
formed a special committee to elaborate a set of model regulations for the control of and trade in irradiated food. This committee should also provide valuable guidelines for the government to harmonize the national legislation relating to the practical application of food irradiation in accordance with the Codex standard and the Code of practice.

CONCLUSIONS

(1) For better utilization, a multi-purpose pilot irradiation plant should be considered for the irradiation of many items in order to keep the price per tonne of product treated competitive.

(2) A national committee should be established to advise the authorities and to guide the process through the existing systems toward practical application.

(3) Market testing on a local and an international basis should be approved.

(4) Consumer acceptance is an important task lying ahead. Informing and educating consumers should be done through education channels, the press and other organizations.

REFERENCES


THE SOUTH AFRICAN FOOD IRRADIATION PROGRAMME
Role of Government institutions

W. J. DE WET
Chemistry Department,
Nuclear Development Corporation
of South Africa (Pty) Ltd,
Pretoria, South Africa

Abstract

THE SOUTH AFRICAN FOOD IRRADIATION PROGRAMME: ROLE OF GOVERNMENT INSTITUTIONS.

The strategy decided upon in the South African responsible Government institutions to establish food irradiation technology commercially is sketched. A situation has been reached where three irradiation facilities are processing a large variety of food products in excess of 200 t/week. The future role regarding statutory inputs to further promote commercialization is indicated. Resulting from the approach we are pursuing on a national basis, it is our expressed opinion that continued international collaboration, involving the support and blessings of the relevant international agencies, is essential for successfully paving the way to international trade in irradiated food.

INTRODUCTION

The enormous potential of food irradiation as a food preservation and sanitation method for application in the South African context has been appreciated since as far back as the late fifties. From an export point of view for example, South Africa, as an important food exporting country, is situated poorly geographically, but extremely well seasonally. Cheaper transport by sea without the volume/weight limitations typical of air freight could enhance export opportunities immensely. For wider internal distribution of many perishable commodities, extended keeping qualities with associated improved average quality could also be achieved through radiation treatment. Despite the full realisation at the time of the implications for eventual national and international acceptance of food irradiation technology, arising from the uncertainties which surrounded the wholesomeness of irradiated food, the relevant South African
statutory institutions nevertheless embarked on an exploration programme which only started in earnest in 1972. I might add that as time went on we became more convinced of the unique attributes of this technology and its eventual successful future.

**Technological Development Programme**

The former Atomic Energy Board (since 1982 the Nuclear Development Corporation of South Africa (Pty) Ltd, abbreviated NUCOR) and our Department of Agriculture tackled a joint technological programme in 1970. Excellent progress has since been made on a whole variety of products, as can be seen in Table 1 in which presently cleared products are listed. Most of these are now being processed commercially on a regular basis in reasonable volumes.

Our experience has been that, for virtually all the cleared products, the treatments had to be investigated for specific application circumstances, which underlines the importance of national food irradiation programmes. Fruits are the most difficult commodities, with combination treatments essential in most cases. During the precommercial phase and even in the commercial phase new problems, technological in nature, arose with subtropical and other fruits, which emphasise the importance of a back-up technological infrastructure to counteract such problems promptly. A typical example of such a problem is the accentuated blackening which develops on irradiated bananas if they are kept unduly long in ripening rooms or if they are transported and/or stored at sub-optimum temperatures, when cold injury occurs. (The interactive requirements are specifically elaborated on in Dr. van der Linde's presentation (paper IAEA/SM-271/42)).

In contrast to the complexities inherently associated with many fresh product applications, disinfection studies and organoleptic assessments are relatively straightforward for dry processed products.
### TABLE 1. UNCONDITIONALLY CLEARED PRODUCTS IN SOUTH AFRICA (JANUARY 1985)

#### Fresh products (cleared 1977 - 1979)

<table>
<thead>
<tr>
<th>Product</th>
<th>Date Cleared</th>
</tr>
</thead>
<tbody>
<tr>
<td>Potatoes</td>
<td>1977</td>
</tr>
<tr>
<td>Mangoes</td>
<td>1978</td>
</tr>
<tr>
<td>Papayas</td>
<td>1978</td>
</tr>
<tr>
<td>Chicken</td>
<td>1978</td>
</tr>
<tr>
<td>Onions</td>
<td>1978</td>
</tr>
<tr>
<td>Garlic</td>
<td>1978</td>
</tr>
<tr>
<td>Strawberries</td>
<td>1978</td>
</tr>
</tbody>
</table>

#### Fresh and non-dry processed products (cleared since 1981)

<table>
<thead>
<tr>
<th>Product</th>
<th>Date Cleared</th>
</tr>
</thead>
<tbody>
<tr>
<td>Avocados</td>
<td></td>
</tr>
<tr>
<td>Bananas</td>
<td></td>
</tr>
<tr>
<td>Fruit juices (frozen)</td>
<td></td>
</tr>
<tr>
<td>Green beans</td>
<td></td>
</tr>
<tr>
<td>Litchis</td>
<td></td>
</tr>
<tr>
<td>Mango pickles</td>
<td></td>
</tr>
<tr>
<td>Tomatoes</td>
<td></td>
</tr>
<tr>
<td>Brinjals</td>
<td></td>
</tr>
<tr>
<td>Soya pickle products</td>
<td></td>
</tr>
<tr>
<td>Ginger</td>
<td></td>
</tr>
<tr>
<td>Vegetable paste</td>
<td></td>
</tr>
</tbody>
</table>

#### Dry processed products (cleared since 1981)

<table>
<thead>
<tr>
<th>Product</th>
<th>Date Cleared</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bananas</td>
<td></td>
</tr>
<tr>
<td>Almonds</td>
<td></td>
</tr>
<tr>
<td>Cheese powder</td>
<td></td>
</tr>
<tr>
<td>Yeast powder (sugar-based)</td>
<td></td>
</tr>
<tr>
<td>Herbal tea (Rooibos)</td>
<td></td>
</tr>
<tr>
<td>Various spices*</td>
<td></td>
</tr>
<tr>
<td>Various dehydrated vegetables*</td>
<td></td>
</tr>
</tbody>
</table>

* Involved individual submissions at times.

Although numerous studies have been done most successfully on red meat and red-meat products, no immediate prospects for commercialisation seem apparent.

The planning and monitoring of the progress of the technological programme has throughout been the responsibility of the NUCOR subcommittee on Radiation Applications. Committee members have included representatives from the food industry, heads of several of our Agricultural Research Institutes, university people from food science
and agricultural disciplines, a senior official from the Department of Health and Welfare, etc. This forum served, apart from its main purpose, to ensure that various bodies were kept fully informed on local as well as international developments regarding food irradiation.

We are entering what can be considered as a second phase in technological development, i.e. the utilisation of irradiation in combined treatments to develop canned product equivalents with improved organoleptic or natural product qualities. Such shelf-life-stable products should obviously have acceptable safety margins, particularly those involving high-protein products. A *Clostridium botulinum* laboratory is being planned for this purpose. Apart from this a number of studies on promising commodities are being jointly investigated with two agricultural research institutions. These studies involve products such as dried fruits, melons, table grapes, stone fruits, etc. Certain aspects of food packaging materials are also receiving attention. Since the start of commercialisation interesting requests for investigation have also been increasingly forthcoming from the food industry.

The two disciplines microbiology and post-harvest pathology form, in our experience, the cornerstone of a sound technological programme. Basic investigations on the underlying aspects in combination treatments, the influence of radiation on ripening enzymes, the accentuated internal browning experienced when certain fruits are irradiated, and cell-wall damage studies are being continued in close association with experts at several universities. Radiation chemical studies on the formation of certain radiolytic products are being rounded off.

Pre-commercial Involvements

South Africa's concern regarding the future of food irradiation, in common with many other countries and also the relevant international agencies, has been that the one outstanding question regarding the toxicological safety of
irradiated food be resolved. The South African statutory authorities thus most willingly authorised the financial and scientific contributions we have made to IFIP. IFIP, as all of you know, was specifically undertaken as an international effort to deal expertly with this one overriding obstacle. The propitious success achieved by IFIP in this regard is known to us all but is, strangely enough, perhaps not fully accepted by all. However, the outcome has been accepted without hesitation by the South African Department of Health and Welfare to the full extent set by the 1976 and 1980 JECFI recommendations.

Because of the impetus given by 1976 JECFI recommendations that food irradiation should be classified as a physical process rather than an additive one and that five products (wheat, potatoes, chicken, papayas and strawberries) are to be considered unconditionally safe for human consumption if irradiated, it was decided by NUCOR to build a pilot irradiation facility (open pool facility, 50 kCi cobalt-60) for testing the technology as well as for irradiating reasonable amounts of subtropical fruits for simulated storage and transport and actual transport behaviour. This was a joint undertaking with the Letaba Co-operative, an agricultural co-operative in the subtropical fruit production area of North-eastern Transvaal. An additional task undertaken was to obtain trade exemptions for the first few commodities listed in Table 1 by means of submissions to our Department of Health and Welfare as required by the existing food legislation (Foodstuffs, Cosmetics and Disinfectants Act, Act 54 of 1972.) This enabled trial marketing studies involving at least a few products to ensure a reasonably sufficient impact. A Co-ordinating Advisory Committee with representatives from NUCOR and the Department of Agriculture and from Industry, Commerce and Tourism was founded for co-ordination and planning. Fair amounts of four of the approved products (potatoes, mangoes, papayas and strawberries, 122, 20, 20 and 7 tonnes, respectively) were marketed under the RADURA emblem from August
1978 to July 1979 in certain supermarkets in the Pretoria and Johannesburg areas. This venture, publicised as widely as possible, succeeded to a large extent, although certain problems were encountered. Consumer's acceptance, for example, amounted to 90% or more but poor-quality products which were sometimes offered were associated with the process, which indicated that for a favourable introductory attempt, factors of this nature must be specially guarded against.

Following the trial marketing study a two-day National Symposium was arranged in October 1979 to which Dr. Elias, project director of IFIP (1975 - 1981), was invited as the main guest speaker. This symposium, which covered all facets of food irradiation, attracted 160 people who represented all the sectors of the food and agricultural spheres and also consumer organisations, which we felt should all be informed.

Towards commercialisation

Prompted by the success of the trial marketing study and particularly the tremendous breakthrough contained in the 1980 JECFI recommendations, a strategy for the marketing of irradiated foods received in-depth consideration towards the beginning of 1981. Both NUCOR and the Department of Agriculture were, in view of their statutory mandates not strictly in a position to be directly involved in the marketing of foods. All along, NUCOR's interest in food irradiation was associated with its promotional responsibilities regarding radioisotope and radiation applications in South Africa, whilst the Department of Agriculture intimated that its involvement could only go as far as technical aspects related to marketing. It was thus clear that the private sector would have to be involved in all the processing and marketing aspects of irradiated food. Fortunately, two irradiation processing companies were founded in 1981. One of these companies came into existence as a result of NUCOR's decision to transfer the gamma sterilisation of medical items to the private sector, a processing activity introduced by NUCOR
in 1970 and offered to all manufacturers of such items in South Africa on a service basis. The company which took this over, ISO-STER (Pty) Ltd, acquired a Canadian facility (JS-8900, maximum Cobalt-60 loading of 6 Mci) which was commissioned in August 1981. Apart from presently processing all the disposable medical items, the company is also treating a fair amount of plastic products as well as a growing volume of a number of dry processed food items. The present loading of this facility is more than 600 kCi. Our own JS-6500 facility, previously used for the medical sterilisation, became entirely available for food irradiation. An upgrading of its conveyer system to four times its previous throughput has made this facility very suitable for food irradiation and it is utilised on a service and subcontracting basis apart from being used for large-scale experimental studies on certain food items. Its present Cobalt-60 loading is more than 300 kCi. The other company formed, HEPRO (Pty) Ltd, took over and upgraded the old pool facility at the Letaba Co-operative in the North-eastern Transvaal to a batch facility, a JS-8200, by acquiring the necessary components from AECL (RCC). This facility became operative in 1982 and its present Cobalt-60 loading is more than 100 kCi.

During the planning stages for extended marketing some supermarkets were of the opinion, as expressed during discussions as well as at joint formal meetings, that their future participation should enjoy the necessary statutory protection. A steering committee for co-ordinating the marketing of radurised foods, to act as an advisory committee to the Minister of Agriculture, was appointed in 1981 for this purpose. The following are represented on this committee: NUCOR, the Department of Agriculture (Economics and Marketing), the SA Trade Institute, ASSOCOM, the Consumers' Union, the Citrus Exchange, the SA Association for Food Science and Technology, and a representative of the processors. A senior official of the Department of Health and Welfare is also involved but only in an observer capacity. The committee, which is chaired by the director of Product Standards of the Department of Agriculture
(Economics and Marketing), has already held several meetings at which problems related to the protection of the process, processors and all related parties as well as to marketing priorities, labelling, publicity, codes of good manufacturing practice, control measures with respect to import/export of irradiated foods etc. have been discussed and equitable solutions offered. More recently an Executive Committee has been proposed which could take immediate action. On the still contentious subject of labelling, our situation is that no labelling as a result of the treatment is required. The use of the RADURA label as a sticker emblem is optional but it is commonly used. Outer containers are stamped for batch identification. Regarding the protection issue, litigation steps are not excluded in claims disputing the basic tenets of released clearances.

Valuable data on consumer acceptability, etc have been obtained over the past two years of reasonably active commercial marketing involving many of the cleared products in Table 1 in quantities of several thousand tonnes in total. Our experience so far regarding acceptability substantiates the results obtained in 1979 during trial marketing.

In a few instances, some resistance was and is still being experienced at times regarding full acceptance by some people in retail management and even in institutional control boards, but this opposing attitude did not prove insurmountable following an education/information-based approach.

With general acceptability reasonably assured and a clearer picture of real advantages seen against processing costs practically demonstrated to the food industry, the consumer trade and the consumer a situation is developing which calls for further expansion in commercialisation. A logical next step would be the introduction of food irradiation technology in the south of the country, namely the Western Cape, as all three existing facilities are in the north. The Western Cape is an important producing region for a variety of food items which could benefit greatly by radiation treatment and
this was borne out by a techno-economic study recently conducted for investigating the erection of an irradiation facility in the Cape. Hopefully, private enterprise could be sufficiently persuaded to take up this challenge. Following the Cape, Natal is likely to be next in line to receive attention.

The right type of facility for these developments will be less expensive pallet irradiators to minimise handling, storage and hold-up, as well as be suited for multi-purpose applications. Design features are presently being considered for throughputs of several thousand tonnes per annum.

CONCLUSION

If the infrastructure sketched above is judiciously continued over the next few years on a national exploration and exploitation basis, food irradiation technology is expected to develop to a firm and future-secured position in South Africa. The commercial application of food irradiation in South Africa should contribute to international acceptance and, partly for this reason, our efforts are at present exclusively directed at the national establishment of the technology. The initiatives taken by the responsible statutory institutions and also the private processors in South Africa have certainly not been disappointing so far. South Africa is a strong proponent for continued international co-operation, and the formation of the International Consultative Group on Irradiated Foods announced last year is viewed by us as an important further vehicle to pave the way for wide international acceptance of the technology from a national usage and an import/export point of view. If international trade could be initiated under the auspices of the international agencies involved, this will greatly contribute to the orderly and guarded establishment of international trade in irradiated products. Without such protective involvement resistance may gain momentum and destroy the future of this efficacious food processing technique which has a potentially wide application.
DOSIMETRY AND ACCEPTANCE OF IRRADIATED FOOD

(Poster Session III)
The objective of the United States Department of Energy’s Byproducts Utilization Program is to encourage widespread commercial use of nuclear by-products. A major beneficial use of the caesium-137 by-product is for the low-dose gamma-ray treatment of various food commodities. The Cesium Agricultural Commodities Irradiator (CACI) is an important step in achieving broad commercial use and acceptance of irradiation as a disinfestation method for selected fruits, vegetables, and field crops in the United States of America. The main purposes of CACI are:

1. **RESEARCH**
   - To evaluate the technical feasibility of irradiating specific commodities
   - To establish optimal irradiation protocols for currently restricted export commodities, with attention to control variables such as conditioning treatments, temperatures, and atmospheres
   - To evaluate irradiation as an *alternative* to existing methods of quarantine treatment, some of which are under regulatory scrutiny.

2. **DEMONSTRATION**
   - To demonstrate the beneficial use of caesium-137
   - To demonstrate, with food industry involvement, the efficient utilization of irradiation for disinfestation and preservation of certain commodities at near-commercial throughputs and load sizes.
CACI will be a panoramic, wet-storage gamma irradiator using ~ 3 MCi of caesium-137 contained in ~ 55 double-walled stainless steel capsules from the Waste Encapsulation and Storage Facility (WESF) at Rockwell Hanford. The capsules will be contained in two independently operable plaques in one plane, with flexibility to optimize product dose uniformity.

The CACI irradiation chamber will be capable of providing total absorbed doses from ~ 10 Gy to ~ 10 kGy at dose rates of 0.1 to 2 kGy/h. An automated overhead product carrier system to accommodate near-commercial throughputs in cartons, and two pallet-sized rotating platforms will be provided. Additional features will include control and equipment rooms, separate unirradiated and irradiated product storage areas, refrigerated areas, and laboratory facilities. CACI will have all the essential safety features required by the Nuclear Regulatory Commission and will be designed in accordance with current American National Standards Institute specifications.

IAEA-SM-271/57P

TRANSPORTABLE CESIUM IRRADIATOR (TPCI)
FOR ON-SITE FOOD IRRADIATION RESEARCH

N. FERRELL, R. ANDERSEN
CH2M HILL,
Albuquerque, New Mexico,
United States of America

The concept of a portable research irradiator that can be transported from one research site to another had its birth within the United States Department of Energy's Byproducts Utilization Program. The main thrust of this programme is now directed towards the design, construction, and evaluation of demonstration irradiators utilizing a caesium-137 gamma source.

The TPCI facility, which is scheduled to be operational in September 1985, has several unique design features which are discussed in detail in the paper. The operational characteristics of this research irradiator will allow most users to transport the facility to the location near the intended research where it may temporarily become part of the normal process flow.

The latest information regarding the TPCI utilization plan and operation scheduling is summarized and procedural steps are outlined for researchers interested in utilizing the facility.

---

1 1 Ci = 3.70 × 10^{10} Bq.
SCIENTIFIC CONSIDERATIONS FOR THE USE
OF 10 MeV X-RADIATION IN FOOD PROCESSING*

M.C. LAGUNAS-SOLAR
Crocker Nuclear Laboratory,
University of California,
Davis, California

S.M. MATTHEWS, D.R. SLAUGHTER
Lawrence Livermore National Laboratory,
Livermore, California

United States of America

The recommendation of the Joint FAO/IAEA/WHO Expert Committee in 1980, on the Wholesomeness of Irradiated Food, limits the radiation sources to radionuclides (60Co and 137Cs) and machine sources generating up to 5 MeV X-radiation and up to 10 MeV electron beams. This recommendation is generally being accepted throughout the world. However, there is no scientific basis for excluding the use of up to 10 MeV X-radiation converted from a 10 MeV electron accelerator when, at the same time, the direct use of 10 MeV electron beams is permitted. The major factor to be taken into consideration for establishing the present recommendations is clearly the need to decrease the possibility of inducing radioactivity in food via photonuclear reactions. There is no theoretical or experimental evidence suggesting that induced radioactivity with up to 10 MeV electron beam energy is larger than 0.01% of the natural radioactivity content in food. Furthermore, food itself, its packaging, and to a much lesser extent the material adjacent to a 10 MeV electron accelerator facility, can act as electron-to-X-ray converters, generating a broad spectrum of X-rays (bremsstrahlung radiation) of up to 10 MeV. The direct electron-beam processing as currently defined will then be in violation with the intent of establishing the 5 MeV X-ray limit. Bremsstrahlung production in several typical foods and packaging materials will be calculated in order to evaluate the potential implications of increasing the X-radiation limits.

* Supported by the University of California Nuclear Sciences Fund.
The application of ionizing radiation in the processing of food depends largely on economic factors and technical considerations. The ability to process large food containers, with dose ratios as low as possible, is required in order to achieve and predict uniform effects, while also complying with regulatory specifications. Because of economic restraints it is desirable that this is accomplished while treating pallet-size food packages. Simple calculations of the photon flux as a function of depth using Lambert-Beer's law \( I = I_0 e^{-\mu x} \) do not include the dose buildup effect, which is due mostly to Compton-scattered photons (less energy than the primary radiation) and to a lesser extent to X-rays resulting from photoelectric interactions, followed by Auger electrons, annihilation radiation from the pair-production process, and bremsstrahlung from the slowing down of energetic electrons. Dose buildup depends on photon energy, physical characteristics of the absorber, and the geometry of radiation source and food package (absorber). A comparison of results obtained by solving a Boltzmann transport equation for both the primary and secondary radiations in thick food packages, using area sources of \(^{137}\text{Cs}, ^{60}\text{Co}, \) and X- and electron radiation from several different energy (2 to 10 MeV) accelerators, is discussed. The results are compared with experimentally determined dose ratios. These results will aid the evaluation of the potential of the different radiation sources currently being considered for the large-scale radiation processing of food.

* Supported by the University of California Nuclear Sciences Fund.
PETITIONS AND CLEARANCES IN ISRAEL — AN UPDATE

M. LAPIDOT
Soreq Nuclear Research Center,
Yavne, Israel

The criteria of the local Ministry of Health for clearance of irradiated foods are based on the submission of material including petitions and clearances in at least one other country. A petition for preventing sprouting in potatoes, submitted in 1966 on the basis of the petitions and clearances in the USA, the USSR, and Canada, enabled the Ministry of Health to publish regulations in 1967, in which it was forbidden to irradiate food for commercial purposes unless a particular item was cleared in a schedule of the regulations. The first schedule, clearing potatoes irradiated up to 15 krad, was issued with these regulations. Submission of a petition for irradiated onions, based on that of Canada, resulted in clearance of onions irradiated up to 10 krad.

A petition for irradiated poultry, based on that in the Netherlands and on the JECFI recommendations, was submitted in 1981 and clearance for radurization of poultry up to 700 krad was issued in 1982.

The Ministry of Health decided that it would also consider radicidized animal feed under the regulations issued for irradiated foods. A petition submitted in 1972 resulted in clearance of poultry feed irradiated up to a dose of 1.5 Mrad, using cobalt-60 gamma rays (as in all preceding clearances).

The need for commercial radicidation of animal feeds under economically feasible conditions led to the conclusion that electron accelerators must be employed. A new petition, based on the identical effect of gamma rays and electrons as evidenced by the Recommended Standard for Food Irradiation, was submitted in 1983 and was followed immediately by a petition for irradiation of spices and condiments, and for irradiation of onions, garlic, and shallots, on the basis of the strong commercial interest of the respective industries.

The Ministry of Health has revised the Food Irradiation Regulations in view of the Recommended Standard of the Codex Alimentarius, and the new Regulations were published in March 1985. These include schedules for the items cleared above, as also for spices irradiated up to 1 Mrad, and for onions, garlic, and shallots up to a dose of 15 krad.

In view of additional commercial interest from industry and agricultural producers, several additional petitions have been prepared to be submitted in

\[1 \text{ rad} = 1.00 \times 10^{-2} \text{ Gy}.\]
March and in May 1985. These include petitions for the irradiation of wheat and wheat products, rice, pulses, dried vegetables and fruits, dry food ingredients, strawberries, mangoes, citrus fruits, mushrooms, and dates. Clearances are expected in the second half of 1985. Additional petitions are being prepared for submission at that time.

FRENCH PROGRAMME IN REFERENCE DOSIMETRY FOR IONIZING RADIATION PROCESSING OF FOOD

D. MOSSE, M. CANCE, J.P. SIMOEN
Laboratoire de métrologie des rayonnements ionisants,
Office des rayonnements ionisants,
Centre d'études nucléaires de Saclay,
Gif-sur-Yvette, France

As the French primary laboratory and as an official calibration centre of the Bureau National de Métrologie (BNM), the Laboratoire de Métrologie des Rayonnements Ionisants (LMRI) is in charge of a quality assurance programme that aims at ensuring the traceability of dosimetric measurements in the field of gamma and electron radiation processing of food. This programme comprises establishment of standardizing procedures for characterizing in dosimetric terms the instruments of measurement and the radiation fields of radiation processing plants. These procedures will mainly be based on the use of an electron spin resonance (ESR) measurement system of free radiation-induced radicals in integrated organic detectors such as the amino-acid L-alanine. The system set up at LMRI is a BRUKER ER 100 D ESR spectrometer linked to a microcomputer VICTOR S1 for acquisition and in-line treatment of experimental data. The dosimetric characteristics of the system (good equivalence of the dosimeters to materials of interest, large range of dose and dose rate measurable) and its technical characteristics (flexibility of use, size of dosimeters, stability of free radicals) are well adapted to the specific applications under consideration.
RADURIZED FOODS — A CHALLENGE TO MARKETING

T.A. DU PLESSIS, J.G. NIEMAND
Iso-Ster (Pty) Ltd,
Kempton Park, South Africa

Few food processing techniques have been subjected to such intense fundamental scrutiny as the radiation treatment of foodstuffs (radurization). It is thus somewhat disappointing that the commercialization of this very promising process has been so slow. Generally this situation is attributed to man's fear and misunderstanding of matters related to nuclear energy and the emotional connotations that it has in some countries, as well as the initial reluctance of the Food and Drug Administration in the United States of America to recognize radurization as a process and not as a food additive. However, in retrospect, other equally important factors can be given for the lethargic progress experienced to date.

Most of the earlier research was directed at potential military applications with little commercialization in mind. Accordingly, the types of foodstuffs that were researched do not easily lend themselves to application in the food industry, while presenting serious radiation-technological problems. Ironically, the types of products that do lend themselves to radurization with little or no radiation-technological problems were to a large extent ignored. This is clearly demonstrated by the fact that most of the initial research was directed towards products such as raw and processed meats, and fresh fruit and vegetables, while dry and dehydrated products received little attention. In this respect it appears that collaboration between researchers and the food industry could have been closer.

As a contract radiation processor, the marketing of radurization presented a particular challenge to our company. In developing a marketing strategy consideration had to be given to a number of factors determining marketing approach. Amongst the more important of these factors were: the choice of foodstuffs selected had to be restricted to those products compatible with the radiation sterilization activities of the company, which excluded the possibility of processing fresh and raw products. Lastly, efforts were directed towards the food processing industries in close proximity to our plant which probably brought us to the most important factor, which was that we were dealing primarily with professionals in the food industry who appreciated the benefits offered by this new process and, consequently, we had limited dealings with the actual consumer and his more emotional attitude. The validity of this marketing approach is borne out by the fact that of the current (January 1985) 55 unconditional clearances granted by the local health authorities for radurized foodstuffs, a total of 42 clearances were...
granted for products to be radurized by our company. Of this total, 39 products were cleared in the last six months and it is interesting to note that 77% of the foodstuffs currently cleared for radurization fall in the category of dried and dehydrated products.

We also experienced the cardinal importance of gaining the support of the local regulating authority without whose understanding and support little progress would have been made while a further important factor which substantially assisted the marketing of the process was the founding of a body known as the Steering Committee for the Marketing of Radurized Foods. The members of this body are drawn from various research, industrial, consumer and legislative bodies and this provided the necessary credibility and removed a great deal of the apprehension that existed during the earlier days.

AN AUTOMATED SYSTEM FOR MEASURING THE DOSE PROVIDED TO IRRADIATED FOOD

T. PRUSIK
Allied Corporation,
Morristown, New Jersey

T. WALLACE
University of Lowell,
Lowell, Massachusetts

United States of America

This dosimetry system consists of a label in a bar code format with special polymers which change colour as a function of radiation dose. A specially designed scanner interprets the colour change on the label and provides a direct reading of radiation dose and a computerized information system. The dosimetry labels containing product identification information in standard bar code symbology and the radiation sensitive polymer printed in a unique bar code format are applied to the shipping case before irradiation. A special microcomputer equipped with an optical scanning wand is used to decode the bar code and determine the dose level from the colour of the polymer bar codes. The paper describes results on indicator performance. In particular, results from dose rate, temperature, humidity, and stability studies are discussed.
FREE RADICALS FORMATION AND DECAY IN IRRADIATED SPICES

J.J. SHIEH, E. WIERBICKI
United States Department of Agriculture,
Agricultural Research Service,
Eastern Regional Research Center,
Philadelphia, Pennsylvania,
United States of America

INTRODUCTION

This investigation of free radicals produced in the continuous radiolysis of spices and vegetable seasonings was undertaken for two reasons. First, irradiation processing of spices and spiced meat products may result in the formation of long-lived free radicals. Secondly, such free radicals, irrespective of their lifetimes, are among the important precursors of final radiolytic products. The free radical intermediates produced by ionizing radiation may be observed using electron spin resonance techniques.

For this investigation, seeds of black pepper, sage leaves and onion as an illustration of bulbs in the form of powder or flakes were selected for the irradiation studies.

METHOD

Sample irradiation. Samples were irradiated at controlled temperatures using a self-contained caesium-137 radiation source. This source currently has a strength of 147 000 Ci. This radiation source was described previously.

Analytical measurement. Measurements of radiation-generated free radicals were made on dry samples in an electron spin resonance spectrometer (Model E-109B, Varian Associates). The resonator of the spectrometer was thermostatically controlled to measure chemical changes in samples at temperatures between 77°K (−196°C) and room temperature.

---

1 1 Ci = 3.70 X 10^{10} Bq.
RESULTS

Irradiation of black pepper, sage and dehydrated onions at dosages of 1, 3, 10 and 30 kGy at 25°C produced free radicals detectable in the electron spin resonance spectrometer. The initial singlet-like pattern, which was ascribed to a carbon-centred radical, diminished gradually in signal intensity without conversion to another type of free radical in the various spices. The ESR spectrum of irradiated dehydrated onions is characterized by a singlet-like pattern. Although the amount of free radicals produced was directly related to the irradiation dose, the free radicals were not long lived and decayed within 4 to 5 days at 25°C with a half-life of 0.45 days (Figs 1 and 2). A fairly small amount of endogenous stable free radicals (due to processing or something else) was observed in this investigation. Irradiation of sage and black pepper under identical conditions produced free radicals which decayed rapidly reaching background level within about 10 days (see Fig.3 and Table I).
FIG. 2. Effect of storage time on decay of free radicals generated by gamma irradiation. The dehydrated onions were irradiated at 25°C with 0.5, 1.0, 10 and 30 kGy and then stored.

FIG. 3. Decay of free radicals generated by gamma irradiation with storage time. Black pepper and sage were irradiated at 25°C with 30 kGy and then stored.
### Table I. ESR Signal Intensity of Irradiated Sage

<table>
<thead>
<tr>
<th>Dose (kGy)</th>
<th>Storage time (d)</th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0</td>
<td>1</td>
<td>2</td>
<td>10</td>
<td>24</td>
</tr>
<tr>
<td>1</td>
<td>5.3</td>
<td>3.6</td>
<td>3.3</td>
<td>2.0</td>
<td>2.0</td>
</tr>
<tr>
<td>3</td>
<td>31.5</td>
<td>19.0</td>
<td>8.5</td>
<td>4.5</td>
<td>2.9</td>
</tr>
<tr>
<td>10</td>
<td>54.5</td>
<td>27.0</td>
<td>22.0</td>
<td>11.5</td>
<td>6.5</td>
</tr>
<tr>
<td>30</td>
<td>84.0</td>
<td>28.8</td>
<td>22.0</td>
<td>7.5</td>
<td>6.4</td>
</tr>
</tbody>
</table>

*Note:* Intensity of 4.0 in non-irradiated sample was observed.

### Conclusion

The kinetic information obtained by monitoring the changes in the ESR signal at 25°C as a function of time, yielded some useful results. First, the initial singlet-like pattern in irradiated spices diminished gradually in signal intensity without conversion to another type of free radical. Secondly, the free radicals produced in the samples due to irradiation treatment did not persist but instead decayed, although a small amount of stable free radicals was observed in our samples.
ELECTRON AND GAMMA DOSIMETRY BY
GLUTAMINE LYOLUMINESCENCE

A. MILLER
Accelerator Department,
Risø National Laboratory,
Risø, Roskilde, Denmark

Liqing XIE*
Institute of Low Energy
Nuclear Physics,
Beijing Normal University,
Beijing, China

Lyoluminescence (LL) of glutamine is a reasonably precise technique for dosimetry in the range used for food irradiation, namely four decades from 10 to $10^5$ Gy. We have studied some properties of glutamine LL irradiated with cobalt-60 photons and 10 MeV electrons, namely:

- effects of dose rate
- effects of relative humidity
- effects of storage time.

These factors are found to influence the response by less than 10%.

* Present address: Accelerator Department, Risø National Laboratory, Risø, Roskilde, Denmark.
THE SUITABILITY OF CHEMOLUMINESCENCE AS A MEANS OF IDENTIFYING RADIATION PROCESSED SPICES

D.A.E. EHLMANN, H. DELINCEE, W. KALUS, T. GRÜNEWALD
Bundesforschungsanstalt für Ernährung, Karlsruhe, Federal Republic of Germany

A number of countries have already cleared radiation processing of foods and permit the elimination of microorganisms from spices. In the Federal Republic of Germany the Food Law prohibits radiation processing in general and, until that law is changed, it is only possible to obtain an exemption in specific cases. For example, clearance for the radiation processing of spices will be valid only for certain individual producers and for the spice varieties listed in their clearances. Obviously, reliable and sufficiently fast methods of identifying radiation-processed spices are indispensable in order to enforce the Food Law, to control trade with radiation-processed spices and their labelling.

There is no lack of effort to develop such methods, but none has been proved reliable in practice as yet. Free radicals in dry spices are rather stable and might be useful as indicators. Earlier studies on electron spin resonance in dried products failed to reveal any effect unique to radiation processing. In a chemoluminescent reaction with luminol most dry spices produce a light emission which appears to be unique to radiation treatment. However, a number of counter-effects are already known which extinguish or mask the luminescence.

The chemoluminescence signal is rather weak and very sensitive detectors with sufficiently low background are needed. The reaction takes place at the surface of the particles only and the procedure of mixing the spice with the reagent determines the amount of light detected. The effect is proportional to the dose; the response function is, however, determined by the type of produce. A knowledge of the kind of spice and of the composition of a mixture is necessary in order to draw any conclusions on possible radiation treatment. In particular, the salt content, e.g. in curry, contributes to light emission by the lyoluminescence of irradiated salt and simulates a much higher radiation dose to the spice. Whereas the original publication on the use of the effect presented a rather low background for all unirradiated samples, grinding with high stresses on the particles also produces a luminescence effect which it has not yet been possible to differentiate from the one produced by irradiation. The method needs further study and clarification of its reliability before its use for irradiation identification with spices can be recommended.
Very few publications are available on dosimetry in the radiation processing of free-flowing, bulk materials such as spices. Small dosimeters suspended in the stream of the particulate solids seem to offer a solution to the dosimetry problem. Where the clearance for radiation-processed spices poses a strict upper radiation dose limit instead of the statistical approach of the 'overall average dose' concept of the Codex Alimentarius Commission, reliable determination of the dose distribution to the individual particles of the foods is indispensable. The semiconductors discussed are a solution to the problem because they can easily be recovered from the particulate foods and no special health problems will arise from their use in foods.

A permanent change in a special time effect of the switching behaviour of semiconductor diodes can be used to measure radiation dose over a wide range of doses and dose rates. A thermal conditioning treatment allows the dosimeter to be re-used several times. For the studies reported commercially available diodes were used. Better suitability for application in granular materials may be obtained by manufacturing diodes that approximate more closely the size and density of particulate foods.

The flow pattern in a vibrating trough conveyor determines the speed at which the particles pass the irradiation field and the absorbed radiation dose depends on the residence time in that particular field. Only if the diodes are suspended in the stream of particles in such a way that their velocity distribution is identical to that of the food particles, or if the correlation of the two velocity distributions is well determined, will it be possible for the radiation dose distribution in the food product to be directly determined with the diode dosimeter.

BIBLIOGRAPHY

COMMERCIAL DEVELOPMENTS:
IRRADIATION SOURCES AND ASPECTS
OF THE IMPLEMENTATION
OF FOOD IRRADIATION

(Session VI)

Chairman

R.F. MORRIS
United States of America
DESIGN CONSIDERATIONS FOR FOOD IRRADIATORS IN DEVELOPING COUNTRIES

K. KRISHNAMURTHY, D.R. BONGIRWAR
Bhabha Atomic Research Centre,
Trombay, Bombay, India

Abstract

DESIGN CONSIDERATIONS FOR FOOD IRRADIATORS IN DEVELOPING COUNTRIES.

The process of radiation preservation of foods is on the threshold of actual application. The research and development efforts, spanning the past three decades, have established the feasibility of this methodology for post-harvest conservation of various items of food for longer durations. The use of food irradiation has been considered relevant particularly in developing countries where the infrastructure for storage and distribution is far from satisfactory. The purpose of irradiation differs with each item to be treated and the actual requirements of the irradiation facilities need to be precisely worked out. The dose of irradiation and the anticipated total throughputs of a commodity to be treated are also important parameters in designing suitable sources. Recent field storage trials with onions have yielded encouraging results. Therefore studies were initiated to develop a conceptual model of an irradiator for the treatment of onions. The considerations have included (a) mathematical modelling based on a computer program for the optimization of irradiation geometry for line and planar sources, respectively, (b) systems engineering for the evaluation of the process parameters, and (c) projections of the economics of the process. An operational system for processing approximately 3 t/h of onions in a portable demonstration plant has been proposed.

1. INTRODUCTION

The process of radiation preservation of foods is on the threshold of commercialization. Research spanning the last three decades, carried out in many parts of the world, has categorically established the superiority, safety and feasibility of the process for treating a variety of food products. A few large-scale gamma irradiators have been set up in recent years in countries such as France, the German Democratic Republic, Italy, Japan, the Netherlands, South Africa, the USA, and the USSR, etc., with a view to developing market potential and consumer appreciation of this process [1]. The safety of irradiated food has now been internationally accepted and the barriers in international trade are also being progressively removed as a result of the recommendation of the Codex Alimentarius Commission (CAC), which has evolved standards for irradiated foods and has recommended a code of practice for the operation of irradiation facilities for the treatment of foods [2]. Thus the international scenario shows promise for the rapid growth of the technology.
Food irradiation, in fact, is of great relevance to developing countries, particularly for the conservation of the agricultural produce. Most of these countries are in the tropics, where temperature and humidity conditions tend to accelerate food spoilage and losses. It has been reported that post-harvest losses of cereals and legumes in 1976 could have fed almost 170 million people and predictions are that by 1985 food losses may total 107 million tonnes, worth US $11.5 \times 10^9 [3, 4].

The processes of special interest to the developing regions are:

- Sprout inhibition in root crops such as onions, potatoes, garlic, etc.
- Disinfestation of grain
- Delayed ripening in fruits
- Microbial decontamination of spices, dried fish, etc.
- Shelf-life extension of fresh commodities such as fish, vegetables, etc.

The attractiveness of the process stems from the fact that food preservation is effectively achieved with alternative energy sources, with commercial energy supplies being redeployed for other end uses. The introduction and growth of the technology in these countries, however, depend on a number of factors. These include techno-economic evaluation and consumer awareness. The viability of the process depends largely on the favourable economics for farmers and traders. It was, therefore, considered necessary to develop suitable demonstration plants for processing root crops and wheat. The purpose of irradiation and the doses required differ with each commodity. This points to specific design considerations relevant to the items to be treated.

2. GENERAL CONSIDERATIONS

Radiation processing is well recognized as a capital intensive process. Most of the developing countries having low techno-economic status find it difficult to accept the process until totally proven to their own advantage elsewhere. However, the key to the practical introduction and application of food irradiation processing largely depends on the successful development of cost effective and simple food irradiator designs to meet local demands.

Two types of irradiator systems are generally essential to meet this requirement:

- Portable or semi-portable units — for practical demonstration of the process and for market acceptance studies.
- Fixed irradiation facilities — for techno-economic evaluation and commercialization of the process. Food irradiator design concepts relevant to developing countries should, among others, take into account the following considerations:
  - Low capital investment
  - Plants of low to medium throughputs
— Low marginal cost for the processing
— Seasonality of products processed
— Technological simplicity and labour involvement
— Low operational and maintenance cost
— Minimum operator qualification and training
— High safety standards

Evidently some of these factors are conflicting in their demands and an optimized approach is therefore very difficult to achieve.

3. CONCEPTS OF LOW-COST IRRADIATORS

A number of food irradiator concepts have been evolved in the past few years. These concepts are basically aimed at providing compact and optimal energy efficient designs for processing products such as onions, potatoes, wheat, etc.

The first consideration in the conceptual design is the source—product irradiation geometry. Optimization of this parameter, as regards radiation output, uniformity of dose absorption in the product and radiation utilization efficiency is important to attain a purposeful engineering design. There are at least three basic irradiation geometries which have been extensively investigated for developing low-cost irradiators in countries such as Hungary, India and Japan. They may be grouped as:

— Cylindrical source geometry — with products in concentric cylindrical channels surrounding the source
— Single-line source geometry — with products in slab geometry above and below the source
— Planar—grid source geometry — with products above and below the planar source — product flowing through the grids.

4. PRESERVATION OF ONIONS — IRRADIATOR REQUIREMENTS

The irradiation techniques for inhibiting sprouting in onions and potatoes have been well established [5, 6]. Field trials on the storage of onions have established beyond doubt the efficacy of the process for extending storage of onions in field conditions [7]. The basic technological demands of developing countries seem to be different from those in the developed regions [8, 9].

On the basis of an analysis of the earlier studies, it was felt that the following were the major considerations for evolving a suitable design for an onion irradiator particularly as a demonstration unit:

(1) The unit should be transportable by road and capable of being located at various production or trade centres. The unit should also be capable of being
TABLE I. ONION IRRADIATOR SPECIFICATIONS

<p>| | | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Source size (single unit)</td>
<td>670 mm long X 40 mm dia.</td>
</tr>
<tr>
<td></td>
<td>(overall triply encapsulated)</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>Cobalt-60 source strength</td>
<td>20 000 Ci</td>
</tr>
<tr>
<td>3</td>
<td>Conveyor size</td>
<td>430 mm wide and 1000 mm long</td>
</tr>
<tr>
<td>4</td>
<td>Shielding (lead)</td>
<td>250 mm (minimum)</td>
</tr>
<tr>
<td>5</td>
<td>Overall size of shield</td>
<td>2200 mm X 2200 mm X 2500 mm (height)</td>
</tr>
<tr>
<td>6</td>
<td>Weight</td>
<td>20 t</td>
</tr>
<tr>
<td>7</td>
<td>Product processed</td>
<td>Onions</td>
</tr>
<tr>
<td>8</td>
<td>Treatment dose</td>
<td>6 kGy (minimum)</td>
</tr>
<tr>
<td>9</td>
<td>Overdose ratio</td>
<td>2.25</td>
</tr>
<tr>
<td>10</td>
<td>Capacity for processing</td>
<td>3 t/h (at 20 000 Ci loading)</td>
</tr>
<tr>
<td>11</td>
<td>Power requirement</td>
<td>1 kW (220 V single phase) or Diesel generator</td>
</tr>
<tr>
<td>12</td>
<td>Water requirement</td>
<td>Nil</td>
</tr>
<tr>
<td>13</td>
<td>Space requirement</td>
<td>4 m X 4 m X 4 m (with special flooring)</td>
</tr>
</tbody>
</table>

transported in a knocked down condition such that each piece weighs not more than five to six tonnes and can safely be assembled for operation.

(2) The radiation source design should facilitate the loading and unloading of the source on site and permit standard lead containers of reasonable weight for transportation on village roads.

(3) A processing rate of 2 to 3 t/h would be adequate for demonstration purposes, with a minimum dose of 60 Gy (6000 rad); the maximum dose not exceeding 150 Gy (overdose ratio of 2.5).

(4) The investment should be low with reasonable returns ensured to provide favourable economics.

(5) Power and water requirements should be limited to the absolute minimum.

(6) The product should preferably be irradiated in loose form or in bulk in quantity, i.e. onions from jute bags are poured in the hopper and allowed to flow by gravity on a conveyor.

A transportable lead-shielded irradiator with a simple source design would facilitate transport, assembly and installation at any site. The concept provides for mobility for locating the irradiator at any site. Also the compact lead-shielded facilities could be built without additional expenditure on civil structures. Based on these considerations, a single-line source moving-bed irradiation scheme was studied. The design features of the irradiator are briefly summarized in Table I.
5. EVALUATION OF IRRADIATOR MODEL AND OPTIMIZATION STUDIES

The major parameters of concern in the design optimization have been (a) source geometry, (b) source/product geometry, (c) biological shielding which should result in facilitating maximal utilization of the radiation. A single-line source geometry with source overlap geometry would enable achieving compact source/shield design. A computer program based on the 'Fudge 4 A' Code [10] developed at Brookhaven National Laboratory was evolved to calculate the dose distribution due to a linear source in a static system with products of varying thickness uniformly distributed on a bed of width 'W' and length 'L' and separated from the source by a series of air gaps 'A'. The calculation of dose distribution in an infinite product geometry from a finite plane source employed 12 point cause quadrature integration routine. This subroutine can accommodate factors such as self-absorption within the source, absorption in the clad and conveyor materials, finiteness of the source dimensions, variations in the air gap between the source and the product, dose buildup in the product material due to multiple collisions, etc.

A network matrix of 15 dose points was chosen and averaged over the entire bed of products (see Fig.1). Dose rates were evaluated on these points again for the

![FIG.1. Typical dose distribution in product from a single source of 3 cm width and 67 cm length.](image)

<table>
<thead>
<tr>
<th>DOSE RATE (krad/h)</th>
<th>Average A-F</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>B</td>
</tr>
<tr>
<td>1</td>
<td>17.34</td>
</tr>
<tr>
<td>2</td>
<td>17.28</td>
</tr>
<tr>
<td>3</td>
<td>17.09</td>
</tr>
<tr>
<td>4</td>
<td>16.72</td>
</tr>
<tr>
<td>5</td>
<td>16.00</td>
</tr>
<tr>
<td>6</td>
<td>9.70</td>
</tr>
<tr>
<td>7</td>
<td>9.65</td>
</tr>
<tr>
<td>8</td>
<td>9.48</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>DOSE RATE (krad/h)</th>
<th>Average A-F</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>B</td>
</tr>
<tr>
<td>9</td>
<td>9.17</td>
</tr>
<tr>
<td>10</td>
<td>9.07</td>
</tr>
<tr>
<td>11</td>
<td>6.18</td>
</tr>
<tr>
<td>12</td>
<td>6.13</td>
</tr>
<tr>
<td>13</td>
<td>6.00</td>
</tr>
<tr>
<td>14</td>
<td>5.75</td>
</tr>
<tr>
<td>15</td>
<td>5.34</td>
</tr>
</tbody>
</table>
flow of material on the return part of the conveyor. Two situations were envisaged for calculating the overdose ratios. The first situation is one in which product material that follows an extremely low dose profile in the upper pass continues to follow the same profile (as a mirror image) on the return flow, thus receiving the lowest possible dose during irradiation. The overdose ratio resulting from such an unlikely flow of products is termed Worst Overdose Ratio (WOR).

In the second situation the product which follows one profile in the upper pass on the conveyor gets a totally reversed profile during the return pass on the lower conveyor. This is also an extreme situation unlikely to happen and the overdose ratio resulting from such a flow is termed Best Overdose Ratio (BOR).

The overdose ratio in a practical situation, however, may lie between these two limiting values (BOR-WOR) and hence for the purpose of design optimization the worst overdose ratio was taken as the limiting value set by the specifications. The optimization of radiation utilization efficiency was studied, keeping the limiting overdose ratio (WOR) to a value of 2.25 while varying the factors such as air gap, product thickness, and source size. A typical analysis has been presented in Table II.

Figures 2 and 3 show the relation between the efficiency, product thickness, air gaps and overdose ratio as computed by the program. The calculations, however, assume a homogeneous flow of the product of reduced density, or packing density, allowing for the finiteness of shape and size of onions.

6. ENGINEERING DESIGN AND OPERATION

The engineering design features of the irradiator are outlined in Fig.4. The entire irradiator (excluding the lead container attachment for the source load/unload operation) occupies an area of 2.2 m × 2.2 m (4.85 m²) and measures about 2.5 m in height including the loading port. The unit can be housed in any existing room of 4 m × 4 m in area. The estimated weight of the whole assembly is about 20 t excluding the source shipping container. The entire shield assembly is built up of subunits, each weighing about 1 to 6 tonnes. The shield can be dismantled and assembled with ease after the source is safely retracted into the shipping container. The whole assembly could be made ready from knocked down conditions in about four days at any site. The total assembly is encased in steel to protect the source unit in the event of an accident while in use.

7. CONVEYOR

The conveyor design closely follows the scheme originally proposed by Kuhl et al. [11] for their pilot plant for irradiation of potatoes. The conveyor consists of an endless belt of stainless-steel mesh wire wound over two drums located on either side external to the shield and driven by a suitable motor. The conveyor is about
TABLE II. A TYPICAL PROGRAM OUTPUT – ONION IRRADIATOR – PRODUCT–SOURCE GEOMETRY OPTIMIZATION STUDIES

<table>
<thead>
<tr>
<th>Source dimensions</th>
<th>Width = 3.0 cm; Length = 67.0 cm</th>
</tr>
</thead>
<tbody>
<tr>
<td>Conveyor bed dimensions</td>
<td>Width = 42.0 cm; Length = 60.0 cm</td>
</tr>
<tr>
<td>Activity of the source</td>
<td>201.0 Ci (0.007 PBq)</td>
</tr>
<tr>
<td>Product thickness</td>
<td>4.0 cm</td>
</tr>
<tr>
<td>Air gap (between source and conveyor)</td>
<td>8.0 cm</td>
</tr>
<tr>
<td>Product density</td>
<td>0.70 g/cm^3</td>
</tr>
<tr>
<td>Processing volume</td>
<td>20.16 L</td>
</tr>
<tr>
<td>Weight of the product</td>
<td>14.11 kg</td>
</tr>
<tr>
<td>Worst maximum dose rate</td>
<td>6126.0 rad/h (61.26 Gy/h)</td>
</tr>
<tr>
<td>Worst minimum dose rate</td>
<td>3892.1 rad/h (38.92 Gy/h)</td>
</tr>
<tr>
<td>Worst overdose ratio</td>
<td>2.27</td>
</tr>
<tr>
<td>Best maximum dose rate</td>
<td>5009.1 rad/h (50.09 Gy/h)</td>
</tr>
<tr>
<td>Best minimum dose rate</td>
<td>4643.9 rad/h (46.43 Gy/h)</td>
</tr>
<tr>
<td>Best overdose ratio</td>
<td>1.08</td>
</tr>
</tbody>
</table>

FOR A MINIMUM DOSE OF: 6000 rad (60.0 Gy)

At the worst efficiency
- Activity to process 1 t/h : 21 965.8 Ci (0.814 PBq)
- Speed of the conveyor : 1.42 m/min

At the best efficiency
- Activity to process 1 t/h : 18 402.1 Ci (0.666 PBq)
- Speed of the conveyor : 1.42 m/min

Worst efficiency : 5.25%
Worst product throughput : 9.15 kg/h (0.007 PBq)
Best efficiency : 6.27%
Best product throughput : 10.92 kg/h (0.007 Pbq)

430 mm wide moving over a source line of about 760 mm active length. The belt speed could be adjusted to regulate the exposure time. The conveyor belt is located asymmetrically with respect to the source in order to provide uniform irradiation of the product.

The product from the upper belt is brought onto the lower belt within the irradiation chamber with specially designed ‘V’ shaped guides and ducts. The source target geometry was optimized to provide an efficiency of radiation utilization of about 13%.
8. RADIATION SOURCE

The radiation source consists of a single standard composite source unit (CSU), the design of which is shown in Fig. 4. The source unit could easily accommodate up to 1.48 PBq (40 600 Ci) of cobalt-60. The design of the irradiator envisages the use of the source over a half-life period of cobalt-60 unless otherwise warranted by exigencies. Loading and unloading of the source could be performed with the help of a shipping container that can be attached to the irradiator. Special tools have been designed to perform these operations with ease. Once the source is loaded the shipping container would be withdrawn after ensuring the gates of the source entry ports of the irradiator were closed and sealed.

9. DRIVE SYSTEM

The drive system for the conveyor is located external to the irradiator with appropriate controls to enable speed adjustment in the ratio of 1:10, for dose adjustments, necessary during cobalt-60 loading at the start and after decay with time since the initial loading.

10. OPERATION

The material to be irradiated is loaded from the top entry provided with a vibrator feeder. The product gently falls onto the conveyor belt through the
maze entry and is carried over the source in the forward direction. A 'V' shaped wiper guides the material through ducts to the lower conveyor moving in the opposite direction. After irradiation the material is brought out through the ducts and maze exit and collected in gunny bags or sacks. The flow path of the product is depicted as 1—8 in Fig.4. The speed of the conveyor is initially adjusted with dosimetric measurements to impart the desired dose to the product. The irradiator operation then consists of 'ON' and 'OFF' of the switches for the conveyor motor and routine adjustment of the belt speed. The general specifications of the irradiator are shown in Table I.
11. ECONOMICS

The analysis of economics [12] is based on the actual size of the demonstration plant fabricated to study the mechanical feasibility of the process. The analysis shown in Figs 5 and 6 indicates that with a capital investment of about Rs. 1.0 million the major share of which goes to the cost appreciating material (lead) the pay-back period could be two to five years when irradiation charges are considered at Rs. 100/t or Rs. 80/t (US $1 = Rs. 10.0).

ACKNOWLEDGEMENTS

Thanks are due to Shri T.S. Murthy, Head, Radiation Technology Division, and Dr. G.B. Nadkarni, Head, B & Ft Division, for their support and suggestions.

REFERENCES


THE MULTI-PURPOSE FOOD IRRADIATION PLANT IN THAILAND

C. BANDITSING, V. PRINKSULKA, S. PIADANG, M. SUTANTAWONG, K. NOOCHAPRAMOOL, Y. PRACHASITISAKDI
Biological Science Division,
Office of Atomic Energy for Peace,
Bangkok, Thailand

Abstract

THE MULTI-PURPOSE FOOD IRRADIATION PLANT IN THAILAND.

Because of the effect of the hot climate speeding the ripening of fruits and sprouting of vegetables, and because of spoilage microorganisms, pathogenic microorganisms, and insect infestation, agricultural product losses in Thailand are approximately 30%. To solve these problems, the Government of Thailand is strongly interested in setting up a multi-purpose agricultural pilot-plant demonstration facility for government-industry-consumer benefit in the domestic and export markets for agricultural products. The pilot plant will be operated by staff of the Office of Atomic Energy for Peace, an institution which has held responsibility for research and development work in food irradiation since 1963. Food irradiation services will be provided to the public for irradiation of four selected food items, first for 6200 operating hours. These are frozen shrimps, frozen chicken, onions, and potatoes for 10,000, 3000, 5000 and 5000 tonnes per year, respectively. The rest of the service will be given to other commodities. The revenue from the facilities will be approximately 38 million bahts. The fixed cost of this investment will be 81 million bahts and annual operating costs and expenses 25.94 million bahts. The cost estimates for land and development, building, shielding, and cold room, $^{60}$Co source transport and installation, source pass and related mechanisms, and design are 10, 15, 28, 27 and 1 million bahts, respectively. The internal rate of return is 34%. In addition, the cost-benefit ratio is 1.78 at an interest rate of 12% and 1.49 at an interest rate of 18%.

1. INTRODUCTION

Thailand is an agricultural state. Agricultural product losses in this tropical country resulting from the hot climate speeding ripening of fruits and sprouting of vegetables, spoilage microorganisms, pathogenic microorganisms, and insect infestation are approximately 30%.

Both onions and potatoes have a short shelf-life and so cannot be stored long enough for out-of-season domestic consumption. Thailand is faced with great problems of exporting fruits because of their short shelf-life and insect infestation. Both seafood and poultry play an important role in the economy of the nation.
To solve the above-mentioned problems, the Government of Thailand is strongly interested in setting up a multi-purpose agricultural pilot-plant demonstration facility for the benefit of industry and consumer in the domestic and export markets for Thai agricultural products. A primary function of this facility is to serve as a market development tool for improving the general economic growth of the country. Most of the economic growth will come through increased exports, either through the ability to export currently embargoed items or by extending the marketing life to open up currently marginal markets. The capacity of this facility shall be sufficient for a full-scale market impact on a regional basis for fresh produce, and on a large-test scale for export produce. Processing will cover conveyor adaptation for adjunct material handling facilities for diverse agricultural products. These will include known market items such as onions, potatoes and rice, and will explore new export markets for tropical fruits, flowers, fish, shrimp, chicken and other products.

The Office of Atomic Energy for Peace (OAEP) is the only institution in Thailand with responsibility for research and development of food irradiation for the purposes of extending shelf-life of food, insect disinfestation, radicidation, and sprout inhibition since 1963. Many publications have been produced and there is a pool of well-trained scientists available for work on the commercialization of food irradiation.

The multi-purpose agricultural pilot-plant demonstration facility in this project will be operated by the staff of OAEP. Food irradiation services will be provided to the public for irradiation of four selected food items, first for 6200 operating hours. These are frozen shrimps, frozen chickens, onions, and potatoes for 10 000, 3000, 5000 and 5000 t per year, respectively. The rest of the service will be given to other commodities. The revenue from the facilities will be approximately 38 million bahts compared with the fixed investment cost of 81 million bahts and annual operating costs and expenses of 25.94 million bahts. The cost estimates for land and development, building, shielding and cold room, $^{60}$Co source transport and installation, source pass and related mechanisms, and design are 10, 15, 28, 27 and 1 million bahts, respectively. Financial analysis on the above assumptions suggests that the project will be economically viable. It will also obtain an adequate return on the capital invested. The internal rate of return is 34%. In addition, the cost-benefit ratio is 1.78 at an interest rate of 12% and 1.49 at an interest rate of 18%.

Details of the multi-purpose food irradiation plant are as follows:

- Plant capacity: 500 kCi cobalt-60 multi-purpose irradiator.
  Throughput: 2.23 t/h at 3 kGy and 25% efficiency; 26.70 t/h at 0.1 kGy and 10% efficiency.

- Plant location: Bang Pli, Samutprakan.

The reasons for selecting Bang Pli, Samutprakan, as location for the projected food irradiation plant are the following:
Bang Pli is adjacent to the areas where shrimp, chicken and fish that would benefit from radiation treatment are produced.

Bang Pli is an industrialized area adjacent to Bangkok, the centre of a transport system for agricultural products which could efficiently service a food irradiation plant.

2. FOOD ITEMS OF POTENTIAL INTEREST FOR RADIATION PROCESSING

Surveys conducted in 1983 showed that shrimp, chicken, onions and potatoes are food items that have potential for either export or local consumption and would benefit from radiation treatment. Pre-feasibility studies for each of these food items show the following results.

2.1. Shrimp

The frozen shrimp industry of Thailand has grown in recent years and shrimp now represents an important export item. In 1982 Thailand exported 22,909 t of shrimp for 2,764 million bahts to Japan, the USA, and Hong Kong. So far, the market for frozen shrimp has expanded with increased production.

Rejection of exported frozen shrimp was due to bacterial contamination and the decomposition of the products. The operating cost per kg of frozen shrimp irradiated at 3 kGy for elimination of Salmonella and reduction of total bacterial count was calculated to be 1.88 bahts and the service fee will be charged at 2.50 bahts per kg. The addition of production cost of 2.50 bahts per kg or 2% commodity cost is still low and economically viable.

2.2. Chicken

The poultry industry plays an important role in the economy of the nation. It serves as a main source of protein and provides foreign exchange earnings. Poultry production is increasing every year. The value of exported frozen chicken increased from 1,187 million bahts in 1981 to 1,309 million bahts in 1982.

It must be emphasized that the quality of exported frozen chicken does not always meet the high bacteriological standards or specifications set up by most of the importing countries. This will lead to rejection and result in economic losses. To improve and maintain the quality of the product and to minimize losses due to spoilage, an efficient hygiene and quality control system is needed.

Irradiation of frozen and chilled chicken at 3 kGy would be sufficient to improve its public health quality and to extend its shelf-life. The service fee to be charged of 2 bahts per kg is still much less than the rejection value of 4 bahts per kg, thus making the irradiation process economically feasible.
### TABLE I. ONION PRICES IN DIFFERENT MARKETS IN 1982 AND 1983 (bahts/kg)

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>1983</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Onion price at farms</td>
<td>8.50</td>
<td>4.96</td>
<td>3.00</td>
<td>3.58</td>
<td>3.00</td>
<td>2.93</td>
<td>4.34</td>
<td>4.87</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>Bangkok market price</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Chiangmai onions</td>
<td>–</td>
<td>6.50</td>
<td>3.30</td>
<td>3.62</td>
<td>4.06</td>
<td>3.95</td>
<td>5.19</td>
<td>6.63</td>
<td>10.63</td>
<td>18.00</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>Kanchanaburi onions</td>
<td>18.13</td>
<td>13.17</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1982</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Average Chiangmai market price</td>
<td>–</td>
<td>–</td>
<td>5.50</td>
<td>3.26</td>
<td>5.00</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>Average onion price at farms in Sunpatong, Chiangmai</td>
<td>–</td>
<td>–</td>
<td>1.54</td>
<td>2.15</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
</tr>
</tbody>
</table>

*Note: Information obtained from the Office of Northern Agriculture, Chiangmai.*
2.3. Onions

Onions are one of the economically important vegetables of Thailand. The annual production and consumption are approximately 50 000 and 30 000 t, respectively. However, about 50% of the harvest was discarded during storage because of rotting and sprouting. Over-production during the season decreases the price to only 0.89 baht/kg (March 1980), in contrast to the high price of the remaining small amount of conventional cold stored short shelf-life onions out of season (September) and imported onions (October), i.e. 10 and 18 bahts/kg, respectively (see Table I). The retail price of this product in most of the markets in Bangkok was 45 bahts/kg in November 1983.

Although the annual onion production is higher than the consumption by 20 000 t, Thailand still imports onions for local consumption during the scarce season from September to November (see Table II) and in many years from July to December. The amount imported from July to December in 1981 was 4 710 046 kg at a cost of 55 918 741 bahts (see Table III). So far, conventional cold storage is able to extend the shelf-life of onions by only 2–3 months.

Research on shelf-life extension of onions by radiation was conducted in the USA, Canada, Japan, the USSR, India, Israel, Thailand, and many other countries. Sprout inhibition of onions by gamma irradiation conducted at the Office of Atomic Energy for Peace (OAEP) demonstrated that onions irradiated at 30–120 Gy showed a negligible percentage of sprouting after 6 months' storage at 12°C. In addition, no significant difference was found regarding weight losses between irradiated and non-irradiated onions under the same conditions. On the recommendation of OAEP, the Ministry of Public Health gave clearance to irradiated onions in 1973. By using a Gammabeam 650 irradiator, an onion radiation service was made available in 1974 on request for approximately 700 t. The service charge was 0.25 baht/kg (20 bahts = 1 US $). Since then, many undertakings have requested this service. This means that they can make profit on irradiated onions or, in other words, it is economically feasible. The costs or expenses and profit of 6 months' storage at 10°C of irradiated onions are shown in Table IV. The costs of irradiated onions, freshly harvested and cured onions from farms, transport, labour, packaging (wooden crate with a capacity of 30–40 kg), irradiation service, 10°C cool storage for six months, and interest, is 7228.44 bahts/t. After six months' storage, it is estimated that the income of selling the 60% irradiated onions remaining after rotting losses is 9000.00 bahts. Therefore the profit is 1771.56 bahts/t or 1.77 bahts/kg. If the price of onions from farms is 1 baht instead of 2 bahts/kg and the market price is 20 bahts instead of 15 bahts/kg the profit would be 7.77 bahts instead of 1.77 bahts/kg. Therefore, it can be concluded that onion irradiation is economically feasible. If a multi-purpose commercial food irradiation plant were set up in Thailand, it would certainly demonstrate government-industry-consumer benefits in bringing this technology into the domestic and export markets for Thai agricultural products.
**TABLE II. HARVESTING SEASON AND SELLING PERIOD OF ONIONS**

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Kanchanaburi</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sunpatong, Chiangmai</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fang, Chiangmai</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Imports</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*Note: ——— Harvesting season; ——— Selling period. Information obtained from the Office of Agricultural Economics.*
### TABLE III. QUANTITY AND VALUE OF ONION IMPORTS DURING 1979–1981

<table>
<thead>
<tr>
<th>Month</th>
<th>Year</th>
<th>1979</th>
<th>1980</th>
<th>1981</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Quantity</td>
<td>Value</td>
<td>Quantity</td>
</tr>
<tr>
<td>Jan.</td>
<td></td>
<td>125 000</td>
<td>809 000</td>
<td>316 209</td>
</tr>
<tr>
<td>Feb.</td>
<td></td>
<td>907</td>
<td>48 038</td>
<td>–</td>
</tr>
<tr>
<td>Mar.</td>
<td></td>
<td>3 000</td>
<td>341 964</td>
<td>–</td>
</tr>
<tr>
<td>Apr.</td>
<td></td>
<td>–</td>
<td>–</td>
<td>1 087</td>
</tr>
<tr>
<td>May</td>
<td></td>
<td>–</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>June</td>
<td></td>
<td>–</td>
<td>–</td>
<td>454</td>
</tr>
<tr>
<td>July</td>
<td></td>
<td>–</td>
<td>–</td>
<td>156 000</td>
</tr>
<tr>
<td>Aug.</td>
<td></td>
<td>298 414</td>
<td>352 080</td>
<td>791 859</td>
</tr>
<tr>
<td>Sep.</td>
<td></td>
<td>921 688</td>
<td>6 706 845</td>
<td>852 023</td>
</tr>
<tr>
<td>Oct.</td>
<td></td>
<td>957 516</td>
<td>7 161 499</td>
<td>1 054 824</td>
</tr>
<tr>
<td>Nov.</td>
<td></td>
<td>778 270</td>
<td>6 425 288</td>
<td>994 516</td>
</tr>
<tr>
<td>Dec.</td>
<td></td>
<td>321 529</td>
<td>2 504 504</td>
<td>320 622</td>
</tr>
<tr>
<td></td>
<td>Total</td>
<td>3 406 324</td>
<td>26 349 218</td>
<td>4 487 594</td>
</tr>
</tbody>
</table>

*Note: Data obtained from the Office of Agricultural Economics. Quantity: kg; value: bahts.*
TABLE IV. COST OR EXPENSE AND PROFIT OF IRRADIATED ONIONS AFTER SIX MONTHS' STORAGE

<table>
<thead>
<tr>
<th>Expense and income</th>
<th>Amount (bahts/t)</th>
<th>Total (bahts/t)</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>Freshly harvested onions from farm</td>
<td>2 000.00</td>
<td>2 000.00</td>
<td>Average price (commercial information) is 1 baht/kg</td>
</tr>
<tr>
<td>Transport</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>- Farm to Chiangmai</td>
<td>100.00</td>
<td>2 100.00</td>
<td></td>
</tr>
<tr>
<td>- Chiangmai to Bangkok</td>
<td>333.00</td>
<td>2 433.00</td>
<td></td>
</tr>
<tr>
<td>Labour</td>
<td>10.00</td>
<td>2 443.00</td>
<td></td>
</tr>
<tr>
<td>Packaging</td>
<td>500.00</td>
<td>2 943.00</td>
<td>Wooden crate with a capacity of 40 kg</td>
</tr>
<tr>
<td>Non-irradiated onion cost</td>
<td></td>
<td>2 943.00</td>
<td></td>
</tr>
<tr>
<td>Irradiation service charge</td>
<td>750.00</td>
<td>3 693.00</td>
<td>0.75 bahts/kg</td>
</tr>
<tr>
<td>10°C cool storage for 6 months</td>
<td>3 000.00</td>
<td>6 693.00</td>
<td>Approximately 0.50 bahts/kg per month</td>
</tr>
<tr>
<td>Interest for 6 months</td>
<td>535.44</td>
<td>7 228.44</td>
<td>Annual interest rate 16%</td>
</tr>
<tr>
<td>Cost of irradiated onions after 6 months' storage</td>
<td>7 053.00</td>
<td>7 228.44</td>
<td></td>
</tr>
<tr>
<td>Price of onions after 6 months' storage</td>
<td>15 000.00</td>
<td></td>
<td>Price of onions (commercial information) out of season is 20 bahts/kg</td>
</tr>
<tr>
<td>Income</td>
<td>9 000.00</td>
<td></td>
<td>Approximately 60% of irradiated onions are marketable</td>
</tr>
<tr>
<td>Profit</td>
<td>1 771.36</td>
<td></td>
<td>Approximately 1.77 bahts/kg</td>
</tr>
</tbody>
</table>

As far as onions are concerned, this country would cut imports by 56 million bahts per annum and increase exports by extending the market life to open up current marginal markets.

2.4. Potatoes

Potatoes are also considered one of the commercially important agricultural products in Thailand. The annual production from 1974 to 1982 was 7 000 to 14 000 t. Although there are two growing seasons a year, the problem of potato shelf-life extension for domestic out-of-season consumption still remains due to
TABLE V. GROWING SEASON OF POTATOES IN THE NORTH OF THAILAND

|-----|------|------|------|------|------|------|------|------|------|------|------|
| growing season | ------------------ | harvesting season | growing season
on the mountain | harvesting season

sprouting and rotting (see Table V). Cold storage at 10°C extends the market life by only 2–3 months.

The application of radiation to extend the shelf-life of potatoes and many other agricultural products led the Thai Government to consider a multi-purpose agricultural pilot-plant demonstration facility for government-industry-consumer benefit. Research on potato sprout inhibition by radiation at OAEP showed that irradiating potatoes at 120 Gy stored at 10°C extended their shelf-life by more than 6 months.

The cost or expense and benefit of irradiated potatoes is shown in Table VI. The expenses for 4 months' storage of irradiated potatoes, freshly harvested potatoes, transport, labour, packaging (wooden crate with a capacity of 30–40 kg), irradiation service, 10°C cold storage, and the interest for this investment is 5996.63 bahts/t. After 4 months' storage, approximately 70% of irradiated potatoes are marketable, bringing the income to 8400 bahts/t or 8.40 bahts/kg. The profit of irradiated potatoes after 4 months' storage at 10°C is 2403.37 bahts/t or 2.40 bahts/kg. Therefore commercialization of this agricultural product is feasible.

3. PRELIMINARY ECONOMIC FEASIBILITY STUDY OF A FOOD IRRADIATION PLANT

A preliminary economic feasibility analysis is based on the following factors:

(1) The plant will require a 500 kCi 60Co source.
(2) The plant will irradiate only frozen shrimps, frozen chickens, onions, and potatoes for 15 years with a utilization factor of 6200 h per year. Initial
TABLE VI. COST OR EXPENSE AND PROFIT OF IRRADIATED POTATOES

<table>
<thead>
<tr>
<th>Expense and income</th>
<th>Amount (bahts/t)</th>
<th>Total (bahts/t)</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>Freshly harvested potatoes from farm</td>
<td>2 000.00</td>
<td>2 000.00</td>
<td>Commercial information</td>
</tr>
<tr>
<td>Transport</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>- Farm to Chiangmai</td>
<td>100.00</td>
<td>2 100.00</td>
<td></td>
</tr>
<tr>
<td>- Chiangmai to Bangkok</td>
<td>333.00</td>
<td>2 433.00</td>
<td></td>
</tr>
<tr>
<td>Labour</td>
<td>10.00</td>
<td>2 443.00</td>
<td></td>
</tr>
<tr>
<td>Packaging</td>
<td>500.00</td>
<td>2 943.00</td>
<td>Wooden crate with a capacity of 35—40 kg</td>
</tr>
<tr>
<td>Non-irradiated potato cost</td>
<td></td>
<td>2 943.00</td>
<td></td>
</tr>
<tr>
<td>Irradiation service charge</td>
<td>750.00</td>
<td>3 693.00</td>
<td>0.75 baht/kg</td>
</tr>
<tr>
<td>$10^6$C cool storage</td>
<td>2 000.00</td>
<td>5 693.00</td>
<td>Approximately</td>
</tr>
<tr>
<td>for 4 months</td>
<td></td>
<td></td>
<td>0.50 baht/kg per month</td>
</tr>
<tr>
<td>Interest for 4 months</td>
<td>303.63</td>
<td>5 996.63</td>
<td>Annual interest rate 16%</td>
</tr>
<tr>
<td>Cost of irradiated potatoes after 4 months’ storage</td>
<td></td>
<td>5 996.63</td>
<td></td>
</tr>
<tr>
<td>Price of potatoes after 4 months’ storage</td>
<td>12 000.00</td>
<td></td>
<td>Commercial information</td>
</tr>
<tr>
<td>Income</td>
<td>8 400.00</td>
<td></td>
<td>70% of irradiated potatoes are marketable</td>
</tr>
<tr>
<td>Profit</td>
<td>2 403.37</td>
<td></td>
<td>Approximately</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>2.40 bahts/kg</td>
</tr>
</tbody>
</table>

volumes for frozen shrimps, frozen chickens, onions, and potatoes will be 10 000, 3000, 5000 and 5000 t, respectively, which is equivalent to 34, 5, 8 and 21% of the total production in 1987 (Table VII). The total production of each food item is projected to increase in the following years and the estimated total production is shown in Table VIII.

(3) The revenue to be derived from the operation of the project is in the form of service fees: 2.50 bahts/kg for frozen shrimps (2% of commodity cost); 2.00 bahts/kg for frozen chickens (4% of commodity cost); and 0.75 baht/kg for onions and potatoes, which is equivalent to 25% of the commodity cost at harvest.
<table>
<thead>
<tr>
<th>Product</th>
<th>Production (t)</th>
<th>Service (kGy)</th>
<th>Dose (kGy)</th>
<th>Throughput (t/h)</th>
<th>Fee (bahts/kg)</th>
<th>Utilization (h)</th>
<th>Revenue (million bahts)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Shrimp</td>
<td>29 359</td>
<td>10 000</td>
<td>3.0</td>
<td>2.23</td>
<td>2.50</td>
<td>4 484</td>
<td>25.00</td>
</tr>
<tr>
<td>Chicken</td>
<td>62 308</td>
<td>3 000</td>
<td>3.0</td>
<td>2.23</td>
<td>2.00</td>
<td>1 345</td>
<td>6.00</td>
</tr>
<tr>
<td>Onion</td>
<td>62 379</td>
<td>5 000</td>
<td>0.1</td>
<td>26.70</td>
<td>0.75</td>
<td>187</td>
<td>3.75</td>
</tr>
<tr>
<td>Potato</td>
<td>24 118</td>
<td>5 000</td>
<td>0.1</td>
<td>26.70</td>
<td>0.75</td>
<td>187</td>
<td>3.75</td>
</tr>
<tr>
<td>Total</td>
<td>23 000</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>6 203</td>
<td>38.50</td>
</tr>
</tbody>
</table>

* Per cent of total production: shrimp = 34, chicken = 5, onion = 8, potato = 21.
### TABLE VIII. ESTIMATED PRODUCTION PROJECTION OF AGRICULTURAL PRODUCTS

<table>
<thead>
<tr>
<th>Year</th>
<th>Frozen shrimp</th>
<th>Frozen chicken</th>
<th>Onion</th>
<th>Potato</th>
</tr>
</thead>
<tbody>
<tr>
<td>1978</td>
<td>15 378</td>
<td>9 286</td>
<td>40 432</td>
<td>4 071</td>
</tr>
<tr>
<td>1979</td>
<td>18 625</td>
<td>14 158</td>
<td>43 656</td>
<td>4 071</td>
</tr>
<tr>
<td>1980</td>
<td>17 935</td>
<td>18 503</td>
<td>46 880</td>
<td>6 300</td>
</tr>
<tr>
<td>1981</td>
<td>18 760</td>
<td>26 768</td>
<td>50 104</td>
<td>8 857</td>
</tr>
<tr>
<td>1982</td>
<td>22 909</td>
<td>32 962</td>
<td>48 910</td>
<td>13 630</td>
</tr>
<tr>
<td>1983</td>
<td>23 280</td>
<td>38 324</td>
<td>53 017</td>
<td>14 557</td>
</tr>
<tr>
<td>1984</td>
<td>24 800</td>
<td>44 320</td>
<td>55 358</td>
<td>16 947</td>
</tr>
<tr>
<td>1985</td>
<td>26 319</td>
<td>50 316</td>
<td>57 698</td>
<td>19 337</td>
</tr>
<tr>
<td>1986</td>
<td>27 839</td>
<td>56 312</td>
<td>60 038</td>
<td>21 728</td>
</tr>
<tr>
<td>1987</td>
<td>29 359</td>
<td>62 308</td>
<td>62 379</td>
<td>24 118</td>
</tr>
<tr>
<td>1988</td>
<td>30 879</td>
<td>68 305</td>
<td>64 720</td>
<td>26 509</td>
</tr>
<tr>
<td>1989</td>
<td>32 399</td>
<td>74 301</td>
<td>67 060</td>
<td>28 899</td>
</tr>
<tr>
<td>1990</td>
<td>33 919</td>
<td>80 297</td>
<td>69 400</td>
<td>31 289</td>
</tr>
<tr>
<td>1991</td>
<td>35 439</td>
<td>86 293</td>
<td>71 741</td>
<td>33 680</td>
</tr>
<tr>
<td>1992</td>
<td>36 957</td>
<td>92 289</td>
<td>74 081</td>
<td>36 070</td>
</tr>
<tr>
<td>1993</td>
<td>38 477</td>
<td>98 286</td>
<td>76 422</td>
<td>38 461</td>
</tr>
</tbody>
</table>

Frozen shrimp: \[ Y = 1519.70 x - 2990284.60, \] \( r = 0.8872 \)

Frozen chicken: \[ Y = 5996.20 x - 11852140.60, \] \( r = 0.9933 \)

Onion: \[ Y = 2340.40 x - 4587995.60, \] \( r = 0.9355 \)

Potato: \[ Y = 2390.40 x - 4725606.20, \] \( r = 0.9426 \)

(4) The project will cost 81 million bahts.

Capital cost (1 US $ = 23 bahts)

- Land and development: 10.00
- Building and shielding: 11.64
- \(^{60}\text{Co}\) source, transportation and installation: 28.00
- Source pass mechanism, hoist, conveyor system, control console, safety interlock system, survey meters, dosimetry, spare parts, electronics and others: 26.49
- Cold room and machine: 3.33
- Cars: 0.54
- Design: 1.00

Total: 81.00
(5) Annual operating costs and expenses amount to 25.94 million bahts.

<table>
<thead>
<tr>
<th>Annual operating costs and expenses</th>
<th>million bahts</th>
</tr>
</thead>
<tbody>
<tr>
<td>- Salaries of employees and administration</td>
<td>1.75</td>
</tr>
<tr>
<td>- Reloading of radioisotope (12.5% of price)</td>
<td>3.50</td>
</tr>
<tr>
<td>- Utilities</td>
<td>1.03</td>
</tr>
<tr>
<td>- Maintenance &amp; components</td>
<td>1.05</td>
</tr>
<tr>
<td>- Office expenses</td>
<td>0.75</td>
</tr>
<tr>
<td>- Insurance</td>
<td>0.70</td>
</tr>
<tr>
<td>- Research &amp; development</td>
<td>0.50</td>
</tr>
<tr>
<td>- Others</td>
<td>0.75</td>
</tr>
<tr>
<td>- Return on investment (18% IRR, 15 years)</td>
<td>15.91</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>25.94</strong></td>
</tr>
</tbody>
</table>

3.1. Financial analysis

Financial analysis showed that an irradiation project based on the above assumptions will be economically viable and will produce an adequate return from the capital invested. The internal rate of return is high (IRR = 34%). The cost-benefit ratio is 1.78 at an interest rate of 12% and 1.49 at an interest rate of 18%. The total capital is projected to be recovered in the 7th year.
EVALUACION ECONOMICA DEL PROCESO DE IRRADIACION PARA UNA PLANTA MULTIPROPOSITO

V.J. MARTIN, A. MONTALBAN, S. CURBELO
Centro de Investigaciones Nucleares,
Universidad de la República O. del Uruguay,
Montevideo, Uruguay

Abstract–Resumen

ECONOMIC EVALUATION OF THE IRRADIATION PROCESS FOR A MULTIPURPOSE PLANT.

On the basis of a technico-economic study of a multipurpose irradiation facility of 130 kCi of $^{60}$Co, it was calculated from fixed costs (US $312 050) and variable costs (US $266 950), these figures stemming from a total initial investment (US $1 476 570) for 20 000 t of product (potatoes and onions) and an irradiation capacity of 10 t/h, that the cost of production would be US $0.032/kg of processed product. The results are applied to an economic analysis of a private firm, with two options for commercial operation, by applying the breakeven point and the rate of recovery of the invested capital.

EVALUACION ECONOMICA DEL PROCESO DE IRRADIACION PARA UNA PLANTA MULTIPROPOSITO.

Basándose en estudios tecnológicos y económicos para una planta de irradiación multipropósito de 130 kCi de $^{60}$Co, se calcula un costo de dól. 0,032/kg de producto procesado a partir de los costos fijos (dól. 312 050) y los costos variables (dól. 266 950), los cuales se originan en la inversión total inicial (dól. 1 476 570) para 20 000 t de producto (papas y cebollas) y una capacidad de irradiación de 10 t/h. Los resultados son aplicados a la realización del análisis económico de una empresa privada con dos opciones comerciales de operación, mediante la aplicación del punto de equilibrio y de la velocidad de recuperación del capital invertido.

INTRODUCCION

En las condiciones de Uruguay, como en la mayoría de los países en vías de desarrollo, los programas de irradiación son factibles sólo si se piensa en una planta de irradiación multipropósito.

En 1970 comienzan a efectuarse estudios de factibilidad técnico-económicos con la finalidad de instalar en el país una planta de irradiación. Con la colaboración de la Comisión Nacional de Energía Atómica (CNEA) de Argentina, en el período 1972—1974 se realizan estudios tecnológicos. El 31/VII/1974 se autoriza la comercialización y consumo de papa irradiada con rayos gamma de $^{60}$Co y se investiga la aceptabilidad del tratamiento de radiopreservación por el público consumidor.
Las investigaciones en el área de irradiación se realizan en el Centro de Investigaciones Nucleares (CIN) de la Universidad de la República O. del Uruguay, y las mismas comprenden: papas, cebollas, ajos, citrus, productos del chacinado envasados al vacío, pescado, material médico descartable y turba como soporte en la producción de inoculantes para leguminosas, complementándose con estudios económicos para la operación de una planta de irradiación.

**PAPAS Y CEBOLLAS**

La papa es el principal cultivo hortícola con una superficie de 23 000 ha y una producción promedio anual de 120 000 t, mientras que la cebolla ocupa el quinto lugar en importancia, con una superficie cultivada de 2000 ha y una producción de 17 000 t.
Cada habitante consume por año 38,6 kg de papas y 6 kg de cebollas, con lo que el volumen anual consumido alcanza las cifras de 90 000 t de papas y 15 000 t de cebollas.

Para ambos productos, la variabilidad de rendimientos debida a la acción de factores climáticos, el costo y la inadecuada infraestructura existente de conservación son las causas de altos porcentajes de pérdidas y de las dificultades de abastecimiento a la población en el período de escasez, que en general se extiende de agosto a octubre. En la necesidad de cubrir el consumo interno en estos meses, en los últimos 14 años Uruguay ha tenido que realizar importaciones de papa por un valor de dól. 8 832 000 y de cebolla por dól. 2 408 000.

COMERCIALIZACION Y EVOLUCION ANUAL DEL PRECIO

El flujo de producto desde el agricultor hasta el consumidor final sigue diferentes canales de comercialización con la participación de uno o varios intermediarios.

Antes de su venta a intermediarios y envío a la zona de comercialización, los productos son clasificados por su tamaño y calidad. Las papas son envasadas en sacos de 50 kg y las cebollas en cajones de 30 kg, realizándose el transporte generalmente por camión (Figs. 1, 2).

El estudio de la evolución anual del precio permite distinguir que en los meses de enero a abril se registran los mayores ingresos del producto al mercado, lo cual coincide con un menor precio de venta, según se observa en los Cuadros I y II.

La relación de precios entre el período de escasez y los meses de mayor producción es de 1,99 para papas y de 2,75 para cebollas (Cuadros III y IV).
CUADRO I. PAPAS. VARIACIÓN ANUAL DE PRECIOS (en dól. por kg)

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Enero</td>
<td>0,080</td>
<td>0,148</td>
<td>0,236</td>
<td>0,162</td>
<td>0,100</td>
<td>0,180</td>
<td>0,140</td>
<td>0,116</td>
<td>0,231</td>
<td>0,206</td>
<td>0,184</td>
</tr>
<tr>
<td>Febrero</td>
<td>0,060</td>
<td>0,144</td>
<td>0,237</td>
<td>0,145</td>
<td>0,090</td>
<td>0,181</td>
<td>0,147</td>
<td>0,115</td>
<td>0,197</td>
<td>0,222</td>
<td>0,234</td>
</tr>
<tr>
<td>Marzo</td>
<td>0,070</td>
<td>0,140</td>
<td>0,237</td>
<td>0,158</td>
<td>0,083</td>
<td>0,158</td>
<td>0,161</td>
<td>0,110</td>
<td>0,171</td>
<td>0,220</td>
<td>0,279</td>
</tr>
<tr>
<td>Abril</td>
<td>0,090</td>
<td>0,134</td>
<td>0,200</td>
<td>0,155</td>
<td>0,085</td>
<td>0,168</td>
<td>0,178</td>
<td>0,134</td>
<td>0,157</td>
<td>0,228</td>
<td>0,321</td>
</tr>
<tr>
<td>Mayo</td>
<td>0,106</td>
<td>0,149</td>
<td>0,193</td>
<td>0,129</td>
<td>0,089</td>
<td>0,178</td>
<td>0,189</td>
<td>0,131</td>
<td>0,192</td>
<td>0,257</td>
<td>0,278</td>
</tr>
<tr>
<td>Junio</td>
<td>0,140</td>
<td>0,153</td>
<td>0,185</td>
<td>0,102</td>
<td>0,089</td>
<td>0,192</td>
<td>0,172</td>
<td>0,296</td>
<td>0,208</td>
<td>0,244</td>
<td>0,301</td>
</tr>
<tr>
<td>Julio</td>
<td>0,138</td>
<td>0,192</td>
<td>0,193</td>
<td>0,110</td>
<td>0,117</td>
<td>0,206</td>
<td>0,196</td>
<td>0,349</td>
<td>0,225</td>
<td>0,301</td>
<td>0,347</td>
</tr>
<tr>
<td>Agosto</td>
<td>0,173</td>
<td>0,235</td>
<td>0,206</td>
<td>0,106</td>
<td>0,150</td>
<td>0,187</td>
<td>0,210</td>
<td>0,344</td>
<td>0,282</td>
<td>0,328</td>
<td>0,433</td>
</tr>
<tr>
<td>Septiembre</td>
<td>0,159</td>
<td>0,223</td>
<td>0,202</td>
<td>0,105</td>
<td>0,146</td>
<td>0,175</td>
<td>0,235</td>
<td>0,343</td>
<td>0,339</td>
<td>0,296</td>
<td>0,434</td>
</tr>
<tr>
<td>Octubre</td>
<td>0,154</td>
<td>0,335</td>
<td>0,215</td>
<td>0,134</td>
<td>0,153</td>
<td>0,170</td>
<td>0,382</td>
<td>0,368</td>
<td>0,399</td>
<td>0,315</td>
<td>0,641</td>
</tr>
<tr>
<td>Noviembre</td>
<td>0,161</td>
<td>0,346</td>
<td>0,216</td>
<td>0,142</td>
<td>0,177</td>
<td>0,166</td>
<td>0,242</td>
<td>0,418</td>
<td>0,570</td>
<td>0,321</td>
<td>0,477</td>
</tr>
<tr>
<td>Diciembre</td>
<td>0,149</td>
<td>0,287</td>
<td>0,207</td>
<td>0,100</td>
<td>0,165</td>
<td>0,153</td>
<td>0,145</td>
<td>0,299</td>
<td>0,382</td>
<td>0,299</td>
<td>0,325</td>
</tr>
<tr>
<td><strong>Promedio anual</strong></td>
<td>0,123</td>
<td>0,207</td>
<td>0,211</td>
<td>0,129</td>
<td>0,120</td>
<td>0,196</td>
<td>0,200</td>
<td>0,252</td>
<td>0,279</td>
<td>0,270</td>
<td>0,355</td>
</tr>
<tr>
<td>----------</td>
<td>-------</td>
<td>-------</td>
<td>-------</td>
<td>-------</td>
<td>-------</td>
<td>-------</td>
<td>-------</td>
<td>-------</td>
<td>-------</td>
<td>-------</td>
<td>-------</td>
</tr>
<tr>
<td>Enero</td>
<td>0.068</td>
<td>0.270</td>
<td>0.061</td>
<td>0.139</td>
<td>0.134</td>
<td>0.126</td>
<td>0.263</td>
<td>0.284</td>
<td>0.100</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Febrero</td>
<td>0.109</td>
<td>0.234</td>
<td>0.066</td>
<td>0.16</td>
<td>0.119</td>
<td>0.124</td>
<td>0.312</td>
<td>0.254</td>
<td>0.134</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Marzo</td>
<td>0.107</td>
<td>0.203</td>
<td>0.062</td>
<td>0.146</td>
<td>0.104</td>
<td>0.121</td>
<td>0.344</td>
<td>0.309</td>
<td>0.145</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Abril</td>
<td>0.168</td>
<td>0.222</td>
<td>0.056</td>
<td>0.141</td>
<td>0.124</td>
<td>0.354</td>
<td>0.235</td>
<td>0.277</td>
<td>0.174</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mayo</td>
<td>0.188</td>
<td>0.233</td>
<td>0.063</td>
<td>0.137</td>
<td>0.121</td>
<td>0.351</td>
<td>0.324</td>
<td>0.231</td>
<td>0.180</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Junio</td>
<td>0.146</td>
<td>0.350</td>
<td>0.065</td>
<td>0.118</td>
<td>0.183</td>
<td>0.124</td>
<td>0.343</td>
<td>0.211</td>
<td>0.314</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Julio</td>
<td>0.364</td>
<td>0.313</td>
<td>0.070</td>
<td>0.143</td>
<td>0.244</td>
<td>0.381</td>
<td>0.324</td>
<td>0.290</td>
<td>0.292</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Agosto</td>
<td>0.545</td>
<td>0.199</td>
<td>0.115</td>
<td>0.577</td>
<td>0.246</td>
<td>0.386</td>
<td>0.412</td>
<td>0.343</td>
<td>0.486</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Septiembre</td>
<td>0.592</td>
<td>0.186</td>
<td>0.108</td>
<td>0.724</td>
<td>0.258</td>
<td>0.435</td>
<td>0.326</td>
<td>0.309</td>
<td>0.326</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Octubre</td>
<td>0.714</td>
<td>0.188</td>
<td>0.194</td>
<td>0.554</td>
<td>0.411</td>
<td>0.628</td>
<td>0.574</td>
<td>0.419</td>
<td>0.479</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Noviembre</td>
<td>0.303</td>
<td>0.209</td>
<td>0.230</td>
<td>0.544</td>
<td>0.372</td>
<td>0.482</td>
<td>0.414</td>
<td>0.479</td>
<td>0.479</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Diciembre</td>
<td>0.314</td>
<td>0.074</td>
<td>0.090</td>
<td>0.168</td>
<td>0.225</td>
<td>0.207</td>
<td>0.294</td>
<td>0.392</td>
<td>0.309</td>
<td>0.304</td>
<td>0.376</td>
</tr>
</tbody>
</table>

CUÁDRIL II. CEBOLLAS. VARIACIÓN ANUAL DE PRECIOS (en dól. por kg)
CUADRO III. PAPAS. RELACION DE PRECIOS ENTRE MESES DE VENTA (B) Y MESES DE COSECHA (A)
((A) y (B) expresados en nuevos pesos uruguayos (N$))

<table>
<thead>
<tr>
<th>Año</th>
<th>Meses de cosecha (A)</th>
<th>Meses de venta (B)</th>
<th>Relación B/A</th>
<th>Importaciones (toneladas)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1970</td>
<td>0,020</td>
<td>0,030</td>
<td>1,5</td>
<td>13,359</td>
</tr>
<tr>
<td>1971</td>
<td>0,010</td>
<td>0,030</td>
<td>3,0</td>
<td>5,269</td>
</tr>
<tr>
<td>1972</td>
<td>0,040</td>
<td>0,070</td>
<td>1,8</td>
<td>3,127</td>
</tr>
<tr>
<td>1973</td>
<td>0,055</td>
<td>0,143</td>
<td>2,6</td>
<td>25,000</td>
</tr>
<tr>
<td>1974</td>
<td>0,145</td>
<td>0,347</td>
<td>2,4</td>
<td>13,900</td>
</tr>
<tr>
<td>1975</td>
<td>0,425</td>
<td>0,490</td>
<td>1,2</td>
<td>1,200</td>
</tr>
<tr>
<td>1976</td>
<td>0,435</td>
<td>0,417</td>
<td>1,0</td>
<td></td>
</tr>
<tr>
<td>1977</td>
<td>0,385</td>
<td>0,743</td>
<td>1,9</td>
<td>1,975</td>
</tr>
<tr>
<td>1978</td>
<td>0,980</td>
<td>1,150</td>
<td>1,2</td>
<td></td>
</tr>
<tr>
<td>1979</td>
<td>1,180</td>
<td>2,247</td>
<td>1,9</td>
<td>8,080</td>
</tr>
<tr>
<td>1980</td>
<td>0,980</td>
<td>3,287</td>
<td>3,4</td>
<td>3,151</td>
</tr>
<tr>
<td>1981</td>
<td>2,195</td>
<td>3,813</td>
<td>1,7</td>
<td></td>
</tr>
<tr>
<td>1982</td>
<td>2,525</td>
<td>4,150</td>
<td>1,6</td>
<td></td>
</tr>
<tr>
<td>1983</td>
<td>7,185</td>
<td>18,627</td>
<td>2,6</td>
<td>1,200</td>
</tr>
</tbody>
</table>

Promedio 1,99

En 1976 se obtuvo la mayor producción de papas con 166 000 t, lo cual coincide con la menor relación de precios (1, 0) entre los meses de escasez y los de cosecha; en 1980 se obtiene la mayor producción de cebollas con 27 000 t, y la relación de precios de 3,57 indica que ésta es independiente del volumen producido, debido a la imposibilidad de conservar el producto después del mes de julio.

Las cebollas conservadas en frigorífico no presentan problemas hasta octubre, en tanto que las que conserva el productor o acopiador en galpones pierden todo su valor comercial hacia fines de julio, cuando el producto llega al precio promedio anual.

Teniendo en cuenta que el país posee la capacidad para aumentar la producción, puede considerarse que la importación es debida a la falta de un método eficiente de conservación.
CUADRO IV. CEBOLLAS. RELACIÓN DE PRECIOS ENTRE LOS MESES DE VENTA (B) Y MESES DE COSECHA (A)
((A) y (B) expresados en nuevos pesos uruguayos (N$))

<table>
<thead>
<tr>
<th>Año</th>
<th>Meses de cosecha (A)</th>
<th>Meses de venta (B)</th>
<th>Relación B/A</th>
<th>Importaciones (toneladas)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1970</td>
<td>0,04</td>
<td>0,10</td>
<td>2,71</td>
<td>-</td>
</tr>
<tr>
<td>1971</td>
<td>0,01</td>
<td>0,02</td>
<td>2,00</td>
<td>-</td>
</tr>
<tr>
<td>1972</td>
<td>0,12</td>
<td>0,26</td>
<td>2,17</td>
<td>-</td>
</tr>
<tr>
<td>1973</td>
<td>0,12</td>
<td>0,51</td>
<td>4,21</td>
<td>-</td>
</tr>
<tr>
<td>1974</td>
<td>0,26</td>
<td>0,40</td>
<td>1,55</td>
<td>-</td>
</tr>
<tr>
<td>1975</td>
<td>0,15</td>
<td>0,31</td>
<td>2,10</td>
<td>-</td>
</tr>
<tr>
<td>1976</td>
<td>0,53</td>
<td>2,50</td>
<td>4,76</td>
<td>481,3</td>
</tr>
<tr>
<td>1977</td>
<td>0,50</td>
<td>1,24</td>
<td>2,48</td>
<td>159,7</td>
</tr>
<tr>
<td>1978</td>
<td>2,46</td>
<td>4,96</td>
<td>2,02</td>
<td>3 549,0</td>
</tr>
<tr>
<td>1979</td>
<td>2,32</td>
<td>2,79</td>
<td>1,20</td>
<td>2 211,0</td>
</tr>
<tr>
<td>1980</td>
<td>1,19</td>
<td>4,23</td>
<td>3,57</td>
<td>1 270,0</td>
</tr>
<tr>
<td>1981</td>
<td>2,45</td>
<td>4,53</td>
<td>1,85</td>
<td>3 702,0</td>
</tr>
<tr>
<td>1982</td>
<td>2,73</td>
<td>4,34</td>
<td>1,59</td>
<td>4 820,0</td>
</tr>
<tr>
<td>1983</td>
<td>5,63</td>
<td>35,15</td>
<td>6,35</td>
<td>37,0</td>
</tr>
</tbody>
</table>

Promedio 2,75

PERDIDAS DE PESO

De acuerdo con los estudios tecnológicos realizados en Uruguay y con la fluctuación anual del precio que determina los períodos de irradiación y comercialización (Figs. 3, 4), consideramos las pérdidas totales durante el almacenaje en un 20% para las papas (Fig.5) y un 30% para las cebollas (Cuadro V).

ESTUDIOS DE INVERSION Y COSTOS DE IRRADIACION

La capacidad de la planta de irradiación es determinada por la producción total y la dosis requerida. En nuestro caso se fijó la producción en 14 000 t de papas y 6000 t de cebollas y la dosis de irradiación en 80 Gy.

Para la irradiación de 20 000 t de producto, con una capacidad de irradiación de 10 t/h, la inversión total de capital viene dada por la suma de los importes correspondientes a la unidad de irradiación de 130 kCi de capacidad inicial, a los locales de prealmacenamiento y almacenamiento y a miscelánea (Cuadro VI).

Los costos específicos del proceso por kg de producto (Cuadro VII) son calculados a partir de los costos fijos y los costos variables, según la inversión total realizada y los volúmenes de papas y cebollas a ser procesados. Se determina que, para 20 000 toneladas de producto, el costo de irradiación por kg es de dól. 0,032.

EVALUACIONES ECONOMICAS Y BENEFICIO DE UNA PLANTA DE IRRADIACION DE ALIMENTOS

Para que una planta de irradiación opere con éxito como empresa privada, los beneficios no pueden estar solamente basados en un aumento de la calidad del producto y en una disminución de las pérdidas post-cosecha. El beneficio económico de la empresa, que justifique la gran inversión inicial, es la llave para el desarrollo comercial del proceso.
CUADRO V. CEBOLLAS. PESO REMANENTE EXPRESADO COMO PROCENTAJE DEL PESO INICIAL

<table>
<thead>
<tr>
<th>DIA</th>
<th>0 Gy</th>
<th>H.M.</th>
<th>50 Gy</th>
<th>100 Gy</th>
<th>150 Gy</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>100,0</td>
<td>100,0</td>
<td>100,0</td>
<td>100,0</td>
<td>100,0</td>
</tr>
<tr>
<td>30</td>
<td>99,1</td>
<td>98,4</td>
<td>99,1</td>
<td>98,6</td>
<td>89,0</td>
</tr>
<tr>
<td>60</td>
<td>88,7</td>
<td>97,9</td>
<td>98,7</td>
<td>88,4</td>
<td>83,9</td>
</tr>
<tr>
<td>90</td>
<td>98,3</td>
<td>97,3</td>
<td>93,2</td>
<td>83,0</td>
<td>78,6</td>
</tr>
<tr>
<td>120</td>
<td>56,9</td>
<td>91,2</td>
<td>82,3</td>
<td>72,3</td>
<td>58,3</td>
</tr>
<tr>
<td>125</td>
<td>32,0</td>
<td>85,6</td>
<td>71,8</td>
<td>71,4</td>
<td>58,0</td>
</tr>
<tr>
<td>130</td>
<td>13,5</td>
<td>85,1</td>
<td>66,3</td>
<td>66,7</td>
<td>52,8</td>
</tr>
<tr>
<td>145</td>
<td>–</td>
<td>84,2</td>
<td>60,8</td>
<td>66,0</td>
<td>52,2</td>
</tr>
<tr>
<td>160</td>
<td>–</td>
<td>70,6</td>
<td>55,5</td>
<td>61,3</td>
<td>47,5</td>
</tr>
<tr>
<td>175</td>
<td>–</td>
<td>61,2</td>
<td>45,6</td>
<td>61,1</td>
<td>42,5</td>
</tr>
</tbody>
</table>

Nota: Las pérdidas totales incluyen las fisiológicas y por putrefacción.

La decisión de invertir de un empresario se basará en evaluaciones económicas que incluyan, entre otras, el punto de equilibrio entre los costos totales (CT) y los ingresos totales (IT) o en la velocidad de retorno del capital invertido (VRC).

PUNTO DE EQUILIBRIO (PE)

El costo total anual es expresado por la ecuación:

\[ CT = CVT + CFT \]

donde:
- CT son los costos totales;
- CVT son los costos variables/kg por kg procesados;
- CFT son los costos fijos totales.

La ecuación del ingreso total (IT) para el volumen de producto procesado es:

\[ IT = \text{precio/kg por kg procesados} \]

El punto de equilibrio (Fig.6) está dado por la igualdad de las dos ecuaciones:

\[ CT = IT \]
CUADRO VI. ESTIMACION DE INVERSION DE CAPITAL

<table>
<thead>
<tr>
<th>Irradiación y pre-almacenamiento</th>
<th>Dóls.</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Equipos (irradiador)</td>
<td>147 600</td>
</tr>
<tr>
<td>2. Costos de instalación</td>
<td>18 000</td>
</tr>
<tr>
<td>3. Fuente de cobalto (130 000 Ci)</td>
<td>66 300</td>
</tr>
<tr>
<td>4. Gastos de transporte para la fuente</td>
<td>13 000</td>
</tr>
<tr>
<td>5. Recinto (hormigón a dóls. 175/m³)</td>
<td>72 000</td>
</tr>
<tr>
<td>6. Laboratorio, oficina, servicios (400 m² a dóls. 250/m²)</td>
<td>120 000</td>
</tr>
<tr>
<td>7. Area de descarga, corredores y pre-almacenamiento (2700 m² a dóls. 46/m²)</td>
<td>124 200</td>
</tr>
<tr>
<td><strong>Subtotal</strong></td>
<td>561 100</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Almacenamiento</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>8. Galpones de almacenamiento (8200 m² a dóls. 46/m²)</td>
<td>377 200</td>
</tr>
<tr>
<td>9. Cajones jaula (1,2 X 0,8 X 1,0 m)</td>
<td>400 000</td>
</tr>
<tr>
<td><strong>Subtotal</strong></td>
<td>777 200</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Miscelánea</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>10. Carretillas elevadoras (2)</td>
<td>30 000</td>
</tr>
<tr>
<td>11. Carros hidráulicos (3)</td>
<td>1 200</td>
</tr>
<tr>
<td>12. Cintas transportadoras para selección (3)</td>
<td>8 800</td>
</tr>
<tr>
<td>13. Balanza</td>
<td>2 000</td>
</tr>
<tr>
<td>14. Equipo de laboratorio y oficina</td>
<td>3 000</td>
</tr>
<tr>
<td>15. Terreno</td>
<td>25 000</td>
</tr>
<tr>
<td>16. Proyecto y dirección de obras civiles</td>
<td>15 000</td>
</tr>
<tr>
<td>17. Imprevistos (calculado como el 10% sobre todos los rubros, excepto 7., 8. y 9.)</td>
<td>53 270</td>
</tr>
<tr>
<td><strong>Subtotal</strong></td>
<td>138 270</td>
</tr>
</tbody>
</table>
CUADRO VI (cont.)

<table>
<thead>
<tr>
<th></th>
<th>Totales</th>
<th>Dóls.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Irradiación y pre-almacenamiento</td>
<td></td>
<td>561 100</td>
</tr>
<tr>
<td>Almacenamiento</td>
<td></td>
<td>777 200</td>
</tr>
<tr>
<td>Miscelánea</td>
<td></td>
<td>138 270</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td></td>
<td><strong>dóls. 1 476 570</strong></td>
</tr>
</tbody>
</table>

a Calculado para la irradiación de 20 000 t. de producto (papas y cebollas). Capacidad de irradiación: 10 t/h.

VELOCIDAD DE RETORNO DEL CAPITAL (VRC)

La velocidad de retorno del capital invertido es definida como el tiempo necesario para recuperar la inversión inicial (II) a partir del beneficio obtenido.

\[
VRC = \frac{\text{II}}{\frac{\text{B/kP}}{\text{VAP}}}
\]

donde:
- VRC es la velocidad de retorno del capital
- II es la inversión inicial
- B/kP es el beneficio por kg procesado
- VAP es el volumen anual procesado

OPCIONES ECONOMICAS DE UNA EMPRESA PRIVADA

Una planta de irradiación de alimentos que opere como empresa privada tiene tres opciones comerciales:

A) Compra de papas y cebollas en los meses de cosecha, tratamiento de irradiación, almacenamiento y venta del producto en los meses de escasez.
B) Venta del servicio de irradiación.
C) Combinación de las dos opciones anteriores.
CUADRO VII. SELECCION, IRRADIACION, ALMACENAMIENTO Y SELECCION FINAL

<table>
<thead>
<tr>
<th>Costos fijos</th>
<th>Dóls.</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Amortización del capital</strong></td>
<td></td>
</tr>
<tr>
<td>A) Equipos (calculado sobre 10 años, rubros 1., 2., 3. y 4.)</td>
<td>24,490</td>
</tr>
<tr>
<td>B) Edificios (calculado sobre 20 años, rubros 5., 6. y 7.)</td>
<td>15,810</td>
</tr>
<tr>
<td>C) Miscelánea (calculado sobre 10 años, rubros 10. a 18.)</td>
<td>13,830</td>
</tr>
<tr>
<td>D) Galpones de almacenamiento (calculado sobre 10 años)</td>
<td>37,720</td>
</tr>
<tr>
<td>E) Cajones jaula (calculado sobre 20 años)</td>
<td>40,000</td>
</tr>
<tr>
<td><strong>Intereses (12% sobre todos los rubros)</strong></td>
<td>177,200</td>
</tr>
<tr>
<td><strong>Impuestos y seguros</strong></td>
<td>3,000</td>
</tr>
<tr>
<td><strong>Subtotal costos fijos</strong></td>
<td>312,050</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Costos variables</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Reemplazo de cobalto (12% de la carga inicial)</td>
<td>7,950</td>
</tr>
<tr>
<td>Mano de obra</td>
<td>190,000</td>
</tr>
<tr>
<td>Combustible y mantenimiento de carretillas elevadoras</td>
<td>50,000</td>
</tr>
<tr>
<td>Luz, agua, teléfono</td>
<td>5,000</td>
</tr>
<tr>
<td>Materiales diversos</td>
<td>2,000</td>
</tr>
<tr>
<td>Mantenimiento de la planta y galpones</td>
<td>10,000</td>
</tr>
<tr>
<td>Materiales de laboratorio y dosimetría</td>
<td>2,000</td>
</tr>
<tr>
<td><strong>Subtotal costos variables</strong></td>
<td>266,950</td>
</tr>
<tr>
<td><strong>Subtotal costos</strong></td>
<td>579,000</td>
</tr>
<tr>
<td><strong>Imprevistos (10% sobre subtotal costos)</strong></td>
<td>57,900</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>Dóls. 636,900</td>
</tr>
</tbody>
</table>

Nota: Para 20 000 toneladas de producto, el costo es de dóls. 0,032/kg.

EVALUACION DE LAS OPCIONES ECONOMICAS

En nuestro caso analizamos las opciones A) y B) mediante la aplicación del punto de equilibrio y la velocidad de retorno del capital invertido, para un volumen de 20 000 toneladas de producto procesado.
FIG. 6. Evaluación económica – Punto de equilibrio.
CUADRO VIII. EVALUACION ECONOMICA DE UNA PLANTA DE IRRADIACION OPERANDO COMO EMPRESA PRIVADA (OPCION A))

<table>
<thead>
<tr>
<th></th>
<th>Papas</th>
<th>Cebollas</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Compra de producto (t)</td>
<td>14 000</td>
<td>6 000</td>
<td>20 000</td>
</tr>
<tr>
<td>2. Compra (dóls./t)</td>
<td>162</td>
<td>198</td>
<td></td>
</tr>
<tr>
<td>3. Total de compra (dóls.)</td>
<td>2 268 000</td>
<td>1 188 000</td>
<td>3 456 000</td>
</tr>
<tr>
<td>4. Costos variables (dóls.)</td>
<td></td>
<td></td>
<td>266 950</td>
</tr>
<tr>
<td>5. Costos fijos (dóls.)</td>
<td></td>
<td></td>
<td>312 050</td>
</tr>
<tr>
<td>6. Costo total (3. + 4. + 5.) (dóls.)</td>
<td></td>
<td></td>
<td>4 035 000</td>
</tr>
<tr>
<td>7. Pérdidas totales (%)</td>
<td>20</td>
<td>30</td>
<td></td>
</tr>
<tr>
<td>8. Venta (t)</td>
<td>11 200</td>
<td>4 200</td>
<td>15 400</td>
</tr>
<tr>
<td>9. Venta (dóls./t)</td>
<td>260</td>
<td>1 923 600</td>
<td></td>
</tr>
<tr>
<td>10. Ingreso total (dóls.)</td>
<td>2 912 000</td>
<td>1 923 600</td>
<td>4 835 600</td>
</tr>
<tr>
<td>11. Beneficio (10.—6.) (dóls.)</td>
<td></td>
<td></td>
<td>800 600</td>
</tr>
</tbody>
</table>

OPCION A) COMPRA Y VENTA DEL PRODUCTO

El precio de compra de las 14 000 toneladas de papas y 6000 t de cebollas fue establecido como el promedio de los meses de cosecha para el período 1973—1983, en tanto que el precio de venta corresponde al promedio de los meses de comercialización para el mismo período (Cuadros I y II).

A dóls. 162/t de papa y dóls. 198/t de cebolla, la inversión total asciende a la suma de dóls. 4 035 000 (Cuadro VIII y Fig.6, opción A)).

Los ingresos totales calculados para la venta de 11 200 t de papas a dóls. 260/t y 4200 t de cebollas a dóls. 458/t, son de dóls. 4 835 600. Por lo tanto, el beneficio obtenido en esta opción es de dóls. 800 600 y se alcanza el punto de equilibrio al procesar 5609 t de producto (Fig.6, opción A)).

En este caso, el beneficio por tonelada de producto procesado es de dóls. 40,03; fijando un volumen anual de 20 000 toneladas y una inversión inicial de dóls. 1 476 570, la velocidad de recuperación del capital es de 1,84 años.
CUADRO IX. COMPARACION DE LAS OPCIONES ECONOMICAS ESTUDIADAS

<table>
<thead>
<tr>
<th>Opciones</th>
<th>Inversión total (dóls.)</th>
<th>Volumen anual procesado (t)</th>
<th>Costo total (dóls.)</th>
<th>Ingreso total (dóls.)</th>
<th>Beneficio (dóls.)</th>
<th>Punto de equilibrio (t)</th>
<th>Velocidad de retorno del capital (años)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Opción A</td>
<td>1 476 570</td>
<td>20 000</td>
<td>4 035 000</td>
<td>4 835 600</td>
<td>800 600</td>
<td>5 609</td>
<td>1,84</td>
</tr>
<tr>
<td>Opción B</td>
<td>1 476 570</td>
<td>20 000</td>
<td>636 900</td>
<td>1 800 000</td>
<td>1 163 100</td>
<td>4 071</td>
<td>1,27</td>
</tr>
</tbody>
</table>
OPCION B) VENTA DEL SERVICIO DE IRRADIACION

Considerando que el proceso de conservación por irradiación debe ser competitivo con el de conservación por frío y que el costo de este último, desde la cosecha hasta el período de comercialización, es de dólares 0,11/kg, se fija el precio de venta del servicio de irradiación en dólares 0,09/kg.

En la Fig. 6, opción B), se observa que los beneficios obtenidos al procesar 20 000 toneladas son de dólares 1 163 100 y se alcanza el punto de equilibrio en 4071 toneladas.

El beneficio por toneladas de producto procesado es de dólares 58,155; fijando un volumen anual de 20 000 toneladas y una inversión inicial de dólares 1 476 570, la velocidad de recuperación del capital será de 1,27 años.

La realización de estas evaluaciones económicas muestra que, para una empresa privada, la opción B) presenta características más atractivas que la Opción A) (Cuadro IX).

BIBLIOGRAFIA


ELECTRONS VERSUS GAMMA RAYS – ALTERNATIVE SOURCES FOR IRRADIATION PROCESSES

M.R. CLELAND, G.M. PAGEAU
Iotech, Inc.,
Englewood, Colorado,
United States of America

Abstract

ELECTRONS VERSUS GAMMA RAYS – ALTERNATIVE SOURCES FOR IRRADIATION PROCESSES.

Energetic electrons and gamma rays are used for a variety of commercial irradiation processes such as the modification of polymeric materials, the sterilization of medical devices, the preservation of foods and the treatment of municipal and industrial wastes. The chemical and biological effects of these radiations are similar, but the differences in their physical characteristics and economics may favour one over the other for a particular application. Electron accelerators with energies under 5 MeV producing intense, high-power beams are mainly used for curing coatings and thin plastic and rubber products, while gamm-ray sources emitting diffuse radiation with substantially greater penetration are used predominantly for medical products and some agricultural commodities. The increasing demand for large gamm-ray sources and the currently limited supplies are now stimulating the development of electron accelerators of 5 to 15 MeV with more penetration that can provide an alternative to gamma sources for the treatment of packages and bulk materials. High-power bremsstrahlung (X-ray) generators can also be considered for applications requiring still greater penetration. Where either electrons or photons can provide satisfactory dose distributions within the products, the productivity of accelerators and gamma sources can be compared on the basis of available power and utilization efficiency. For example, a 10 MeV, 20 kW machine would be equivalent to 2 MCi of $^{60}$Co, assuming 50% and 35% power utilization, respectively. The price of such an accelerator might be comparable to that of a $^{60}$Co source, while at twice this power level, the accelerator would be substantially less expensive than $^{60}$Co. Operating and maintenance costs for a 40 kW machine would also be less than the cost of gamma source replenishment in a 4 MCi facility. High-power accelerators are also justifiable for smaller facilities since their higher capital cost can be compensated for by a reduction in operating cost due to a shorter work schedule.

1. INTRODUCTION

Radiation processing with energetic electrons or photons can produce beneficial effects in many materials and commercial products. On the molecular level similar results can be obtained with either type of radiation since photons transfer their energies to secondary electrons within the absorbing materials.

Both forms of energy can be obtained from electrical equipment, which can be designed to produce either external
electron beams or bremsstrahlung (X-rays), as well as from radioactive substances, which emit both beta and gamma rays.

Practical and economic considerations have favored the use of low-energy electron accelerators for applications requiring intense radiation with limited range, for example, the modification of plastic and elastomeric materials, whereas gamma-ray sources have been preferred for the sterilization of medical devices and for food preservation, where diffuse, penetrating radiation is needed.

The complementary nature of these technologies is destined to become more competitive in the future as more powerful high-energy machines are developed in response to increasing demand for the treatment of packaged and bulk materials [1,2]. The information in this paper may be useful in determining which modality, electrons or gammas, will be more appropriate for a particular application.

2. POWER REQUIREMENTS

Commercial treatment processes need a substantial power output from the radiation source to provide the energy absorbed by the irradiated materials as well as that which is lost to the surroundings. The power requirement increases with the dose and the mass throughput rate according to the following formula:

\[ P = \frac{(D/f)(M/T)}{3600} \]

where \( P \) is the emitted power in kilowatts, \( D \) is the absorbed dose in kilogram, \( M \) is the mass of the treated material in kilograms, \( T \) is the exposure time in hours and \( f \) is the power utilization factor. This formula follows directly from the definition of the dose unit, i.e., one kGy equals one kW·s/kg or 1/3600 kW·h/kg.

For example, consider a typical gamma-ray facility sterilizing disposable medical devices in shipping cartons. The dose is assumed to be 25 kGy, the annual throughput rate one million cubic feet (28 300 cubic meters) with an average specific gravity of 0.2. With a continuous operation (6000 h/a) the mass throughput rate would be 707 kg/h. The power utilization factor would be between 0.25 and 0.35, depending on the configuration of the source and product conveyor. Therefore:

\[ P = \frac{(25/0.35)(707/3600)} \]

\[ P = 14 \text{ kW (minimum)} \]
Since the emission rate of Co-60 capsules is about 14 kW per MCi, this result is consistent with the common rule that a million cubic feet per year requires a megacurie of cobalt.

High-energy electron beams can be utilized somewhat more efficiently than isotropically emitted gamma rays and a power utilization factor of 0.50 is a conservative estimate for this application [3]. Therefore, the equivalent electron beam power requirement would be about:

\[ P = 14 \left( \frac{0.35}{0.50} \right) \]

\[ P = 10 \text{ kW} \]

A Co-60 loading of 2 MCi is not uncommon today and some facilities already have 4 MCi. In order to be competitive, electron accelerators need corresponding productivities, i.e., from 20 to 40 kW of electron beam power, with sufficient energy to penetrate packaged products, a not unreasonable expectation.

3. ENERGY REQUIREMENTS

One of the attractive characteristics of gamma radiation is its penetration in dense materials. The dose distribution in homogeneous absorbers tends to diminish exponentially with increasing depth. In water or moist foods the dose is reduced to 50% of the surface value at a depth of about 9 cm [4].

Unit density objects of twice this thickness can be treated from opposite sides with good dose uniformity. For example, with 18 cm, the front, middle and back doses from the first exposure would be 100, 50 and 25% respectively. The sum of the doses after the second exposure would be 125, 100 and 125% as shown in Fig. 1, so that the maximum/minimum dose ratio would be 1.25. With 36 cm the max/ min dose ratio would increase to about 2.1.

The depth dose distribution from electron irradiation is substantially different, the dose tending to increase in the middle of the treated object and to diminish steeply toward the back side. With 10 MeV electrons in water, the maximum dose would be 135% of the front surface dose at a depth of about 2.5 cm. The dose would fall to 50% of the surface dose at about 4.2 cm and would be down to 10% at 4.9 cm, the maximum range of the electrons [5,6].

Two-sided treatment can be used to double the allowable thickness to about 8.5 cm of unit density material at 10 MeV. The dose distribution would then be 100% at both sides and also
in the center but with two maxima of 135% located 2.5 cm from either side as shown in Fig. 2. The max/min dose ratio would be 1.35, slightly higher than with gamma rays.

In the energy range from 5 to 15 MeV, the energy requirement for two-sided irradiation is proportional to the product thickness and can be estimated with the following formula:

$$E = 1.2 \, tp$$

where $E$ is the electron energy in MeV, $t$ is the thickness in centimeters and $p$ is the product density in grams/cubic centimeter. The coefficient 1.2 has been deduced from
single-sided data [7]. The maximum thicknesses would be about 4.5 cm at 5 MeV, 8.5 cm at 10 MeV and 13 cm at 15 MeV, substantially less than the gamma-ray capability.

With low-density materials such as packages of medical devices, the allowable thickness is inversely proportional to the density, i.e. using 10 MeV electrons, the actual package thickness could be over 40 cm at a density of 0.2 g/cm³ and over 80 cm at a density of 0.1 g/cm³.

Higher electron energies can readily be produced with microwave linear accelerators but may not be acceptable because of the induction of radioactive isotopes in the treated materials. In order to avoid this risk, the FAO/IAEA/WHO joint expert committee on the wholesomeness of irradiated food has recommended that electron energies should not exceed 10 MeV for food treatment processes [8]. However, even at 15 MeV the level of induced radioactivity in meat is only about 0.01 % of the natural background activity [9]. Electron energies above 10 MeV are still acceptable for other applications.

Bremsstrahlung (X-rays) generated by intercepting the electron beam with a dense metallic target can be used to irradiate objects that are too thick for electron treatment. The FAO/IAEA/WHO committee has recommended a 5 MeV limit for this procedure because energetic photons are more likely to induce radioactivity than electrons [8].

At this energy level, a broad bremsstrahlung spectrum has nearly the same penetrating quality as the gamma-rays from Co-60 and photon power outputs equivalent to 4 MCi of Co-60 are technically feasible, but the cost of utilizing this technique full time would be greater due to its high power requirement [10]. Nevertheless, the use of X-rays as an adjunct to electrons in a dual-purpose facility is an attractive concept [11,12].

4. COST ANALYSES

The capital cost of a gamma source increases linearly with its power output whereas the cost of an electron accelerator is determined primarily by its energy level and only secondarily by its power rating. These differences favor gamma sources for small facilities requiring less than 1 MCi of Co-60 but make accelerators attractive for treatment plants needing higher throughput capacities.

The operating schedule of a gamma facility is also different from that of an accelerator plant because the gamma
TABLE I

COMPARATIVE COST ANALYSES - STERILIZATION OF MEDICAL DEVICES
Thruput capacity - 1 million cubic feet per year

<table>
<thead>
<tr>
<th>CAPITAL COSTS ($)</th>
<th>COBALT-60</th>
<th>40 kW LINAC</th>
</tr>
</thead>
<tbody>
<tr>
<td>Facility (Table IV)</td>
<td>3 000 000</td>
<td>2 500 000</td>
</tr>
<tr>
<td>Radiation Source</td>
<td>1 000 000</td>
<td>2 500 000</td>
</tr>
<tr>
<td>Total Investment</td>
<td>4 000 000</td>
<td>5 000 000</td>
</tr>
<tr>
<td>OPERATING COSTS ($)</td>
<td>COBALT-60</td>
<td>40 kW LINAC</td>
</tr>
<tr>
<td>Debt Service</td>
<td>580 000</td>
<td>720 000</td>
</tr>
<tr>
<td>Overheads</td>
<td>200 000</td>
<td>200 000</td>
</tr>
<tr>
<td>Operating Time (h)</td>
<td>(8 000)</td>
<td>(2 000)</td>
</tr>
<tr>
<td>Source Maintenance</td>
<td>150 000</td>
<td>80 000</td>
</tr>
<tr>
<td>Labor (2 for 4 shifts)</td>
<td>200 000</td>
<td>(4 for 1 shift) 100 000</td>
</tr>
<tr>
<td>Total Annual Costs</td>
<td>1 130 000</td>
<td>1 100 000</td>
</tr>
<tr>
<td>Cost per cubic foot</td>
<td>$1.13</td>
<td>$1.10</td>
</tr>
</tbody>
</table>

TABLE II

COMPARATIVE COST ANALYSES - STERILIZATION OF MEDICAL DEVICES
Thruput capacity - 2 million cubic feet per year

<table>
<thead>
<tr>
<th>CAPITAL COSTS ($)</th>
<th>COBALT-60</th>
<th>40 kW LINAC</th>
</tr>
</thead>
<tbody>
<tr>
<td>Facility (Table IV)</td>
<td>3 000 000</td>
<td>2 500 000</td>
</tr>
<tr>
<td>Radiation Source</td>
<td>2 000 000</td>
<td>2 500 000</td>
</tr>
<tr>
<td>Total Investment</td>
<td>5 000 000</td>
<td>5 000 000</td>
</tr>
<tr>
<td>OPERATING COSTS ($)</td>
<td>COBALT-60</td>
<td>40 kW LINAC</td>
</tr>
<tr>
<td>Debt Service</td>
<td>720 000</td>
<td>720 000</td>
</tr>
<tr>
<td>Overheads</td>
<td>200 000</td>
<td>200 000</td>
</tr>
<tr>
<td>Operating Time (h)</td>
<td>(8 000)</td>
<td>(4 000)</td>
</tr>
<tr>
<td>Source Maintenance</td>
<td>270 000</td>
<td>160 000</td>
</tr>
<tr>
<td>Labor (3 for 4 shifts)</td>
<td>300 000</td>
<td>(4 for 2 shifts) 200 000</td>
</tr>
<tr>
<td>Total Annual Costs</td>
<td>1 490 000</td>
<td>1 280 000</td>
</tr>
<tr>
<td>Cost per cubic foot</td>
<td>$0.75</td>
<td>$0.64</td>
</tr>
</tbody>
</table>
TABLE III
COMPARATIVE COST ANALYSES - STERILIZATION OF MEDICAL DEVICES
Thrput capacity - 4 million cubic feet per year

<table>
<thead>
<tr>
<th>CAPITAL COSTS ($)</th>
<th>COBALT-60</th>
<th>40 kW LINAC</th>
</tr>
</thead>
<tbody>
<tr>
<td>Facility (Table IV)</td>
<td>3 000 000</td>
<td>2 500 000</td>
</tr>
<tr>
<td>Radiation Source</td>
<td>4 000 000</td>
<td>2 500 000</td>
</tr>
<tr>
<td>Total Investment</td>
<td>7 000 000</td>
<td>5 000 000</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>OPERATING COSTS ($)</th>
<th>COBALT-60</th>
<th>40 kW LINAC</th>
</tr>
</thead>
<tbody>
<tr>
<td>Debt Service</td>
<td>1 010 000</td>
<td>720 000</td>
</tr>
<tr>
<td>Overheads</td>
<td>200 000</td>
<td>200 000</td>
</tr>
<tr>
<td>Operating Time (h)</td>
<td>(8 000)</td>
<td>(8 000)</td>
</tr>
<tr>
<td>Source Maintenance</td>
<td>520 000</td>
<td>320 000</td>
</tr>
<tr>
<td>Labor (4 for 4 shifts)</td>
<td>400 000 (4 for 4 shifts)</td>
<td>400 000</td>
</tr>
<tr>
<td>Total Annual Costs</td>
<td>2 130 000</td>
<td>1 640 000</td>
</tr>
</tbody>
</table>

Cost per cubic foot $0.53 $0.41

Source is always on while the machine is running only when needed for production. Consequently, the labor cost in a gamma facility is higher because of the necessity of operating around the clock at all times to avoid wasting the radiant energy.

Capital and operating cost estimates are listed in Tables I, II and III for a large gamma sterilization facility running continuously at three capacity levels requiring 1, 2 and 4 MCi of Co-60, respectively. Comparative cost estimates are also given for a 40 kW, 10 MeV accelerator plant producing the same annual throughputs, but operating at its maximum capacity for 2000, 4000 and 8000 hours per year, respectively. Breakdowns of the facility cost estimates are given in Table IV.

The assumed product throughput capacities are consistent with the estimates given above in Section 2, i.e. an annual throughput of 1 million cubic feet of 0.2 density products at a dose of 25 kGy requiring 1 MCi of Co-60 applied continuously for 8000 hours or 40 kW of electron beam power for 2000 hours.

Some other assumptions are that the cost of the Co-60 is $1.00/Ci delivered to the site while the inclusive cost of the linac is $2 500 000. The capital investments for both the
facility and the radiation sources are amortized over 15 years at 12% interest.

The source replenishment rate is 12.3% per year plus $25,000 for transportation and loading, while the operating cost of the linac is $15/hour for electricity (200 kW @ $0.075/kW·h) plus $25/hour for replacement of parts and maintenance.

Overheads include taxes, insurance, facility maintenance, utilities, administrative and management costs. Labor costs assume 4 employees per fully-loaded work shift accounting for 2000 hours of operation at an annual cost of $100,000 per shift, including fringe benefits and lost time.

The bottom lines in Tables I, II and III show that the annual operating cost of an accelerator plant would be comparable to that of a gamma facility at the 1 MCi level and would become progressively less expensive as the throughput capacity increases.

In Table I, the lower capital cost of the gamma facility is balanced by its higher operating costs, notably the source replenishment and the labor. In Table II, the capital costs are the same but the source replenishment and labor costs for the gamma facility are still higher than for the accelerator.

In Table III, the cost of the Co-60 source is substantially higher than the accelerator and the source replenishment is still higher than the electricity and maintenance for the accelerator, although the labor costs in the two cases are the same.
The economy of scale is evident since the cost per cubic foot of product decreases as the throughput capacity increases with either type of radiation source.

5. CONCLUSION

The sterilization of medical devices has been used here as a basis of comparing electron and gamma-ray capabilities because it is an established industrial process with well-defined parameters. However, these considerations of power, energy and cost can also be applied to other radiation applications including food preservation.

The power ratings of the largest existing gamma-ray facilities are relatively modest and can readily be matched and surpassed by modern accelerator techniques. The energy limits imposed to avoid the induction of radioactivity provide adequate penetration for low-density products like medical supplies and thinner objects like packaged foods.

Gamma-ray sources will continue to be attractive for small facilities and for the treatment of bulky objects such as pork and beef carcasses or large boxes of fruits and vegetables where their superior penetration is required.

The use of high-energy accelerators wherever they are effective may alleviate the increasing demand for the limited supplies of gamma-ray sources, thereby assuring their availability for more essential applications.

REFERENCES

ECONOMIES OF SCALE IN SINGLE-PURPOSE FOOD IRRADIATORS

R.M. MORRISON
Economic Research Service,
United States Department of Agriculture,
Washington, D.C.,
United States of America

Abstract

ECONOMIES OF SCALE IN SINGLE-PURPOSE FOOD IRRADIATORS.

The paper presents estimates of the investment requirements and economies of scale for five cobalt-60 irradiators, each treating a different food product. Irradiation costs were estimated for treating papayas, strawberries, pork carcasses, young chicken, and fish fillets in four facilities of different sizes. The costs presented are based on a specific set of assumptions and input prices. All five facilities exhibit declining unit costs over the 6 million to 500 million pounds per year throughput range analysed. These economies of scale are very pronounced at smaller sizes, which means that individual agricultural firms with small volumes will not be able to achieve the lower unit costs possible with high throughputs. However, scale economies for the foods examined in this analysis become less important at annual volumes greater than 50 or 100 million pounds. The most important sources of production economies are labour, buildings and shielding, and machinery. Total average unit costs decline between 45 and 80% over the size ranges analysed for the five irradiators.

Introduction

Food irradiation technology is capital intensive. Building a commercial scale irradiator requires a large investment in special shielded structures, conveyor machinery, and source material. Analysts have asserted that because of this high investment, large quantities of food must be treated to achieve reasonable average unit costs [1].

An examination of plant economies of scale can be used to evaluate this assertion. The term economies of scale refers to the relationship between total average costs per unit of output (unit costs) and the size of the plant. Economies of scale exist if unit costs fall as size increases. If economies of scale exist, large irradiators would be able to treat foods at a lower unit cost than smaller ones. Operators of small irradiators would be at a distinct cost disadvantage if the scale economies are substantial. This would discourage an industry
of small volume, widely-scattered agricultural firms from using the technology.

A question of interest to potential users of irradiation technology, then, is how important is the size of an irradiator and its corresponding throughput to the average cost of the treatment. Can only the very largest irradiators realize reasonable unit costs? Are their costs substantially lower than those of smaller plants? A related question is how severe are the cost penalties for running an irradiator at less than capacity.

This paper presents results of research conducted by the U.S. Department of Agriculture's Economic Research Service on economies of scale in irradiators treating a single food for a specific purpose. The purpose of this research was to identify the key cost components in building and operating a commercial size cobalt-60 irradiator and to illustrate how unit costs vary with size of operation and capacity utilization.

Five foods—papayas, pork, fish, strawberries and chicken—were analyzed. The selected radiation dose levels were below the 1 000 krad (10 kGy) level incorporated in the Codex Alimentarius Commission's proposed international standard for irradiated foods [2]. Irradiators treating papayas, fish, and strawberries were assumed to be free standing facilities. Pork and chicken irradiators were assumed to be physically integrated into existing slaughtering plants. Costs were estimated for four irradiator sizes for each of the five foods. The resulting analytical scenarios demonstrate how the radiation dose, the amount of product throughput, and seasonal versus year round operation affect unit costs.

Applications and Throughputs

Costs were calculated for the following applications1/ and corresponding doses:

- Disinfesting Hawaiian papayas to satisfy quarantine requirements for shipment to the continental United States (26 krads or 0.26 kGy).
- Inactivating Trichinella spiralis, the parasite responsible for the disease trichinosis, in pork (30 krads or 0.3 kGy).

1/ Selection of these applications was based on a review of the scientific literature. Applications were also chosen to illustrate radiation's diverse uses on a variety of foods.
Extending the shelf-life of fish fillets by several days, thereby expanding the geographic market for fresh fish (175 krads or 1.75 kGy).

Decreasing storage decay of strawberries and extending shelf-life by several days (200 krads or 2 kGy).

Reducing the numbers of common food poisoning microorganisms, such as Salmonella and Campylobacter, in fresh young chicken (250 krads or 2.5 kGy).

Throughput capacities were based on actual production conditions in appropriate geographic locations in the United States, such as a major fishing port of the California region with the greatest concentration of strawberry production. These maximum throughputs were then successively halved to approximate annual volumes of existing agricultural plants. Table 1 lists the plant sizes analyzed for each commodity. Yearly throughputs for the pork and chicken irradiators reflect processing capacities of large and medium sized U.S. slaughtering plants.

The processing schedules used in this analysis were designed to cause minimal disruption of existing processing and marketing schedules. Although each model irradiator was operated 24 hours a day, fish fillets, papayas, young chicken and pork were irradiated five days per week rather than a possible seven days to coincide with the shipping and processing schedules currently used in those industries. For the integrated chicken and pork irradiators, the shorter irradiation week means that no additional cold storage capacity is required to hold carcasses for weekend irradiation. An integrated arrangement also allows certain personnel already employed by the slaughtering plant to handle some of the duties associated with the irradiator. Strawberries were irradiated seven days per week, but only four months of the year. Treatment of seasonal agricultural products is more likely to follow this schedule.

Methodology and Major Assumptions

Irradiator design and operation are very specific to the particular commodity, its reaction and tolerance to radiation, national occupational safety requirements, and many other variables. However, development of cost relationships by plant size requires specific assumptions about input prices and operating procedures to provide the standardization needed to make interplant cost comparisons. Capital and operating costs were estimated for the model irradiators based on information
Table 1. Summary of Investment and Annual Costs for Selected Cobalt-60 Irradiators a/

<table>
<thead>
<tr>
<th>Commodity and Annual Throughput in Millions of Pounds</th>
<th>Initial Investment b/</th>
<th>Annualized Fixed Costs c/</th>
<th>Annual Variable Costs d/</th>
<th>Annual Total Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$1000000</td>
<td>$1000</td>
<td>$1000</td>
<td>$1000</td>
</tr>
<tr>
<td><strong>Fish Fillets e/</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>1.0</td>
<td>309</td>
<td>203</td>
<td>512</td>
</tr>
<tr>
<td>12</td>
<td>1.1</td>
<td>336</td>
<td>208</td>
<td>544</td>
</tr>
<tr>
<td>24</td>
<td>1.4</td>
<td>401</td>
<td>224</td>
<td>625</td>
</tr>
<tr>
<td>48</td>
<td>1.9</td>
<td>515</td>
<td>248</td>
<td>763</td>
</tr>
<tr>
<td><strong>Papayas e/</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>12</td>
<td>1.0</td>
<td>301</td>
<td>204</td>
<td>505</td>
</tr>
<tr>
<td>24</td>
<td>1.2</td>
<td>329</td>
<td>216</td>
<td>545</td>
</tr>
<tr>
<td>48</td>
<td>1.5</td>
<td>389</td>
<td>302</td>
<td>691</td>
</tr>
<tr>
<td>96</td>
<td>2.4</td>
<td>547</td>
<td>428</td>
<td>975</td>
</tr>
<tr>
<td><strong>Strawberries e/</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>25</td>
<td>2.0</td>
<td>514</td>
<td>162</td>
<td>676</td>
</tr>
<tr>
<td>50</td>
<td>3.4</td>
<td>835</td>
<td>222</td>
<td>1057</td>
</tr>
<tr>
<td>100</td>
<td>5.7</td>
<td>1388</td>
<td>296</td>
<td>1684</td>
</tr>
<tr>
<td>200</td>
<td>10.4</td>
<td>2518</td>
<td>489</td>
<td>3007</td>
</tr>
<tr>
<td><strong>Young Chicken f/</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>52</td>
<td>2.0</td>
<td>510</td>
<td>305</td>
<td>815</td>
</tr>
<tr>
<td>104</td>
<td>3.3</td>
<td>847</td>
<td>421</td>
<td>1268</td>
</tr>
<tr>
<td>208</td>
<td>6.0</td>
<td>1527</td>
<td>601</td>
<td>2128</td>
</tr>
<tr>
<td>416</td>
<td>11.2</td>
<td>2839</td>
<td>1006</td>
<td>3845</td>
</tr>
<tr>
<td><strong>Pork f/</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>66.5</td>
<td>.9</td>
<td>237</td>
<td>197</td>
<td>434</td>
</tr>
<tr>
<td>133</td>
<td>1.1</td>
<td>290</td>
<td>207</td>
<td>497</td>
</tr>
<tr>
<td>266</td>
<td>1.6</td>
<td>398</td>
<td>285</td>
<td>683</td>
</tr>
<tr>
<td>532</td>
<td>2.5</td>
<td>619</td>
<td>328</td>
<td>947</td>
</tr>
</tbody>
</table>

a/ Costs in this table are expressed in U.S. dollars and based on a specific set of assumptions and input prices listed in Appendix A.
b/ Investment items include: cobalt-60, biological shielding and other building space, irradiator machinery and auxiliary systems, product handling equipment, refrigerated warehouse space, design and engineering, land, and working capital.
c/ Includes the annualized costs for investment items and annual costs for cobalt-60 replenishment, fixed maintenance, insurance and taxes, and salaried personnel.
d/ Includes wages of shift supervisors/plant operators and product handlers, supplies, utilities, and variable maintenance.
e/ Free standing facility; see text for dose level. The strawberry irradiators operate 7 days a week for 4 months per year, instead of 5 days year round as do the other irradiators (see footnote b of table 3).
f/ Integrated facility; see text for dose level. Split pork carcasses are assumed to move through the irradiator suspended from a monorail track. Therefore, machinery and product handling costs are different than for the other foods.
from builders and operators of commercial irradiation facilities. Reliance on their judgement and experiences was essential because of the lack of single purpose food irradiators from which to collect empirical data. The costs presented here are meant to provide the reader with an idea of the magnitude of irradiation treatment costs and how these generalized costs might vary with plant size.

The major assumptions underlying the estimated unit costs are identified below.

1) Irradiators do not operate continuously. Downtime must be allowed for maintenance and source loading. In this analysis, irradiators were assumed to be processing food products for 21 hours of a 24-hour processing day.

2) Net utilization efficiency of the cobalt-60 was assumed to be 25 percent for all irradiators. Net utilization efficiency is the percent of emitted energy absorbed in the product. It is one of the parameters determining how much cobalt-60 is needed. Under actual conditions, this efficiency depends on the design of the irradiator which must consider the product's density and dose uniformity needs.

3) Several major cost components—biological shielding, irradiator machinery, and labor and machinery for product handling—were estimated at common throughput levels across commodities (see Appendix A). These general costs were assigned to irradiators of similar size. Land requirements were assumed to be three acres for all sizes of free standing irradiators. Costs for cobalt-60 loadings and refrigerated storage are estimated for each throughput.

4) For ease of computation, yearly replenishment of the decayed portion of cobalt-60 is assumed and treated as a yearly expense. Operators of irradiators with small loadings are more likely to purchase enough cobalt-60 to allow several years of maximum operation rather than incur the high transportation charges of annual replenishment. Therefore, costs may be slightly overstated for small papaya and fish irradiators.

5) Palletized boxes of product were assumed to be restacked in an arrangement compatible with the irradiator design. Because of relatively high labor costs in the United States, depalletizing and repalletizing machines that reduce human labor were used for the three largest size irradiators (see Appendix C). Product handling is an important cost component in radiation processing. The combination of machine and laborers affects both the fixed capital costs and variable labor costs. The appropriate combination depends on the relative efficiencies
and costs of these two substitutes. The combination chosen for each of the five irradiators results in minimum handling costs at capacity levels.

In addition to labor rates, land and construction costs vary regionally within the United States and around the world. If the relative prices of production inputs differ dramatically from those used here, an irradiator operator is likely to select a different combination of inputs to achieve least cost output. This would affect the scale economies. The wage rates and values selected for the production inputs are presented in Appendix A.

The costs of building and operating an irradiator are divided into fixed and variable costs. Together they constitute the total cost of operation for a given level of output. Fixed costs remain unchanged as output is altered. For example, once the biological shielding and machinery are built to accommodate a particular level of throughput, the cost of using these inputs will not change if output is reduced. In contrast, the cost of inputs such as utilities and hourly labor do vary with the use of the irradiator and the corresponding output. Table 2 shows the division between fixed and variable costs for irradiating Hawaiian papayas. Hourly labor, supplies, utilities, and maintenance that depends on how much the facility is used are considered variable cost items.

Fixed and variable costs were expressed on an annual basis so that total costs could be divided by annual output to derive unit costs. Recurring expenses like utilities, salaries, and cobalt-60 replenishment were already expressed on a yearly basis. A capital recovery factor was used to estimate the levelized annual cost of the biological shielding, buildings, machinery, and the initial cobalt-60. This factor computes the amount needed to recover the original investment (purchase price), plus the opportunity cost of the money spent to buy the asset, over its useful life. The formula is defined in Appendix A. Crucial variables in the capital recovery formula are the interest rate, or opportunity cost of money, and the assumed useful life of the asset. In this analysis, the interest rate used was 11.75 percent, the prime rate in the United States in December 1984. The useful lives for the capital assets were assumed to be 25 years for buildings and biological shielding, 10 years for machinery, and 15 years for the initial cobalt-60 loading. The annual fixed and variable costs for each size irradiator at 100 percent capacity are listed in Table 1.

Resulting Economies of Scale

Economies of scale are reflected in the shape of a plant's long-run average cost curve. The steeper the curve, the greater
the economies of scale. The long-run cost curve shows the minimum average cost of producing each output level when all inputs are variable and a firm is free to choose any plant size. One method that economists use to approximate the long-run cost curve is to examine a series of short-run cost curves for individual plant sizes and select minimum unit costs for each output level.

Short-run cost curves for each size irradiator were estimated by computing costs at 25, 50, 75, and 100 percent of capacity. Capacity is defined as the maximum throughput level for which the plant was designed. Variable costs were estimated for each level of capacity utilization. Fixed costs are independent of what portion of capacity is used and remain constant as throughput drops.

Table 3 lists irradiation treatment costs per pound based on the specific set of assumptions and input prices used in this analysis. Costs are for irradiators operated at design capacity. Unit costs for the applications and volumes analyzed range from 8.5 to 0.2 cents per pound. All five irradiators exhibit economies of scale, as demonstrated by their decreasing unit costs as size is doubled. This means that, considering only the treatment cost, larger irradiators would be able to treat products at a lower unit cost than small irradiators. However, in all cases the scale economies become less pronounced as size increases. Potential scale economies become less important at annual volumes greater than 50 or 100 million pounds. For example, the unit costs for the two largest strawberry irradiators operating at full capacity differed by only 0.2 cents per pound.

Economies of scale result from production inputs expanding less than proportionally with volume. To determine the source of the economies, one examines how the major components change with size. Cobalt-60, building and shielding, machinery, and labor accounted for 80 to 85 percent of unit costs in these scenarios. For a cobalt-60 irradiator, the most important sources of production economies are labor, buildings and shielding, and machinery.

Certain employees—plant manager, quality control person, maintenance and clerical personnel, and shift supervisors—are needed regardless of the volume moving through the irradiator. Spreading their salaries over larger outputs, lowers average fixed labor costs. When salaried employees are a major cost item, such as in the fish irradiators which span a smaller size range, large economies occur. Buildings, shielding, and machinery costs are likely to follow the general construction relationship where productive capacity increases faster than
Table 2. Capital Investment and Fixed and Variable Costs for Four Sizes of Papaya Irradiators a/

<table>
<thead>
<tr>
<th>INVESTMENT ITEMS</th>
<th>U.S. dollars</th>
</tr>
</thead>
<tbody>
<tr>
<td>Initial loading</td>
<td></td>
</tr>
<tr>
<td>curies</td>
<td>23700</td>
</tr>
<tr>
<td>delivery &amp; rigging</td>
<td>6000</td>
</tr>
<tr>
<td>total (rounded)</td>
<td>30000</td>
</tr>
<tr>
<td>Biological shielding</td>
<td>285000</td>
</tr>
<tr>
<td>Irradiator machinery</td>
<td>230000</td>
</tr>
<tr>
<td>Auxillary systems</td>
<td>20000</td>
</tr>
<tr>
<td>Control room and dosimetry lab</td>
<td>17000</td>
</tr>
<tr>
<td>Fork lifts, palletizers</td>
<td>30000</td>
</tr>
<tr>
<td>Refrigerated warehouse</td>
<td>70000</td>
</tr>
<tr>
<td>Additional rooms</td>
<td>59000</td>
</tr>
<tr>
<td>Design and engineering</td>
<td>74000</td>
</tr>
<tr>
<td>Land</td>
<td>120000</td>
</tr>
<tr>
<td>Working capital</td>
<td>82000</td>
</tr>
<tr>
<td>Total Initial Investment</td>
<td>1017000</td>
</tr>
<tr>
<td>Source</td>
<td>U.S. dollars</td>
</tr>
<tr>
<td>--------------------------------------</td>
<td>--------------</td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td>Initial loading</td>
<td>4346</td>
</tr>
<tr>
<td>Replenishment</td>
<td>9000</td>
</tr>
<tr>
<td>Building and shielding</td>
<td>63273</td>
</tr>
<tr>
<td>Machinery</td>
<td>49050</td>
</tr>
<tr>
<td>Land</td>
<td>14100</td>
</tr>
<tr>
<td>Working capital</td>
<td>9635</td>
</tr>
<tr>
<td>Fixed maintenance</td>
<td>4000</td>
</tr>
<tr>
<td>Insurance and taxes</td>
<td>19000</td>
</tr>
<tr>
<td>Salaried employees</td>
<td>129000</td>
</tr>
<tr>
<td><strong>TOTAL (rounded)</strong></td>
<td>301000</td>
</tr>
<tr>
<td><strong>VARIABLE COSTS</strong></td>
<td></td>
</tr>
<tr>
<td>Labor</td>
<td></td>
</tr>
<tr>
<td>Shift supervisors/ plant operators</td>
<td></td>
</tr>
<tr>
<td>Product</td>
<td></td>
</tr>
<tr>
<td>Handlers b/</td>
<td></td>
</tr>
<tr>
<td>(3.3)</td>
<td>64000</td>
</tr>
<tr>
<td>(3.4)</td>
<td>66000</td>
</tr>
<tr>
<td>(7)</td>
<td>137000</td>
</tr>
<tr>
<td>(11)</td>
<td>215000</td>
</tr>
<tr>
<td>Supplies</td>
<td>15000</td>
</tr>
<tr>
<td>Utilities</td>
<td>17000</td>
</tr>
<tr>
<td>Variable maintenance</td>
<td>7000</td>
</tr>
<tr>
<td><strong>TOTAL VARIABLE COSTS</strong></td>
<td>204000</td>
</tr>
<tr>
<td><strong>UNIT COST $/lb.</strong></td>
<td>0.0421</td>
</tr>
</tbody>
</table>

* Free standing facility; year round operation, 24 hours per day, 5 days per week; 26 krad (0.26 kGy) dose. The estimated costs in this table are based on a specific set of assumptions listed in Appendix A. Most costs are rounded to the nearest thousand dollars.

* The numbers in parentheses are the number of product handlers needed for each shift.
### Table 3. Irradiation Unit Costs

<table>
<thead>
<tr>
<th>Commodity</th>
<th>Throughput in Millions of Pounds</th>
<th>Dose kGy</th>
<th>Irradiation Unit Costs a/ cents per pound</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fish fillets</td>
<td>1.75</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>6</td>
<td>8.5</td>
<td></td>
</tr>
<tr>
<td></td>
<td>12</td>
<td>4.5</td>
<td></td>
</tr>
<tr>
<td></td>
<td>24</td>
<td>2.6</td>
<td></td>
</tr>
<tr>
<td></td>
<td>48</td>
<td>1.6</td>
<td></td>
</tr>
<tr>
<td>Papayas</td>
<td>0.26</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>12</td>
<td>4.2</td>
<td></td>
</tr>
<tr>
<td></td>
<td>24</td>
<td>2.3</td>
<td></td>
</tr>
<tr>
<td></td>
<td>48</td>
<td>1.4</td>
<td></td>
</tr>
<tr>
<td></td>
<td>96</td>
<td>1.0</td>
<td></td>
</tr>
<tr>
<td>Strawberries b</td>
<td>2.0</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>25</td>
<td>2.7</td>
<td></td>
</tr>
<tr>
<td></td>
<td>50</td>
<td>2.1</td>
<td></td>
</tr>
<tr>
<td></td>
<td>100</td>
<td>1.7</td>
<td></td>
</tr>
<tr>
<td></td>
<td>200</td>
<td>1.5</td>
<td></td>
</tr>
<tr>
<td>Young Chicken</td>
<td>2.5</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>52</td>
<td>1.6</td>
<td></td>
</tr>
<tr>
<td></td>
<td>104</td>
<td>1.2</td>
<td></td>
</tr>
<tr>
<td></td>
<td>208</td>
<td>1.0</td>
<td></td>
</tr>
<tr>
<td></td>
<td>416</td>
<td>0.9</td>
<td></td>
</tr>
<tr>
<td>Pork</td>
<td>0.3</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>66.5</td>
<td>0.7</td>
<td></td>
</tr>
<tr>
<td></td>
<td>133</td>
<td>0.4</td>
<td></td>
</tr>
<tr>
<td></td>
<td>266</td>
<td>0.3</td>
<td></td>
</tr>
<tr>
<td></td>
<td>532</td>
<td>0.2</td>
<td></td>
</tr>
</tbody>
</table>

**a/** Unit costs are based on a specific set of assumptions and input prices listed in Appendix A.

**b/** For strawberry irradiators, employees other than the plant manager, are hired for 4 months of the year. Radiation safety officer, shift supervisors, and plant operators receive 30% bonus to compensate for part time employment. Plant manager is hired for the full year to maintain the irradiator during the non-use season.
cost [3]. This relationship also contributes to the existence of larger scale economies for small volume irradiators.

Although cobalt-60 is an important cost item (especially for irradiators treating large volumes of food at higher doses), it is not a major source of production economies because cobalt needs are directly related to hourly throughput. Only minor economies could be realized through cobalt-60 suppliers offering volume discounts. Therefore, as cobalt-60 becomes a larger portion of total costs, less scale economies are possible. The flatter unit costs for the chicken and strawberry irradiators illustrate this.

The short-run cost curves demonstrate the importance of selecting the appropriate size irradiator. Processors can suffer stiff production cost penalties if too large a plant is run at less than capacity, rather than operating a smaller plant at its ideal throughput. A large irradiator treating small volumes of products has less output over which to spread its high fixed costs. The short-run cost curves for strawberry irradiators, shown in figure 1, illustrate the point clearly. If 50 million pounds of strawberries were treated in a facility designed for that annual volume, the unit cost would be close to 2 cents per pound. A plant built to handle double that volume would incur a unit cost of 3 cents per pound. If the largest strawberry irradiator, designed to irradiate 200 million pounds annually, only processed 50 million pounds per year it would be running at 25 percent of capacity. Unit costs would be above 5 cents per pound—two and a half times larger than the small facility.

Seasonality of production which results in unused capacity and higher unit costs may be the typical situation if irradiation is used for treatment of fruits and vegetables. Production of these commodities is very seasonal. Even those commodities that are grown year round like papaya have definite seasonal harvest patterns. To accommodate the seasonal high volumes, food irradiators would have excess capacity during off periods. Locating an irradiator in agricultural production areas with sequential harvest times for different irradiation-compatible commodities or irradiating non-agricultural items during off seasons would lessen this problem. Animal products are subject to less seasonal fluctuations, but cyclical swings over time could adversely affect use of irradiator capacity.

One of the assumptions underlying the unit costs for fish fillets, papayas, pork, and young chicken is that the irradiator runs just five days per week to coincide with the filleting, packing, and slaughtering schedule. For large plants
Strawberries

Unit cost (cents per pound)

Short run curve
Long run curve

Design capacities
- = 25 million pounds
= 50 million pounds
= 100 million pounds
= 200 million pounds

Million pounds per year

0 25 50 75 100 125 150 175 200

FIG.1. Irradiation unit costs for free standing facility; 4 months' operation per year, 24 hours per day, 7 days per week; 200 krad (2 kGy) dose.

with sizable cobalt-60 investments, this schedule may be too costly. Spreading the same volume out over seven days instead of five would reduce the hourly throughput and the corresponding cobalt-60 loading. Variable costs, especially labor, would rise unless the lower hourly throughput levels reduced product handling costs enough to compensate for weekend labor costs. In the case of the chicken irradiators with large cobalt-60 loadings, switching to a seven day schedule drops unit costs for the same volumes by an average of 18 percent. As pointed out earlier, this extended treatment schedule could disrupt processing and shipping schedules or require extra cold storage space. This would reduce potential cost savings from extending the irradiation schedule.

Conclusions and Other Considerations

This paper presented estimates of average unit costs for four sizes of cobalt-60 irradiators treating five different food products. The estimated costs are based on a specific set of assumptions and input prices. Irradiation technology demonstrates economies of scale with unit costs declining as the irradiator's size increases. These economies of scale are very pronounced for small irradiators, which means that individual agricultural firms with small volumes will not be able to achieve the lower unit costs possible with high throughputs. However, potential scale economies for the commodities included in this analysis generally become less important at annual volumes greater than 50 or 100 million pounds.
The unit costs reported in this paper are for the radiation treatment alone. For free standing facilities that combine throughputs from several producers, the costs of shipping the commodity to the irradiator are an added cost. As free standing irradiators increase in size, they will have to draw on larger geographic areas for their throughput. The transportation costs of getting the commodities to the larger irradiator may outweigh any gains in plant scale economies. This may bring a small irradiator's complete costs more closely in line with a large irradiator.

An analysis of the economies of scale for a particular irradiation treatment is only the first step in a complete assessment of its economic feasibility. Many other factors in addition to the appropriate size plant need to be considered. Transportation costs and disruptions to current marketing procedures must be included. Determination must be made of whether the food product can accommodate the radiation treatment, not technically, but from a market perspective—is there a point in the production and marketing chain with sufficient volume for an irradiator; is the wholesale or retail value high enough to bear the additional cost of radiation processing; will consumers accept irradiation of the product; and other similar issues. Finally, prospective users of radiation processing must determine whether irradiation offers benefits that are equal to, or preferably greater than, the costs.

REFERENCES


## APPENDIX A.

**Budget Item** | **Formulae and Assumptions** | **Source**
--- | --- | ---
**FIXED COSTS** (All costs expressed in U.S. dollars.)

### Integrated and Free Standing Facilities

<table>
<thead>
<tr>
<th>Budget Item</th>
<th>Formula</th>
</tr>
</thead>
<tbody>
<tr>
<td>Curie load</td>
<td>$ # \text{ of curies} = \frac{85 \times \text{throughput in lbs per h x dose (in megarads)}}{\text{net utilization efficiency}}$</td>
</tr>
<tr>
<td>(1 Ci = 3.70 x 10^{10} Bq)</td>
<td>Net utilization efficiency was assumed to be 25% for all irradiators for this analysis. Actual net utilization efficiency depends on the design of the irradiator which must consider product density and dose uniformity needs. Net utilization efficiency is expressed as a fraction of 1, where $1 = 100%$ 60Co utilization efficiency. An additional 12.5% for yearly decay was added to initial loading for those irradiators operating year round. Price of 60Co assumed to be $1.00 per curie for this analysis.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Budget Item</th>
<th>Formual</th>
</tr>
</thead>
<tbody>
<tr>
<td>Delivery of 60Co (cask rental and transport)</td>
<td>$5000 per cask (cask holds 200 000 curies)</td>
</tr>
<tr>
<td>Loading of 60Co (labor and crane rental)</td>
<td>$1000 per 100 000 curies</td>
</tr>
<tr>
<td>Source replenishment</td>
<td>12.5% required each year (delivery and loading costs same as above) to maintain previous year's throughput.</td>
</tr>
<tr>
<td>Budget Item</td>
<td>Formulae and Assumptions</td>
</tr>
<tr>
<td>-----------------------------</td>
<td>------------------------------------------------------------------------------------------</td>
</tr>
<tr>
<td>Biological Shielding</td>
<td>Costs for concrete cell and labyrinth and water-filled pool were estimated for six throughput levels as follows:</td>
</tr>
<tr>
<td></td>
<td>100 ft(^3)/h $285\ 000</td>
</tr>
<tr>
<td></td>
<td>250 ft(^3)/h $300\ 000</td>
</tr>
<tr>
<td></td>
<td>550 ft(^3)/h $325\ 000</td>
</tr>
<tr>
<td></td>
<td>1 000 ft(^3)/h $350\ 000</td>
</tr>
<tr>
<td></td>
<td>2 500 ft(^3)/h $550\ 000</td>
</tr>
<tr>
<td></td>
<td>4 000 ft(^3)/h $650\ 000</td>
</tr>
<tr>
<td>Irradiator Machinery:</td>
<td>Costs were estimated for six throughput levels A and B as follows:</td>
</tr>
<tr>
<td>*source hoist and plaque</td>
<td>A: 100 ft(^3)/h $150\ 000 + $80\ 000</td>
</tr>
<tr>
<td>*control panel</td>
<td>B: 250 ft(^3)/h $150\ 000 + $100\ 000</td>
</tr>
<tr>
<td>*mechanical interlocks</td>
<td>..................................................................................................................................</td>
</tr>
<tr>
<td>*conveyor</td>
<td>550 ft(^3)/h $175\ 000 + $150\ 000</td>
</tr>
<tr>
<td>*carriers</td>
<td>1 000 ft(^3)/h $200\ 000 + $300\ 000</td>
</tr>
<tr>
<td></td>
<td>2 500 ft(^3)/h $225\ 000 + $550\ 000</td>
</tr>
<tr>
<td></td>
<td>4 000 ft(^3)/h $250\ 000 + $800\ 000</td>
</tr>
<tr>
<td>Auxiliary Systems:</td>
<td>Costs were estimated for six throughput levels as follows:</td>
</tr>
<tr>
<td>*deionizer</td>
<td>100 ft(^3)/h $40\ 000</td>
</tr>
<tr>
<td>*chiller</td>
<td>250 ft(^3)/h $50\ 000</td>
</tr>
<tr>
<td>*air handling</td>
<td>550 ft(^3)/h $50\ 000</td>
</tr>
<tr>
<td></td>
<td>1 000 ft(^3)/h $50\ 000</td>
</tr>
<tr>
<td></td>
<td>2 500 ft(^3)/h $55\ 000</td>
</tr>
<tr>
<td></td>
<td>4 000 ft(^3)/h $55\ 000</td>
</tr>
</tbody>
</table>

For irradiators with loadings less than 500 000 curies of \(^{60}\)Co, pool chiller not needed and $20 000 subtracted from above estimates.
<table>
<thead>
<tr>
<th>Budget Item</th>
<th>Formulae and Assumptions</th>
<th>Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control room and dosimetry lab</td>
<td>400 ft² at cost of $35 per ft². A 20% overhead construction fee is added to the calculated cost.</td>
<td>Author's assumption for room size and construction fee. Cost per ft² from Means Square Foot Costs 1984, p. 163.</td>
</tr>
<tr>
<td>Fork lifts, palletizers</td>
<td>Cost of forklifts and palletizers estimated for six levels of throughput (see Appendix C).</td>
<td>See sources listed in Appendix C.</td>
</tr>
<tr>
<td>Design and engineering of total facility layout, product movement, $^{60}$Co utilization, etc.</td>
<td>Estimated at 10% of facility cost.</td>
<td>Author's assumption.</td>
</tr>
<tr>
<td>Fixed maintenance</td>
<td>35% of total maintenance (total maintenance estimated at 1.5% of facility cost).</td>
<td>Industry sources.</td>
</tr>
<tr>
<td>Insurance and taxes</td>
<td>2% of facility and land investment.</td>
<td>Deitch, et. al., 1972, p. 80.</td>
</tr>
<tr>
<td>Working capital</td>
<td>3 months' bills for labor, supplies, and utilities. For irradiators operating only 4 months per year, working capital equals 1 month's bills.</td>
<td>Author's assumption.</td>
</tr>
</tbody>
</table>
| Salaried Personnel                             | **Annual Salaries:**  
  Plant Manager: $35,000 + $10,500 for fringes = $45,000. For integrated facility only 15% of manager's time allocated to irradiator.  
  Radiation safety officer/quality control (RSO/QC): $30,000 + $9,000 for fringes = $39,000  
  30% for fringes as suggested by the Office of Wages and Industrial Relations, U.S. Bureau of Labor Statistics.  
  Base salary for RSO/QC from discussion with health physicist in Ionizing Radiation Branch, U.S. Health and Human Services. | 422                                                                                               |
<table>
<thead>
<tr>
<th>Budget Item</th>
<th>Formulae and Assumptions</th>
<th>Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>Salaried Personnel (cont'd)</td>
<td>Maintenance person: $20,000 + $6,000 for fringes = $26,000. For integrated facility only 30% of maintenance person's time allocated to irradiator. The above personnel only work one shift a day and are considered &quot;on call&quot; for emergencies. Clerical: $14,000 + $4,200 for fringes = $18,200. For integrated facility only 50% of clerical person's time allocated to irradiator. Clerical person only works one shift a day.</td>
<td>Maintenance and clerical wages estimated from information provided by the Office of Wages and Industrial Relations, BLS. Amount of time allocated in an integrated facility based on industry sources and author's assumptions.</td>
</tr>
<tr>
<td>Free Standing Facilities Only</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Land</td>
<td>3 acres for trucks to turn around, parking lot, landscaping, etc. at $40,000 an acre. (Same for all sizes of irradiators.) Actual land costs vary widely.</td>
<td>Acreage requirement from industry sources. Land cost from Appendix C of Bloomster et al., 1984.</td>
</tr>
<tr>
<td>Refrigerated warehouse</td>
<td>Space needed was based on storing four days' worth of throughput in case of unscheduled down times or shipping foul-ups. Product is stacked 15 feet high. 25% additional space allowed for aisles and other unusable space. Cost of $54 per ft², a 20% overhead construction fee is added to the calculated cost.</td>
<td>Author's assumptions.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Cost per ft² from Dodge Construction Systems Costs, 1984, p. 32.</td>
</tr>
</tbody>
</table>
## Budget Item

<table>
<thead>
<tr>
<th>Budget Item</th>
<th>Formulae and Assumptions</th>
<th>Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>Additional rooms and loading/unloading area</td>
<td>1000 ft² for offices, mechanical room, bathroom, and lunchroom. (Same for all sizes of irradiator.) Loading and unloading area depends on throughput and was estimated as follows:</td>
<td>Additional space needed is author's assumption.</td>
</tr>
<tr>
<td></td>
<td>100 ft³/h</td>
<td>400 ft²</td>
</tr>
<tr>
<td></td>
<td>250 ft³/h</td>
<td>400 ft²</td>
</tr>
<tr>
<td></td>
<td>550 ft³/h</td>
<td>400 ft²</td>
</tr>
<tr>
<td></td>
<td>1000 ft³/h</td>
<td>800 ft²</td>
</tr>
<tr>
<td></td>
<td>2500 ft³/h</td>
<td>2000 ft²</td>
</tr>
<tr>
<td></td>
<td>4000 ft³/h</td>
<td>2800 ft²</td>
</tr>
<tr>
<td></td>
<td>Cost of $35 per ft², a 20% overhead construction fee is added to the calculated cost.</td>
<td>Cost per ft² from Means Square Foot Costs 1984 p. 165.</td>
</tr>
</tbody>
</table>

### VARIABLE COSTS

#### Integrated and Free Standing Facilities

<table>
<thead>
<tr>
<th>Supplies</th>
<th>2% of facility cost</th>
<th>Author's assumption.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Utilities</td>
<td>2% of facility cost, plus $.112 per ft³ of refrigerated warehouse space.</td>
<td>Author's assumption. Utilities for refrigerated warehouse from Hudson, 1984.</td>
</tr>
<tr>
<td>Variable maintenance</td>
<td>65% of total maintenance (total maintenance estimated at 1.5% of facility cost).</td>
<td>Industry sources.</td>
</tr>
<tr>
<td>Hourly labor</td>
<td>Annual Salaries: Shift supervisor and plant operator: $30 000 + $9 000 for fringes = $39 000 for 2nd and 3rd shift. Plant operator: $18 000 + $5 400 for fringes = $23 400 for 1st shift.</td>
<td>Estimated from information provided by the Office of Wages and Industrial Relations, BLS, and industry sources.</td>
</tr>
</tbody>
</table>
Budget Item | Formulae and Assumptions | Source
---|---|---
Hourly labor (cont'd) | Material Handler: $15,000 + $4,500 for fringes = $19,500 for each worker per 8-hour shift. Number of handlers needed estimated for six throughput levels (see Appendix B.) (No provision is made for wage differentials for second and third shifts or weekend work. When irradiator is operated 7 days a week, fixed and variable labor costs are adjusted accordingly). |  

Annualized Fixed Costs

The capital recovery factor was used to estimate the levelized annual charge to recover the original investment (purchase price), plus the opportunity cost of the money spent to buy the asset, over the useful life of the asset. Asset assumed to have no salvage value.

\[
\text{Annual charge} = K \times \frac{i(1+i)^n}{(1+i)^n-1}
\]

where:

- \( K \) = original investment
- \( i \) = interest rate (assumed to be 11.75%)
- \( n \) = number of years of useful life

The useful lives for capital assets were assumed to be 15 years for initial ⁶⁰Co loading; 25 years for buildings and biological shielding; and 10 years for machinery.

The other fixed costs were treated as follows:

- land
- working capital
- ⁶⁰Co replenishment
- fixed maintenance
- insurance and taxes
- salaried employees

The total cost of these items is currently estimated at 11.75% of investment.

\[
\text{Unit cost} = \frac{\text{cost}}{\text{throughput per year in lb}}
\]

\[
\text{in $/lb}
\]
APPENDIX B.
Number of Product Handlers Needed for Six Sizes of Irradiators

<table>
<thead>
<tr>
<th>Hourly throughput (ft³)</th>
<th>pallets/h</th>
<th>worker/h per pallet</th>
<th>No. of handlers needed per shift to run irradiator 4/</th>
<th>No. of handlers needed to unload trucks 3/</th>
<th>total No. of handlers needed per day</th>
</tr>
</thead>
<tbody>
<tr>
<td>100 (hand)</td>
<td>2</td>
<td>.28</td>
<td>1</td>
<td>.3</td>
<td>3.3</td>
</tr>
<tr>
<td>250 (hand)</td>
<td>3</td>
<td>.28</td>
<td>1</td>
<td>.4</td>
<td>3.4</td>
</tr>
<tr>
<td>550 (hand)</td>
<td>7</td>
<td>.28</td>
<td>2</td>
<td>1</td>
<td>7</td>
</tr>
<tr>
<td>1000 (palletizers)</td>
<td>12</td>
<td>.103 + 1</td>
<td>3</td>
<td>2</td>
<td>11</td>
</tr>
<tr>
<td>2500 (palletizers)</td>
<td>29</td>
<td>.103 + 2</td>
<td>5</td>
<td>4</td>
<td>19</td>
</tr>
<tr>
<td>4000 (palletizers)</td>
<td>46</td>
<td>.103 + 2</td>
<td>7</td>
<td>7</td>
<td>28</td>
</tr>
</tbody>
</table>

1/ Although the ft³ per pallet differs between products and shippers, I assumed one pallet = 48" x 40" x 78" = 149 760" or approximately 87 ft³ (Source: AMS marketing specialist, USDA). Pallets/h rounded up to next whole pallet.

2/ Source (with modifications): Table 6 - "Labor and equipment time and cost to unload 900 hand-stacked cartons of fresh tomatoes and move to storage" in Mongelli, Feb. 1984, p. 15.

3/ Source: Table 8 - "Labor and equipment time and cost to unload 900 palletized cartons (18 pallets) of fresh tomatoes and move to storage" in Mongelli, 1984, p. 17. The extra 1 or 2 handlers are needed for the depalletizer(s).

4/ Number of product handlers needed per shift rounded up to next whole person.

5/ See Appendix C for calculations. Trucks unloaded during 1 shift.
APPENDIX C

Product Handling Machinery Costs for Six Sizes of Irradiators

<table>
<thead>
<tr>
<th>Hourly Throughput (ft³)</th>
<th>Truckloads per day 1/</th>
<th>Truckloads per h 2/</th>
<th>Worker/h needed per truckload 3/</th>
<th>No. of handlers needed per day to unload trucks 4/</th>
<th>Forklift cost 5/ $</th>
<th>Palletizer cost 6/ $</th>
</tr>
</thead>
<tbody>
<tr>
<td>100 (hand)</td>
<td>2.3</td>
<td>.3</td>
<td>.93</td>
<td>3</td>
<td>30 000</td>
<td>0</td>
</tr>
<tr>
<td>250 (hand)</td>
<td>3.5</td>
<td>.4</td>
<td>.93</td>
<td>4</td>
<td>30 000</td>
<td>0</td>
</tr>
<tr>
<td>550 (hand)</td>
<td>8.2</td>
<td>1</td>
<td>.93</td>
<td>1</td>
<td>30 000</td>
<td>0</td>
</tr>
<tr>
<td>1 000 (palletizers)</td>
<td>14.0</td>
<td>1.8</td>
<td>.93</td>
<td>2</td>
<td>30 000</td>
<td>168 000</td>
</tr>
<tr>
<td>2 500 (palletizers)</td>
<td>33.8</td>
<td>4.2</td>
<td>.93</td>
<td>4</td>
<td>45 000</td>
<td>272 000</td>
</tr>
<tr>
<td>4 000 (palletizers)</td>
<td>53.7</td>
<td>6.7</td>
<td>.93</td>
<td>7</td>
<td>60 000</td>
<td>293 000</td>
</tr>
</tbody>
</table>

1/ Truckloads per day = (No. of pallets per h x 21 h) ÷ 18 pallets per truck.
2/ Trucks arrive and are unloaded during one 8-h shift.
3/ Source: same as footnote 3 of Appendix B.
4/ For largest irradiators, number of handlers needed rounded up to next whole person.
5/ Cost of forklift is $15 000 each.
6/ A semi-automatic depalletizer can handle about 24 pallets per h and requires one handler. The installed cost of the machine plus roller conveyor is assumed to be $84 000. An automatic palletizer can handle many more pallets per h and does not require a handler. The price of an automatic palletizer varies with its speed. The costs of the palletizers used in this analysis were assumed to be $84 000 for 1 000 ft³/h, $104 000 for 2 500 ft³/h, and $125 000 for 4 000 ft³/h. Source: Robin Poppel, Systems Manager for Columbia Machines, Vancouver, Washington.
BIBLIOGRAPHY TO APPENDICES


Hudson, William. President of the International Association of Refrigerated Warehouses, personal communication with author on December 7, 1984.


COMMERCIAL FEASIBILITY OF IRRADIATING SEAFOOD IN THE UNITED STATES OF AMERICA

J.D. KAYLOR*, J.W. SLAVIN**, R.J. LEARSON*

* National Marine Fisheries Service,
  Gloucester Laboratory,
  Gloucester, Massachusetts

** Joseph W. Slavin and Associate,
  Annandale, Virginia
  United States of America

Abstract

COMMERCIAL FEASIBILITY OF IRRADIATING SEAFOOD IN THE UNITED STATES OF AMERICA.

The National Marine Fisheries Service, Gloucester Laboratory, Gloucester, Massachusetts, has carried out commercial feasibility studies of irradiated seafoods. These include irradiation of seafoods on a large scale at different dose levels when measured at the point of minimum absorbed dose, and shipment by common carriers under prevailing conditions of transportation to distant markets, and maintaining a highly desirable degree of freshness. The economics of this semi-commercial irradiator was extrapolated to a full-scale commercial irradiator, and a discussion of certain qualities of management skills is presented. The pending Food and Drug Administration approval of protein foods as it relates to the economic feasibility of irradiating seafoods for shelf-life extension is discussed.

INTRODUCTION

The first investigations into irradiation of seafoods were conducted at the Massachusetts Institute of Technology (MIT) under contract to the Atomic Energy Commission (AEC) in the early 1960's. The contracts revealed that radiation preservation of marine products appeared to be feasible. As a result, the AEC funded a national program on low-dose irradiation preservation of seafoods at several universities by installing small (30 kilocuries) research irradiators. The AEC funded a large cobalt-60 irradiator at the Gloucester Technological Laboratory of the present National Marine Fisheries Service. This irradiator was designed to be a development rather than research irradiator. The difference between the Marine Products Development Irradiator (MPDI) and the above small research irradiators is one of size and purpose. The MPDI was designed to be of semicommercial size capable of irradiating 2000 pounds of product per hour at a dose of 200 000 rads. The research irradiators could only irradiate about 375 pounds at the same dose.

1 1Ci = 3.70 X 10¹⁰ Bq.
2 1 rad = 1.00 X 10⁻² Gy.
The MPDI is a one story rectangular building of almost 4000 square feet which is divided into three principal areas. They are a refrigerated storage room capable of holding 12 tons of product at 33°F (1°C), a product conveying system, and the irradiation cell. Supporting features are a health physics laboratory, a dosimetry laboratory, an office and general storage and work areas.

The irradiator had an initial loading of 235 000 curies of cobalt-60. The active area of the source plaque is about 1 foot by 4 feet and consists of 6 sub-units. Its rated source utilization is about 21% using target overlap for greatest efficiency. Its original design was one ton of fish per hour at 200 000 rads with a maximum to minimum dose ratio of 1.3. This dose ratio is achieved by the irradiator design which is characteristic of a two-direction, multi-position, multi-pass, stop-dwell irradiator.

The purpose of the MPDI was to determine if it was commercially feasible to irradiate fresh seafoods on a large commercial scale and ship them by common carrier under regular conditions of transportation to distant destinations and still retain a high degree of freshness. A second purpose was that of determining the cost of irradiating seafoods.

No business man would invest time and money in such a new food process as food irradiation unless he had solid assurance that the new process would be commercially feasible. A business man might be mildly interested to learn that irradiation of seafoods can significantly extend their shelf-life under laboratory-controlled conditions. That same business man, however, would be impressed to learn that fresh seafoods irradiated in commercial quantities at low-dose levels and shipped under truly commercial conditions do show an increase in shelf-life that is commercially significant. In essence, the business man must be convinced that the favorable results obtained in the laboratory can also be duplicated on a commercial scale before he invests his money.

COMMERCIAL FEASIBILITY STUDIES

In order to determine the commercial feasibility of irradiation preservation of seafoods, we conducted three studies. They were of such nature that if the first had resulted in failure, we would not have undertaken the second, and if the second had resulted in failure, we would not have undertaken the third.

We reasoned that we should determine whether a suitable amount of fish of high freshness level was available. We conducted a survey of the Boston fishing fleet during winter, summer and autumn so as to show any temperature differences of the principal seasons of the year with spring and autumn being considered similar. We developed criteria for subjective measurements at the boat level. Objective measurements of fish temperature were obtained by a carefully calibrated electronic thermometer.

All data were fed into a computer that was programmed to give correlations among the expert subjective measurements and the temperature measurements. The computer showed that subjective examinations of fish had significant to highly significant correlations at the 1-percent level of probability. The complete data derived from over
4 500 individual samples of fish showed that over 78 percent of the fish were fresh enough to fully justify the use of irradiation.

Once we were certain that an ample supply of fresh fish of high quality was assured to justify the irradiation preservation treatment, we reasoned that the whole irradiation preservation concept could fail if conditions of commercial transportation of fresh seafoods were inadequate. We wanted to know the temperature of fresh fillets from processor or point of origin to distant destination. Shipments were made at all seasons of the year so as to reflect the possible effect of ambient temperature. The destinations included the states of New York, Florida, Ohio, Maryland, Texas, and Washington. The amounts shipped and recorded for temperature recording varied from as little as 100 pounds to as high as 4 500 pounds.

The survey was conducted in 1965 and 1966 and it showed that all the common commercial methods of transporting fresh fish fillets by licensed interstate carriers ensure fillet temperatures of 40°F (4.44°C) or lower. This temperature is low enough to permit shipment of irradiated fresh fillets in good condition to the most distant parts of the continental United States.

Having satisfied ourselves that there was an ample supply of high quality fish and that the existing commercial interstate carriers imposed no limiting factor for shipment of irradiated fresh fillets, we turned our attention to an extremely critical phase of our three pronged approach. This third phase concerned what we termed "commercial benefit study." We wanted to know what commercial benefits industry people could find with this new method of food preservation. In order to get answers to this question we interviewed high-level managers of the eight largest chain supermarkets in the nation.

We explained the purpose of irradiation and gave a brief explanation of how it was achieved and we offered to give them (no cost to them) adequate samples of both control and irradiated fish fillets. All the fillets were sent to their head testing laboratories for evaluation (not for sale to the public). At the conclusion of the tests, a spokesman for each of the eight supermarkets was to give us a report. Each of the eight stated that they could and would sell irradiated fresh seafoods in areas where fresh seafoods were not then sold.

Here is how various elements of the food distribution chain viewed the irradiation preservation of seafoods. Producers who were familiar with our work felt that irradiation processing would help to smooth out the lows and highs of availability of fresh fish supplies and would ensure a steadier market. Retailers asserted that using irradiated seafoods would allow holding of the fillets after the peak demand day in the week had passed rather than having to mark down the price or discard the fish due to possible incipient spoilage. The retailers also claimed that the process would enable them to offer fresh fish throughout the week to a degree greater than was then possible. Some in the chains claimed that some savings could be passed along to consumers. Others stated that the advantage to all segments was the expansion of sales of fresh seafoods to areas not available at that time.

These studies were carried out in the mid-sixties and we are now in the mid-eighties and things may have changed in that interval. A review convinces us that there has been no great disadvantageous change.
First, with respect to the percentage of freshness level there has been an improvement because of a concerted government-industry collaborative effort to promote the availability of fish of very high freshness level. It has been remarkably effective especially at the supermarket level where the greatest amounts of fish can be sold.\(^5\)

With respect to desirable temperature of the fillets during distribution by common carrier at the present time, the availability and use of more efficient insulation in the trucks insures an even better degree of temperature maintenance. Added to this is a decided improvement in the efficiency and economy of the mechanical refrigerating equipment of the trucks.

The commercial benefits as envisioned by industry members remain much the same now as they did two decades ago. The one point on which there is some apprehension is the dwindling supply of fish. Stocks of several desirable species of fish are not as abundant as they were twenty years ago. As a consequence, if the lessening trend continues, competition between fresh high quality fillets and high quality irradiated fillets would most likely result in defeat of irradiated fillets because of the added cost.

**U. S. POTENTIAL MARKET FOR IRRADIATED SEAFOOD**

In 1983, consumption of seafood in the United States reached a total of 3.0 billion pounds of which 1.86 billion pounds or 62 percent was marketed as fresh and frozen.\(^3\) Consumption of fresh seafood is estimated to be about 26 percent of total consumption for fresh or frozen or about 484 million pounds annually and the demand for fresh seafoods is still increasing.

A prime market for irradiated seafood would be for groundfish (demersal) fillets and steaks. These products are in high demand and producers would realize benefits from irradiation in extending product shelf-life, stabilizing price fluctuations and expanding markets. The total U. S. supply of fresh and frozen fillets and steaks amounted to 378 million pounds in 1983 of which 298 million pounds or 79 percent were imported. In recent years, there has been a steady increase in the demand for fresh seafood which characteristically commands a higher price than does frozen seafood. The National Marine Fisheries Service reported that in 1983 retail prices of fresh cod, flounder, and haddock fillets were practically always higher than frozen fillets of the same species.

With suitable consumer acceptance, the potential impact of irradiation might be to expand the market for fresh seafood by permitting wider use of imported seafood in the fresh rather than frozen form. At present, most of the domestically produced fillets are marketed as fresh while almost all of the imports are in the frozen form. In recent years, there has been a definite increase in imports of fresh fillets trucked or flown from Canada, Iceland, and Norway and, with successful application of irradiation we would expect this to increase. We are practical enough to realize how dependent we are on imports of this nature and we are of the opinion that we could come to a mutually satisfactory modus vivendi. This is based upon the premise that strict good manufacturing processes would apply mutually.

\(^3\) 1 US billion = 10^9.
The principal market for fresh and frozen seafood in the United States is in institutional outlets, notably restaurants and fast food chains. Successful use of irradiation might permit wider use of fresh products for these huge markets. One case in point is that of shrimp—a high value product—which is in great demand in this country. In 1983, the total U. S. supply of shrimp was 577 million pounds of which almost all is marketed as frozen. More than 70 percent of the shrimp consumed annually is sold through institutional outlets.

Irradiation could be used at low doses of 150 000 to 200 000 rads to extend shelf-life of packaged fresh shrimp, thus permitting marketing of greater quantities of fresh shrimp and, at higher doses, to ensure elimination of Salmonella and other pathogens from imported frozen shrimp. Other potential applications include the use of irradiation in production of minced fish in specialty type products such as surimi to reduce if necessary bacterial loads and possibly in depuration of molluscan shellfish as an approved procedure to permit harvesting from certain producing areas.

ECONOMICS

Twenty years ago, rough estimates were made to obtain the approximate per pound cost of irradiating fillets. At that time cobalt-60 was running anywhere from 33 to 50 cents per curie whereas now the cost is about a dollar. Throughput was calculated at 12.5 million pounds per year taking into account allowance for depreciation of capital investment over a ten-year period, labor, fixed, and variable costs.

We arrived at a cost of 1.9 cents per pound compared with 1.5 cents by Hitt using an irradiator of different design. During the intervening years to the present we estimate that our original cost would be tripled today or at least 5.7 cents per pound. For a more detailed treatment of estimated costs today we recommend study of the recent publication by Dr. Giddings.

IRRADIATOR MANAGEMENT

In the last twenty years we have irradiated not only many foods but also such things as live insects that required extremely low doses of as little as 300 rads. Other jobs ran as high as 500 megarads for special electrical cables for nuclear reactors and the bombarding of precious gem stones in the hope of producing unusual color changes.

From a management standpoint, the one common denominator that applies to all irradiation jobs regardless of the magnitude of absorbed dose is the achievement of the required dose and the proper recording of all pertinent data relative to each irradiation job.

This requirement necessarily leads to the question of just what information should be recorded. It has been our experience that good quality control features should be absolutely paramount. For example, irradiation of seafoods requires the pre-irradiation temperature of the product to be at or as close to 33°F (1°C) as possible and as close to that during the entire irradiation treatment. Provision should also be made for continuous temperature recording during the whole operation until final shipment from the irradiator. Needless to add, the design of the plant should be such that there is no possibility of co-mingling un-irradiated with irradiated material.
Generally, we require complete identification of the applicant, address, date, description of the product to be irradiated, code marks or other distinguishing characters, container size, total amount (weight or number of units), dose requested, dose received, dosimetry system used, phantom description (if any), irradiation time at start and finish, and number and position of the source plaques. In the event of accidental product delay or malfunction of the conveying system, split second timing of retraction of cobalt source must be accounted for so that its eventual return to irradiation position must agree with the original requested dose.

**FOOD AND DRUG ADMINISTRATION**

We are pleased that the Food and Drug Administration (FDA) has taken positive action in respect to the use of ionizing radiation for fruits and vegetables, disinfection of food of insects, and to disinfest spices of microbes. We are of the opinion that one of the greatest uses of ionizing radiation will be for meats, poultry and seafood. Some of these products will require a minimum effective dose that will exceed the present FDA limit of 100 kilorads. An example is the three species of fish (cod, ocean perch (redfish) and flounder) that were irradiated by the MPDI for animal feeding tests that were evaluated by the Joint FAO/IAEA/WHO Expert Committee on Wholesomeness of Irradiated Food (JECFI).

We conducted these irradiations for four years at a dose level of 175 kilorads at the point of minimum absorbed dose. The maximum dose was always over 200 kilorads. The final report of the JECFI was favorable for all foods irradiated at less than one megarad. We trust that FDA will soon make its announcement concerning food irradiation dose levels between the present 100 kilorad level and the one megarad level accepted by the international JECFI.

**REFERENCES**


COMMERCIAL RISKS AND BENEFITS OF INVESTMENTS IN FOOD IRRADIATION ON AN INDUSTRIAL SCALE

L. WIESNER
BGS Beta-Gamma-Service,
Dr. Wiesner GmbH & Co.,
Wiehl-Bomig, Federal Republic of Germany

Abstract

COMMERCIAL RISKS AND BENEFITS OF INVESTMENTS IN FOOD IRRADIATION ON AN INDUSTRIAL SCALE.

Economic aspects and prerequisites of importance for the commercialization of the radiation processing of food products are discussed. Various factors imply that the capital requirements for a complete commercial food irradiation plant and the selling price of the radiation treatment have to be considerably higher than is suggested in many publications. This holds especially for food irradiation facilities conceived for only one type of food, as it will generally not be possible to make use of the economy of scale in such cases. Investment in such dedicated irradiation facilities has to be classified as a high risk venture for various reasons which are described in some detail. The most important risk factor for investments in food irradiation facilities is large changes in demand for irradiation capacity within rather short periods which are completely unpredictable because they are caused by natural phenomena such as weather. As the rational investor looks for a high potential return from high risk ventures to offset the potential loss, the selling price for the radiation processing of food products is further increased. To overcome this drawback the establishment of irradiation centres for a large number of foods and possibly other products is recommended. Such a strategy, for which the BGS centre is cited as an example, reduces at the same time the risk for the rational investor as well as the selling price. Finally, the role of the Joint Division of FAO and IAEA in implementing such a strategy especially in developing countries is stressed.

1. PRESENT STARTING-POINT FOR THE COMMERCIALIZATION OF FOOD IRRADIATION

After 30 years of extensive research and testing, the time for a breakthrough in food irradiation on an industrial scale has come. The way for the breakthrough, which sometimes appeared to be only a remote possibility during the 1970s, was mainly paved

— by the research results of the International Project in the Field of Food Irradiation on the wholesomeness of irradiated food,
— by the conclusion of the Joint FAO/IAEA/WHO Expert Committee on the Wholesomeness of Irradiated Food in 1980 that foods so treated up to an overall average dose of 10 kGy present no toxicological hazard,

As it is now established that proper food processing by ionizing radiation does not have any hazardous side-effects, development efforts have shifted to realizing the technological process for a wide variety of food items in order to make the highly desirable beneficial effects of radiation processing available in practice. These are, in particular:

- the increase in safety of food supplies by the destruction of food-borne pathogens,
- the enlargement of food supplies by killing pests and delaying deterioration processes,
- the reduction of the dependence on specific effects of chemical substances against which living organisms can develop resistance,
- the energy saving from utilizing the high susceptibility of the vital functions of living organic matter to radiation damage.

In spite of these benefits, a lot of advocacy work will be necessary before radiation processing of foods is readily accepted by governments, consumers and investors. Governmental acceptance by abolishing obsolete general prohibitions on trade with irradiated foods and giving clearances for the sale of foods processed with ionizing radiation according to acknowledged standards is obviously the primary prerequisite for commercialization.

However, governmental acceptance alone is almost worthless so long as there is no relatively broad acceptance of irradiated foods by consumers. It is doubtful whether a relatively broad consumer acceptance of irradiated foods exists in many countries or can be achieved within a reasonable time by public information campaigns. Consumer behaviour may eventually change drastically when governments adopt a positive attitude towards food irradiation and justify such an attitude with the conclusions of the Joint FAO/IAEA/WHO Expert Committee and the large benefits of food irradiation.

This consumer reluctance may well be the result of governmental prohibition of trade in irradiated foods set up despite the lack of evidence of hazardous side-effects of the process. Many consumers will have seen the prohibition itself as evidence of such side-effects. It is also uncertain whether, after proper information, many consumers continue to have those reactions to the word “irradiation” that are assumed in many discussions, especially regarding the labelling of irradiated foods.

After governmental sanction and consumer acceptance, demonstrated by market tests and opinion polls, the commercialization of irradiated foods requires the willingness of people to invest quite a lot of money in this field. The factors that influence and even reduce the readiness to invest in the commercialization
of irradiated foods and the strategy to overcome the reluctance of investors by reducing the commercial risks are the main themes of this paper.

2. PRODUCTION COST AND SELLING PRICE IN THE RADIATION PROCESSING OF FOODS

In countless publications the economic feasibility of radiation processing has been discussed for numerous food items and different local situations in terms of estimated treatment costs and accruing advantages such as the reduction of storage losses. Probably there is no single publication that does not come to the conclusion, after such an evaluation of the economic feasibility, that the application of food irradiation would be highly profitable.

Unfortunately, such statements are usually based on the direct processing costs alone and even these are very often estimated without consideration of important cost factors in a commercial operation. For example, the appreciable investment in land for the erection of the irradiation facility and adjacent warehouses is frequently not taken into consideration. Payments have to be made long before any production starts. Thus considerable interest accrues on this expenditure during the construction time and has to be added to the total capital requirement. In some countries taxes have to be paid during the investment period.

The total construction not only comprises the irradiation facility, warehouses and the laboratory, but also space and installations for heating plant and electricity distribution, for social rooms, administration and auxiliary services, if the whole plant is not an integral part of a larger industrial complex with already existing infrastructure.

Apart from the continuous loss of irradiation capacity by the decay of radioactive material in the case of gamma-irradiation facilities, one will be able to use at best only 80–90% of the theoretically available irradiation capacity on account of fluctuations in the delivery of the foods to be irradiated and the necessity to reduce delays in the irradiation of very often perishable foods to a minimum. Investment for an irradiation capacity higher than that needed on an average is the inevitable consequence.

Thus the capital requirements for a complete commercial food irradiation plant will be in most cases considerably higher than suggested in many publications. Usually the irradiation facility proper will contribute substantially less than 50% of the total necessary investment. The profitability of many applications of food irradiation will be heavily reduced by the higher amortization and interest figures associated with higher capital expenditures, at least for the application anticipated.

Moreover, a critical examination of the profitability of a business cannot be based solely on the direct processing costs because there is no commercial
operation without considerable overheads for administration, taxes and sales activities, to name only a few of the indirect cost factors. In the field of food irradiation substantial public information activity will be needed for quite some time. The expenditure on this will further increase the percentage of the overheads that has to be added to the direct processing costs for the calculation of the minimum selling price of the radiation treatment for a given food item. In many instances this minimum selling price will already be double or even triple the treatment costs one finds in publications on the economic feasibility of food irradiation.

3. ECONOMY OF SCALE IN FOOD IRRADIATION

For potential investors in the erection of a food irradiation facility, one has to demonstrate, however, that selling prices considerably above the break-even minimum can easily be maintained in the market for the advantages irradiated foods offer. Especially when interest rates are high it is difficult to find investors for a business that does not look very profitable. Why should anybody invest in a business with all its risks for a return on investment that is not considerably higher than, for example, the 10% or more annual interest offered for bonds with nearly no risk at all?

Unfortunately, investment in a food irradiation facility has to be classified as a high risk venture for a number of reasons. The basic problem which food irradiation shares with all other applications of radiation processing is the unusually small ratio of turnover to invested capital which in general is by far the most important cost factor. This means that a large portion of the total costs is fixed and cannot be adjusted to the actual volume of products which have to be irradiated. Any appreciable deviation of the throughput from its anticipated value consequently has a great effect on the profitability of the business.

Moreover, the investment in an irradiation facility does not change very much with the irradiation capacity installed. In the field of food irradiation this is even true for rather high $^{60}$Co prices as the doses are relatively low. This is illustrated by Fig. 1 in which the increase in the total investment with the annual throughput of food products requiring an average minimum dose of 2–3 kGy is shown, assuming an efficiency of 20–30% in the utilization of the $\gamma$-radiation and a $^{60}$Co price of US $1.20/Ci, including the costs for shipment and installation of the sources. The actual throughputs which can be achieved will be about 25% lower than the theoretical ones shown in Fig. 1 in most cases because of the decay of $^{60}$Co in the course of a year and of fluctuations in demand for the irradiation capacity.

Thus a food irradiation plant that allows the throughput of 75 000 t/a according to the foregoing model assumptions requires only twice the investment for a plant with 25% of that throughput. The difference in investment
Theoretical throughput (10³ t/a)

FIG.1. Relative increase of investment costs with the ⁶⁰Co source strength required for a fixed theoretical throughput; 1.0 corresponds to the investment in the complete irradiation plant without sources.

costs between plants with actual throughputs of 20 000 and 10 000 t/a will be barely more than 20% because the cost of industrial irradiation plants, without the radiation sources, are over a very wide range nearly independent of the intended throughput.

In many applications the difference in the investment costs between plants with different throughputs will be even smaller than in the above-mentioned example because the relatively high average density of food products allows facilities with an efficiency of more than 30% utilization of the γ-radiation. Consequently, less radioactive material is needed for a given throughput.

The cost of the radiation treatment per weight unit of product depends therefore very much on the size of the throughput of the plant. As also the running costs, with the exception of the expenditure for the replenishment of the ⁶⁰Co sources, usually increase noticeably less than proportionally to the throughput, the dependence of the treatment cost per weight unit of product on the throughput is still further increased. The result are well-known curves presented in Fig.2 for the treatment of food products with an average minimum dose of 2–3 kGy.
FIG. 2. Dependence of the relative cost of a radiation treatment on the actual throughput of a product requiring a dose of 2.5 kGy and on the irradiation capacity.

As the relative cost of 1.0 in a facility using an irradiation capacity of 12 500 kGy·t/a already corresponds to a selling price of the order of 40 US$/kGy·t, which increases very rapidly as the irradiation capacity decreases, applications justifying only such small capacities will hardly be economically viable, even if the irradiation dose required is very small. This is the reason for the lack of interest in potato irradiation from industry, already authorized in many countries, as long as pressure is not exerted by governments to use the radiation technique instead of chemicals for sprout inhibition. In most areas it is not possible to obtain the 100 000 t of potatoes necessary for operating a plant with an irradiation capacity that can offer an attractive selling price for sprout inhibition.

This causes another aspect of plants dedicated to the irradiation of certain food products. Very often it will not be possible to make use of the economy of scale, as illustrated in Fig.2, because the amount of food products to be irradiated in any one geographical area does not justify the installation of large irradiation capacities. Moreover, the disadvantages of transport over larger distances to an irradiation facility will frequently outweigh the advantages of the radiation treatment, especially for perishable foods.
Thus the capacity of a food irradiation plant, and with it the selling price of the treatment, has to be determined in accordance with the anticipated demand at a given location. Unfortunately, this demand is even much less predictable in the food irradiation field than in other industrial areas because the variations from year to year are highly irregular and do not follow general trends in the national and international economy.

4. COMMERCIAL RISKS OF INVESTMENT IN FOOD IRRADIATION FACILITIES

Especially for most vegetable food products, large variations in the crop from one harvest to the next resulting from the weather conditions have to be taken into account. Deviations from an average yield of the order of 20—30% occur quite frequently in quite limited areas. Sometimes crops can be almost completely lost through unfavourable weather conditions. The most recent example is the destruction of citrus and other crops in large areas of the Mediterranean and the south-east United States as a result of the unusual frosts in January 1985. A couple of years ago not only was the coffee crop destroyed in Brazil, but also the plants themselves suffered so much from the frosts that it was several years before crops returned to the normal level. In other regions of the earth periods of drought may have similar consequences.

But even if the yield of a harvest falls only somewhat short of the expected average value, this small difference can translate into a much larger difference in the irradiation capacity required. The extension of shelf-life may be of interest for a considerably smaller portion of the already reduced harvest. Local prices of such a food product may increase to such a level that there is no incentive to export part of the crop. If irradiation is used mainly for the extension of the shelf-life of the exported quantities, the use of the installed irradiation capacity could fall to a very low level.

For food products of animal origin such unpredictable large changes from harvest to harvest are less widespread and likely. But even here a bad year may yield less than half the produce of a good year. The fish industry on the west coast of South America, particularly in Peru, has experienced such drops in the catch quite often when the intricate natural balance depending on the cold Humboldt current (Peru coastal current) is upset by strong north winds, bringing in warm water from the equator which then covers the cold water. Similar but less dramatic variations within rather short periods are seen in the catch in certain areas of the North Atlantic. Overfishing may be another reason for a sudden drop in the catch for a longer period until the fish shoals have recovered.

Political developments may also change the profitability of food irradiation plants. In the second half of the 1960s the Federal German fish industry became
very interested in irradiation for the extension of shelf-life. A petition for the irradiation of fish was presented on 28 December 1971 to the responsible Federal German authorities. In 1974, shortly before an authorization for the irradiation of limited quantities of fish for human consumption was issued, the fish industry dropped the whole irradiation project. The extension of their territorial waters by some countries excluded Federal German fishermen from a large part of their traditional areas completely or allowed them to catch only small quantities. The whole catch of the Federal German boats decreased drastically, and for the remainder from far more distant fishing grounds deep-freezing was the method of choice for extending the shelf-life. This development became apparent just before investment in the hardware for the irradiation of fish started.

Similar situations can spring up in countries interested in the irradiation of tropical and subtropical fruits for export to western Europe. The irradiation may permit delivery of higher quality products and may at the same time appear very profitable because losses during transport are substantially reduced. Nevertheless, other countries may lose a large part of the market in western Europe when Spain and Portugal join the Common Market with its trade barriers for the protection of producers in Member States of the community.

Many more examples of the special risks associated with investment in a food irradiation facility can be given:

– Epidemic animal diseases can eliminate the demand for the irradiation of meat and meat products in a certain area for some time.

– Pork irradiation for the control of *Trichinella spiralis*, as planned in the USA, may rapidly become superfluous when the same measures are taken that have practically eradicated trichinosis in Central Europe.

– Cultivation of new varieties of plants, grown under less favourable climatic conditions, may convert countries which import products from such plants to self-suppliers. Genetic engineering techniques may in the near future be able to accelerate the introduction of such new varieties of plants considerably.

– Introduction of new packaging, storage, transport and distribution techniques and procedures can substantially reduce the need for irradiation treatment at a given location and/or for a certain type of food products. In developing countries a new railway line or highway connecting a harbour or a production area with consumption centres, can diminish the transport time to such an extent that one can more or less do without an extension of the shelf-life by irradiation.

– Changes in consumer preferences, perhaps caused by the advent of new products, may cause within a couple years a strong recession in the sales of an irradiated food product. A change for the worse in the income of
a majority of the consumers may have the same effect, at least for products other than the basic staple foods needed for nutrition.

Rational investors would probably also take into account the possibility that opposition to food irradiation may arise again at some time, even if there has already been rather widespread acceptance. As the market is a very unforgiving place, a few bad lots of irradiated food, giving rise to frightening headlines in the media, may rapidly destroy confidence of the consumers and thereby jeopardize the food irradiation business. This risk aspect has to be considered very seriously when people from outside the responsible expert circles, now promoting the large-scale introduction of food irradiation, become heavily involved in the field and take over the process. The incentive to save money and to make money may pave the way occasionally to practices that lead to bad results.

Being conscious of all these types of risks, rational investors would look for a high potential return on their money to offset the potential loss in financing food irradiation facilities. In most industries five or six years are the upper time limit for the return of the money invested that is still accepted for a positive investment decision. Many industrial sectors set shorter time limits when considering the balance between the risks and benefits of an investment.

In view of the risks associated with the financing of a food irradiation facility, times for the complete return of the investment exceeding three full years of normal operation under the anticipated conditions will hardly be acceptable. Such a condition further increases the relative importance of the invested capital in all commercial deliberations and requires correspondingly larger benefits from the irradiation of a food product.

If the expenditures for the irradiation process and its benefits, for example the reduction of losses due to the extension of shelf-life, accrue in the same company, the profitability of an investment can be assessed rather easily on a sufficiently secure basis. But in most cases it will be necessary to sell the benefits produced in one company by irradiating food to somebody else.

As the requisite selling price will be much higher in commercial reality than is anticipated in most publications on the economic feasibility of radiation processing of foods, the additional question arises as to what extent customers, apart from the other aspects of acceptance, will be prepared to pay the price for food irradiation. It is general experience that especially industrial customers are reluctant to pay more for a product of higher quality as long as they feel they can continue to do good business with what they marketed in the past. Obviously thorough market research must be done before any investment is made in a food irradiation facility in order to be reasonably sure that a sufficiently large sector of the market will accept the necessary price of the radiation processing.
5. POSSIBILITIES AND STRATEGIES FOR REDUCING THE INVESTMENT RISKS AND THE SELLING PRICE OF RADIATION PROCESSING

Summing up the foregoing discussion, one can conclude that only very few applications of food irradiation will become commercially feasible in certain parts of the world and that direct or indirect action of governments in favour of radiation processing of foods will be an important prerequisite in many cases for the introduction of food irradiation.

The legal requirement of assurance, for example, that only salmonella-free chickens are sold would make their irradiation almost a necessity and the question of the acceptance of the price for the radiation processing by the market would lose its validity. In addition, investment in facilities for chicken irradiation is relatively attractive because most of the above-mentioned risks especially associated with food irradiation are not relevant to this application. As rather large irradiation capacities would be needed for chicken in many places, a rather low selling price is compatible with an adequate return on investment in this case.

Investment incentives by governments for reducing the risks of private financing of food irradiation facilities are another possibility, especially in cases where increasing food supplies by killing pests and delaying deterioration processes is a national objective.

In countries with largely centrally planned economies the government itself may be the investor in food irradiation facilities. However, very often this does not imply that it is much easier there to promote a decision for the erection of a food irradiation facility than in countries where private investors have to be found. Governments are usually confronted with a much larger number of proposals for new investments that appear profitable for the national economy than they can finance. Thus they are forced to do much the same evaluation of the profitability of an investment proposal as a private investor. Only the relative importance of criteria in the process of taking a decision may be different for governments and for private investors. On the other hand, the decision process is generally considerably protracted in government bureaucracies.

In any type of economy, however, the extent and the pace of the commercialization of food irradiation processes will largely depend on the strategy followed. The preceding discussion suggests a simple strategy which reduces the investment risks and the cost of the radiation treatment at the same time. Projects for food irradiation will usually be less viable or not successful at all if they aim at the radiation processing of only one type of food product. Reductions in the expected demand for irradiation capacity for this type of food product for one or more of the reasons described above, which are beyond the control of even the best marketing and sales management, can rapidly make the whole enterprise an irreparable failure.

The more types of food products treated in an irradiation facility, the smaller the risk of a failure because the probability decreases that the demand
for irradiation capacity is reduced for all or the majority of the processed products at the same time. If the product spectrum is large enough, it will frequently happen that a smaller demand for one type of food product is more or less compensated for by an unexpected larger demand for another type. Thus the growth of the product spectrum reduces the risks drastically.

A facility processing a larger number of different food products will have to be equipped with a higher irradiation capacity than most plants planned for only one type of product. Thus the strategy of irradiating as many types of food products as possible in one facility offers the advantage of the economy of scale, as illustrated in Fig. 2, in addition to the lower return on the invested capital, which becomes acceptable for an option with a considerably lower risk. Finally, the much lower selling price for the radiation processing of foods facilitates the commercial acceptance in the market, which again reduces the risk for the investor.

6. BGS EXPERIENCE IN RADIATION PROCESSING FOR A LARGE PRODUCT SPECTRUM

We have successfully applied this strategy of providing possibilities for the irradiation of a large product spectrum in our irradiation service. As there is at present no licence for the large-scale commercial irradiation of foods in the Federal Republic of Germany, the activities of Beta-Gamma-Service (BGS) are exclusively in other areas of radiation processing.

Though the risks typical for food irradiation do not apply to these other areas, there are other factors which make investment in radiation processing a high risk venture if the strategy chosen is not good. Many possibilities for the industrial application of the radiation cross-linking of polymers and its competitiveness with other techniques, for example, have not yet been thoroughly investigated. Uncertainties regarding the potential role of radiation cross-linked polymers among the large number of other material options cannot be removed in advance. The chances that radiation sterilization can compete with gas sterilization on a purely commercial basis largely depend on unpredictable action of the national governments regarding safety issues and environmental protection measures when ethylene oxide is used for sterilization.

Special risk factors existed for every area of radiation processing scrutinized during the planning phase for the establishment of BGS. But the overall risk of this venture became sufficiently small when we decided to provide from the very beginning irradiation services for an extremely wide spectrum of products, though this meant a considerable increase in the total investment compared with a less ambitious start.

Two electron accelerators with limited multi-purpose functions have been in operation since May 1983 and January 1984, respectively; a versatile


\(\gamma\)-irradiation facility will be commissioned in the second quarter of 1986 and a fourth facility is in the planning stage for completion by the end of 1987. Nevertheless, we are already providing irradiation services for seven different product areas. The sterilization of medical supplies, laboratory equipment, packaging materials and other requisites is just one of these seven product areas. Most of them comprise products used in many different industrial sectors and for quite different purposes.

Within this large product spectrum we experienced both disappointments and surprises during the preparatory phase for the establishment of BGS. In one case we were pretty sure of very rapidly achieving a large sales volume because of the widespread use of this application of radiation processing in the United States of America. When, however, our irradiation facilities came into operation, the corresponding industrial branch in the Federal Republic of Germany had largely solved the technical problem with support from the chemical industry in a different way. Consequently, only a small fraction of the anticipated volume remained for irradiation processing.

On the other hand, applications developed for the solution of technical problems that we had not considered as being of interest for radiation processing. A favourable selling price for the irradiation capacity, thanks to the economy of scale, makes radiation processing economically feasible for quite ordinary requisites of daily use. New developments such as the catalytic purification of exhaust gases from combustion engines require more heatproof materials in cars, which can be produced by radiation cross-linking.

As soon as the irradiation of food products is licensed BGS will offer its services in this field. In the existing facilities this will have to be limited, however, to certain types of food products. It is not difficult to conceive that both customers and authorities will be reluctant to allow the sterilization of medical supplies in the same facility in which, for example, chicken are irradiated to render them pathogen-free.

7. PREREQUISITES FOR THE IMPLEMENTATION OF MULTI-PURPOSE FOOD IRRADIATION CENTRES

In view of such limitations regarding the irradiation of food and non-food products in the same facility, it will in most cases be essential for the implementation of the strategy described above that the radiation processing of more than just one or a few food products is licensed. The past practice of item-by-item licensing has certainly hindered the large-scale commercial use of such food irradiation licences. While the non-use of existing licences in some countries has often been considered as evidence of the lack of a need for food irradiation, the unjustifiable risk for investors must be taken as decisive when the whole venture has to be based on just one or a few products.
The conclusion of the Joint FAO/IAEA/WHO Expert Committee on the Wholesomeness of Irradiated Food and the Standards for Irradiated Food, adopted by the FAO/WHO Codex Alimentarius Commission, have fortunately opened the door to general licensing for the vast majority of food products for which irradiation may be beneficial in the civilian sector. This meets the requirements for the commercial realization and the natural desire of consumers to receive the benefits of food irradiation at a reasonably low price.

The obvious advantages of food irradiation centres for the processing of a variety of foods and possibly other products are faced with one disadvantage: Their planning requires much more preparatory studies and investigation, a lot of teamwork between experts of different disciplines, and careful examination and comparison of the relative merits of special plant designs for the product spectrum envisaged. Developing countries, for which in general the commercialization of food irradiation is much more important and urgent than for most industrialized nations, may often have greater difficulty in bringing together the expert manpower and the resources for the establishment of food irradiation centres than for facilities dedicated to the irradiation of one type of product.

Therefore large tasks and obligations arise in the large-scale commercialization of food irradiation particularly for the Joint Division of FAO and IAEA which already in the past has been a strong, reliable, unperturbed defender and promoter of food irradiation. Thus it has contributed substantially to the progress now enabling us to talk seriously about the prospects and the strategies for the application of this processing technique for food products.
AN INDUSTRIAL VIEW OF COMMERCIAL FOOD IRRADIATION

G.G. GIDDINGS
ISOMEDIX Inc.,
Whippany, New Jersey,
United States of America

Abstract

AN INDUSTRIAL VIEW OF COMMERCIAL FOOD IRRADIATION.

As regulatory impediments to food irradiation are resolved and public acceptance increases, broad industrial-scale food irradiation is approaching commercial reality in the Americas, following the lead of other regions. The focus of attention is now shifting from these obstacles towards corporate strategic planning and tactical positioning, including pragmatic business considerations. For radiation processing firms previously involved primarily with the sterilization of medical devices, health care or similar products, food irradiation calls for modifications in thinking, planning and action to deal properly with a unique and specialized product category and to minimize associated risks to the company, as well as to the future of food irradiation itself, which is approaching, or is perhaps already in the most risky stage of its evolution. For established food processing/packaging firms, and even more so for growers/harvesters, shippers, and distributors of raw agricultural and fishery commodities, the challenge is to become familiar with and comfortable with what is for them a new technology, to evaluate rationally its potential utility, often in comparison with competing alternatives, and to reach sound decisions as to whether or not to adopt the technology, and if so, in what manner. Individuals, organizations and firms that are now, or intend to become involved in industrial food irradiation should make every effort at this critical juncture to assure that public and private sector ventures are solidly based on sound pre-investment screening and feasibility studies in order to minimize the risk of ill-advised, misguided placement of food irradiation facilities.

As this clean, safe, wholesome, non-residue/effluent-generating physical process proceeds to take its permanent place among the more established food processing-treatment-preservation methods, as it already has been and is assuming an increasing share of the health care and non-food industrial and consumer product sanitization/sterilization market, this process as applied to foods and their raw materials and ingredients is at perhaps the most vulnerable stage of its decades-long evolution. At this critical crossroads, successful worldwide industrialization can to a considerable extent be assured by, on the one hand, earning the acceptance, and perhaps in time, even the enthusiastic endorsement of the process, and foods so processed, by a still largely unaware, or at
best vaguely aware general public. A striking illustration of the general lack of awareness among the U.S. consuming public, for example, occurred in January of this year on a nationally televised news program of a major U.S. network, during which the moderator, a worldly and well-informed veteran national and international newsmen, on introducing a segment on food irradiation, admitted to not having previously been aware of the subject, and had difficulty pronouncing "irradiated". We who are so close to, and intimately familiar with, food irradiation should continually remind ourselves that most people are so far vaguely aware of its existence, if at all, and circumstances under which people do gain awareness can be critical to successful industrialization.

Assurance of successful worldwide industrialization of food irradiation can, on the other hand, also to a large extent depend upon parties concerned taking all possible steps to avoid the execution of misguided, ill-advised ventures by overzealous entrepreneurs and others whose desire to get into the business and ride a perceived 'wave', or, whose desire to impact positively upon the world food situation, or for whatever reason, supersedes the application of sound feasibility evaluation and prudent business practices in the private sector, or, sound economic planning and development practices in the public sector as the case may be, when it comes to food irradiation ventures or projects. Increasingly, my firm is being contacted and approached by individuals and organizations within the USA, and especially abroad, for proposals to install a food irradiation facility before they've begun to do the kind of rigorous, comprehensive feasibility or pre-capital investment study that such ventures should require. Our typical response is to offer to participate in an appropriate prefeasibility screening study, to be followed by a thorough feasibility study if warranted, prior to their making any capital investment.

While living in South America for several years, working in the agricultural-fisheries-food processing sector, this writer observed a number of cases of perfectly good technologies sitting idle and gathering 'rust-and-dust' because they were transferred to inappropriate environments for the wrong reasons by overzealous vendors and underinformed recipients. A
further problem that would arise with misplaced radioisotope plants that are idle, or that are operating at well below capacity, is that precious cobalt-60 (or cesium-137) would be decaying away while processing little or nothing, in addition to any 'rust-and-dust' accumulation. Such misplacement and misuse of valuable isotope, above all, we as an industry can ill-afford. This writer has also experienced the special satisfaction that comes with the transfer of an appropriate technology to an environment in which it truly makes a major contribution in filling a real need. Let us resolve that all future food irradiation plants end up in this category. It is not only in developing countries that we are already perceiving possibly misguided, ill-advised food irradiation ventures beginning to take shape. Evidence of same is also appearing here in North America, for example, where this technology is only now beginning to become industrialized for food processing, having long-since been industrialized for non-food processing.

How does one guard against an ill-advised project/investment of the magnitude of from, say, one to a few million U.S. dollars. Always a good starting point is to ask the question - what do I want to know and be reassured about a given project before investing my own funds heavily into it? Such a question should lead to what is variously referred to as a reconnaissance survey, opportunity screening evaluation, and the like, which, if positive, is typically followed by a pre-feasibility study and/or a rigorous technico-economic-market-financial-etc.-feasibility study in the pre-implementation phase before capital is invested. A good guide for conducting same in the context of public sector-funded projects as, for example, in centrally planned economies is the "Manual for the Preparation of Industrial Feasibility Studies" (United Nations Industrial Development Organization, Vienna, U.N. Publication Sales No. E.78.II.B.5, 1978). For ventures that would be private sector-funded, the rigor of preparing a detailed business plan and testing its "bankability" by marketing it to raise capital is usually a good test of the soundness of the venture, though no absolute guarantee of its ultimate success. The competence and credibility of those wishing to implement a proposed venture is often the best single criteria by which to judge the soundness of a proposed industrial venture, especially if the
principals have already developed a record of establishing similar successful ventures. In the absence of pursuing one or another of the foregoing pre-investment evaluations and analyses, the adage "caveat emptor" prevails, all too often to the ultimate dismay of those concerned. Let all who are dedicated to the successful industrialization of food irradiation guard against any such eventualities. The Joint FAO/IAEA Division of Isotope and Radiation Applications of Atomic Energy for Food and Agricultural Development can play a major role in this regard through promoting and sponsoring more of the project pre-investment feasibility-type studies, as needed in developing countries especially, just as it has so admirably done with national and regional research and development programs. Industrialized country assistance agencies such as the U.S. Agency for International Development and Overseas Private Investment Corporation, and the Canadian International Development Agency, can and are doing likewise, in part by providing support for feasibility studies and implementation by radiation processing firms and their local counterparts.

Whereas the Committee on Food Labeling of the WHO/FAO Codex Alimentarius of the U.N. World Food Standards Program is scheduled to convene at Ottawa immediately following the conclusion of this International Symposium to, among other matters, try to resolve the question of the prepackaged irradiated foods labeling standard, the remainder of this paper addresses, and presents one concerned individual's perspective on this most controversial of all issues connected with industrial food irradiation. The labeling matter could bear heavily on at least the near-term food irradiation industrialization potential in North America and elsewhere. While the labeling matter appears to have been positively resolved in at least one or two countries (the Netherlands and the Republic of South Africa) with the use of the "symbol" as something of a quality seal and marketing aid; to label or not to label, and if so, under what conditions and in what manner has become the most controversial and debated aspect of promulgating irradiated food regulations in the USA and Canada, and no doubt elsewhere; and, in reaching a consensus on the "Irradiated Foods" Section 5.2 of the Recommended International General Standard for the Labeling of Prepackaged Foods among the Codex Committee on Food Labeling delegations.
The issue was not resolved at the 17th session of this Committee in October, 1983, at Ottawa, largely because several delegations needed to await the results of internal reviews of the subject then underway within their respective countries in order to be able to take a formal position. In the interim, at the conclusion of the October, 1983 deliberations, Section 5.2.1 was left to read "a food which has been treated with ionizing radiation/energy shall include on the label the statement 'treated by ionizing energy'" in the context of the labeling of prepackaged, 'first generation' irradiated foods (i.e., the entire prepackaged food being what is so treated as opposed to containing previously irradiated components such as ingredients).

The labeling issue is perhaps most problematic in the USA at the present time as the new U.S. irradiated foods regulation nears finalization, and U.S. actions on such matters have tended to influence similar actions by other nations, as well as the Codex Alimentarius. Therefore, in attempting to put the entire issue into sharper focus, the U.S. irradiated foods labeling history is employed here as a case study for analysis. Following the 1958 enactment, by the Congress, of the Food Additives Amendment to the U.S. Food Law — the "Food" section of the Food, Drug, (Device) and Cosmetic Act of 1938, which classified "sources of radiation" as food additives — radiation sterilization of bacon, radiation disinfestation of wheat and wheat flour and radiation inhibition of potato sprouting were approved in 1963-64 by the U.S. Food and Drug Administration (FDA, which is empowered to implement the Act through the promulgation and enforcement of regulations). The U.S. Food Law or Statute (the Act) addresses the 'whys-and-wherefores' of labeling as well as other legal or statutory aspects; however, in approving those first few aforementioned food applications of ionizing radiation, the FDA did not at first include a labeling requirement, evidently in recognition of the fact that there is no clear statutory imperative to do so in the Act. The FDA was actively considering imposing a retail as well as a wholesale level irradiated food labeling requirement during that period; however, evidently for nonlegal, consumer-driven reasons according to testimony for the record of Robert S. Roe, Director of the then FDA Bureau of Scientific Standards and Evaluation before the Joint Congressional Committee on Atomic Energy-Subcommittee on Research, Development and
Radiation during June, 1965 Hearings on food irradiation.

Upon indicating that he felt irradiated food labeling to be a necessary thing that was under consideration, Mr. Roe was asked by a Congressman what effect he felt labeling requirements might have on the acceptability of irradiated food products, to which he replied - "I don't know. We don't want to devise a label that will simply result as a scare. It was our view, however, that labeling should be informative. We have had requests from consumer groups for more informative labeling in many items and we are sympathetic to that". This was taking place during a period in which there was considerable public clamor for labeling of chemical food additives, preservatives and ingredients. That Mr. Roe made no reference to the Act in that portion of his testimony having to do with labeling, referring only to "requests from consumer groups", indicates that the consideration of labeling after the fact of the 1963-64 approvals was solely 'consumer driven'. The first formal pronouncement of an irradiated foods labeling requirement was in connection with the additional approval of electron beam radiation disinfection of wheat and wheat flour in 1966 ("Labeling requirements for food treated by radiation: Low-dose electron beam radiation", FDA, Federal Register 31(134):9491, 1966). Radiation disinfection of wheat and flour with cobalt-60 and cesium-137 gamma radiation was approved in 1963 and 1964, respectively, without any labeling requirement, as were the bacon sterilization approvals of 1963 (cobalt-60 in February; 5 MeV electron beam in August), of 1964 (X-ray in July; cesium-137 in November), and 1965 (10 MeV electron beam), and, the potato sprout inhibition approvals of 1964 (cobalt-60 in July; cesium-137 in October) and 1965 when the maximum permitted dose was raised from 10 to 15 kilorads (U.S. Dept. of Commerce, 1966), ten approvals in all.1 Thus it was not until the eleventh successive food irradiation approval was published in the Federal Register in 1966 that a labeling requirement was included.

The following year, in a March 2, 1967 Federal Register publication, these standing irradiated food regulations were revised to include the following required labeling

\[1 \text{ rad} = 1.00 \times 10^{-2} \text{ Gy}.\]
statements: "Processed/treated by ionizing/gamma/electron/X-radiation" on retail packages, and together with the additional phrase "do not irradiate again" on wholesale packages and on invoices or bills-of-lading of bulk shipments. Although this step was, again, evidently solely in response to a perceived generalized 'consumer' desire for greater food labeling, in the 1966 and 1967 Federal Register publications a legal or statutory authority was offered; namely, that part of the "Food Additives" section of the Act having to do with specifying conditions under which (clearly chemical) food additives may be used "to insure safe use", including "any directions or other labeling or packaging requirements for such additive deemed necessary to assure the safety of such use.....The Secretary may at any time, upon his own initiative, propose the issuance of a regulation prescribing, with respect to any use of a food additive, the conditions under which such additive may be safely used, and the reasons therefor". (Federal Food, Drug and Cosmetic Act as Ammended, Chapter IV-"Food", Section 409 c & d). This rationale remains in the current, existing U.S. regulation today (Title 21-Code of Federal Regulations-Chapter I, Subchapter B - "Food for Human Consumption", Part 179 "Irradiation in the Production, Processing and Handling of Food") for those approvals remaining in effect following the 1968 radiation sterilized bacon cancellation; namely wheat and flour disinestation and potato sprout inhibition ("Human" is underlined here to call attention to the fact that although this Subchapter refers explicitly to "food for human consumption", the FDA applies Part 179 provisions to pet and laboratory animal foods and feeds as well).

However, as Dr. Edward L. Korwek, attorney with the Wash., D.C., Law Offices of Keller and Heckman correctly points out in examining legal aspects of food irradiation, with particular emphasis on the labeling question; while a case might have been made, under the operative "to assure safe use" rationale, for wholesale level labeling (and even that is no longer the case in light of present day knowledge about radiolytic products), "It is difficult in light of present knowledge, however, to understand the rationale under Section 409 for labeling at the retail level.... ." (Korwek, 1983). Clearly, one needs to assure the safe use of the actual "food additive" in this context according to the Statutory definition; namely the "source of radiation". In fact, in that section of Part 179 of the regulations
having to do with "Sources of radiation used for inspection of food, for inspection of packaged food, and for controlling food processing" (i.e., 179.21, which covers in-line, under 1000 rad irradiation for quality control purposes) labeling of the sources as to directions for installation and operation, etc., is specified "To assure safe use of these radiation sources".

But elsewhere under Part 179 pertaining to radiation processed/treated foods, it is the foods themselves that must be labeled "to assure safe use". That this never was a valid legal rationale for especially retail level labeling of irradiated foods themselves (in contrast to industrial use of chemical additives, for which assurance of safe use can be pertinent) is evidenced by the FDA position stated in 1982 as follows: "the fact that the source of radiation is legally a food additive is irrelevant to the issue of labeling. The fact that declaration of irradiation is presently required, results from a determination made during the 1960's that such material facts should be revealed. The agency is reevaluating this issue." (Takeguchi, 1983). This appears consistent with the perception of a 'consumer-driven' need for irradiated food retail labeling as indicated in Mr. Roe's mid-1965 Congressional testimony.

The question then becomes, is this need to reveal "material facts" rationale solely a 'consumer driven' one, as inferred in the above quote (i.e., "...should be revealed"), or, was it being advanced in 1982-83 as a legal or statutory requisite (in which case the operative word would be "...shall be revealed")? In his comment letter to the FDA following its Notice of Proposed Rulemaking publication in the February 14, 1984 Federal Register, attorney Korwek makes the point that although "Sections 403(2)(l) and 201(n) of the Act governing misbranding provide the statutory standards for requiring special labeling (and) under these sections a food is misbranded if it is false or misleading in any particular or if, among other things, it fails to reveal material facts with respect to the consequences that might result from use of the food, under these sections, it is difficult to conceive of a treated food being misbranded for lack of labeling of the method of processing, especially since there would not necessarily be any misrepresentation of identity, ingredients, quality or freshness." (Korwek, 1984). In the same vein, in his 1983 publication, Korwek argues that "there seems to be no precedent
that would support these readings of Sections 403 and 201 ....there is no cognizable right per se under the Act for consumers to know how foods are processed."

The Notice of Proposed Rulemaking (NPRM) that the FDA published in the February 14, 1984 Federal Register agrees in the main with the lack of a need for retail level labeling, for retail level labeling is completely omitted from the proposed new Part 179, which retains only the wholesale level labeling provision, and only for irradiated foods, ingredients, etc. "which is shipped to a food manufacturer or processor for further processing, labeling or packing...." Though no rationale is stated for retaining the wholesale level labeling requirement in this context, it seems apparent that it is intended for purposes of inventory control and avoidance of unnecessary reirradiation. In the lengthy preamble to the proposed new irradiated foods regulation, it is stated under "Labeling" that "The agency now believes that there is no need for a special label on irradiated foods because this proposal would limit the conditions of use of irradiation to those that have already been shown to be safe" (i.e., there is no "safety" or "safe use" basis for labeling). In the context of "Misbranding" it states that "The issue is whether the label of a food would mislead consumers if processing information were not set forth on the label. Material information may not be omitted simply because it concerns the type of processing to which a food is subjected if the effect is to mislead. The agency has concluded that the information about radiation processing is not material in this sense and therefore need not be provided on the label of retail foods."

If, then, the justification given for a retail labeling requirement in the existing regulation, "to assure safe use" is irrelevant, and if such information as identification of the process/treatment used is "not material" and, therefore, its absence is not misleading and, therefore, not misbranding, is there any legal grounds for arguing in favor of retail level labeling in the U.S. context? One seems to be hinted at in the February 14, 1984 Notice of Proposed Rulemaking "Labeling" discussion by such statements as "There is information that indicates that irradiation causes some alteration of the characteristics of some foods in ways that could be important to consumers....there might be changes in organoleptic properties (taste, color, smell, texture)
that could make the processed food more or less desirable to individual consumers. The available information about changes in foods that could be irradiated under this proposed regulation is limited, and FDA is not persuaded that special labeling is necessary. Moreover, processors will have a strong incentive to insure that changes in organoleptic properties are kept to an absolute minimum because consumers, upon purchase, could easily determine inferior quality and would shun the product in the future. Well, 'so-far-so-good' in that effects on eating quality (which, if any, are milder with radiation processing/treatment than with comparable processes and treatments) appears to be acknowledged as a marketability aspect and not the safety or efficacy aspects that the Food and Drug Administration is mandated by the Congress to concern itself with. If a specific application (for example, radiation pasteurization of fluid milk which was dismissed as nonviable for organoleptic change reasons by food irradiation technologists decades ago) results in objectionable eating quality changes of such a magnitude as to render the application practically ineffective, then it will not be done, or not for long if attempted, for marketability reasons. This is, therefore, no legal basis for calling for retail level labeling of all irradiated foods under the "misbranding" definition of "misbranding". Further, since the stated proposition about organoleptic changes is in a real sense itself inaccurate and misleading, it is not an 'ethical' basis either.

Further on in the Notice of Proposed Rulemaking "Labeling" discussion four questions regarding labeling are posed for comments, which provided the substance of a "Dear Consumer" polling letter, dated February 28, 1984, which was sent out to individuals and groups across the country from the Office of the FDA Associate Commissioner for Consumer Affairs.

The real question that is posed, and upon which insertion of a retail level labeling requirement could be decided with the aid of a stilted 'ballot', can be restated as follows: Would consumers be more misled by the presence of a labeling statement such as "treated with ionizing radiation" or "processed with ionizing energy" intended to warn or alert the consumer as to possible objectionable changes in organoleptic properties, but which could be misinterpreted as a warning or alert as to a possible health or safety risk, or would the consumer be more misled by the
absence of any such statement, and thus no warning or alert as to possible undesirable organoleptic change(s) that might "be important to the individual consumer?" Attorney Korwek (1984) discusses the lack of a legal basis for this regulatory approach to deciding the retail level labeling issue, for changes in organoleptic properties are not even implied under the "misbranded food" provisions of the Act. This "organoleptic changes" proposition is technically groundless as well for, again, this writer can conceive of no viable or efficacious food irradiation application which, properly done under well established procedures (i.e., good manufacturing/irradiation practices, which are not regulated through labeling), would give rise to organoleptic changes such as to warrant a label warning or alert. On the contrary, one of the attractive features of this process/treatment is that it causes so little change, if any, in foods compared with alternative or competing processes/treatments. One could cite any number of examples of this point.

Although the Notice of Proposed Rulemaking did not include any retail labeling requirement, some four months before it was published in the February 14, 1984 Federal Register, and around the time of the last Codex Food Labeling Committee meeting, the October 17, 1983 issue of Food Chemical News (p.2, published weekly by Food Chemical News, Inc., Washington DC) stated that "The FDA has decided that labeling of (irradiated) retail food products should be included to make consumers aware that the food has been processed by a method they may find objectionable. The label statement 'treated with ionizing radiation' is expected to be required to appear prominently on the retail labels of irradiated food, under the proposed regulation, which is expected to be published soon. The agency is expected to issue a press release when the proposal appears in the Federal Register, and to recommend that industry embark on a public education campaign to dispel consumer fears of the process." The concern at the moment is that the U.S. industry could yet become burdened with what would appear to be a rather arbitrary imposition of a nebulous and easily misinterpreted retail labeling statement, and the international community as well, before "public education campaigns to dispel consumer fears of the process" have had a chance to proceed, and to likely render the retail
labeling question moot. In fact, such a retail labeling statement is virtually meaningless in the absence of the kind of public awareness-consumer education efforts that would likely render one unnecessary; one that is by itself open to misinterpretation on the one hand and noninformative in the true sense of what the consumer needs to and should know on the other. The often expressed appeal "the consumers right/need to know and make a choice", typically grounded in misunderstanding, confusion and fear of and about the process is really a call for information that will lead to understanding and acceptance of the process as applied to foods, that a nebulous and misleading labeling statement cannot provide. No one associated with the process would deny the consumers need to come to know about and understand the process, including the facts that it is safer and more effective than traditional chemical treatments, milder towards nutrient content (e.g., vitamins) and eating quality attributes ("organoleptic properties") than certain comparable processes and treatments, and probably more economical as well in certain instances, and, capable of potentially improving the general public health through the eradication of pathogens and parasites that cause food-borne illnesses and intoxications from foods as well as feeds. This is much different than the "consumers right/need to know" merely the fact of the use of the process through a potentially misleading, nebulous labeling statement (i.e., "processed/treated with ionizing radiation/energy").

There is a typically overlooked side to this matter where the legal or statutory 'rights' proposition could apply without a very strained interpretation of the Act, and where a convincing ethical rights argument can most certainly be made; namely, producer or industry 'rights'. From the legal standpoint, there may be legal precedent for not allowing a regulatory requirement for a nebulous, potentially misleading labeling burden, that in and of itself would serve no truly useful purpose, to be imposed on industry. If there is no legal precedent for not doing so, then this case could offer an excellent candidate for setting such a precedent. The November 15, 1982 issue of Food Chemical News quotes Dr. Sanford Miller, Director of the FDA Center for Food Safety and Applied Nutrition as predicting significant changes in food labeling during the "next five years" (i.e., 1983-87), stating that "There will be changes in the way the label is
laid out and what FDA insists is on it. Labels are enormously cluttered now, and much of the information is of no value to the consumer'. Yet the poorly informed 'person-in-the-street' (or 'in-the-supermarket'; as in recent U.S. television news segments), when asked, mistakenly regards the label as the medium through which to become informed and educated about food irradiation, or warned so as to avoid some nonexistent perceived risk. The better informed and well-intended but negatively biased 'consumer interests advocate', and, the self-serving antagonist appeal or clamor for a retail labeling statement because of lingering concerns about safety despite authoritative assurances in the first instance (i.e., for risk avoidance purposes), and/or to further confound and impede the regulation and industrialization in the latter instance. The latter go to almost any lengths to have the public believe that there are all kinds of as yet unresolved safety questions, and even credible evidence of health risk when the opposite is the case. The preposterous suggestion was recently made that retail level labeling is needed because "if the foods are labeled, it will be possible in the future to conduct epidemiologic studies, based upon personal interviews, of the possible harmful effects of stable radiolytic products in the labeled foods. Irradiated products should be labeled in large type (16 point capitals or larger) in a color which contrasts clearly with the background color. Optimal labeling would simply specify 'IRRADIATED'. All retailers of food, both grocery stores and restaurants, should be required to display a similar legend on or adjacent to the product which has been irradiated" (Food Chemical News, 10/22/84, p. 16, quoting from a comment letter by a U. of California professor). Even if retail labeling could make possible such an out-of-the-question epidemiological study, which it cannot, a main conclusion of a massive quantitative study of radiolytic and thermo­lytic products in several radiation and heat sterilized meat and poultry items, that "there are no unique radiolytic products" even at doses nearly one hundred times what the FDA is proposing to permit (Radiolysis Products in Radiation Sterilized Bacon, Beef, Chicken, Ham and Pork, Final Report, Dr. Charles Merritt, Jr., Principal Investigator, Science and Advanced Technology Laboratory, U.S., Army Natick Research & Development Laboratories) renders the proposition groundless.
Earlier this year, a radical fringe network in the USA initiated an attempt to seize upon the irradiated food retail labeling 'issue' to call attention to itself and attract funds. Calling itself the "Coalition to Stop Food Irradiation," (CSFI), the San Francisco-based upstart puts out perhaps the most bizarre and 'zany' misinformation yet on the subject, stating in an advertisement in the February-March issue of MOTHER JONES magazine - "CSFI proposed local labeling legislation, and sample labels for both irradiated "food" and nonirradiated foods....Our collective activities to stop the irradiation of food will benefit all of us....Your support will help us launch the Coalition to Stop Food Irradiation". Is this confusion, fear and caprice-punctuated atmosphere surrounding the irradiated foods labeling matter justification for imposing some nebulous, misleading retail label statement that is contrary to the statutes, reason and common sense, upon the private sector, which hopefully still has some 'rights' too. Or is it, as attorney Korwek also emphasized, symptomatic of the fact that the kind of public awareness-consumer education effort now being gotten underway by the recently formed, Washington, DC-based "Coalition for Food Irradiation", which is composed of a cross section of established, reputable and responsible food and allied industry trade organizations and firms, (and hopefully eventually responsible consumer interest organizations) has not yet had time to take effect and offset the false and misleading information that the public has been exposed to, especially during the past year? If reason and common sense, as well as regulatory fairness and even-handedness are to prevail, it seems to this writer that in the USA at least, since the current proposed regulation excludes any conceivable packaged food with the possible exception of retail spice and seasoning packs, the government must not rush into an ill-advised requirement for a retail level label statement for all of the wrong reasons. Rather the proposed regulation should be finalized as it is, without a retail level label requirement for the correct reasons. In this manner, public awareness-consumer education efforts can proceed and accomplish their intended tasks, the public dialog can continue, and by the time prepackaged irradiated food applications are up for approval in the USA, the retail level labeling 'issue' may well have turned around to the point that it has faded away as a nonissue, and factual voluntary promotional retail labeling may have
become of interest to industry, as recent professional consumer attitude studies and surveys in North America are tending to indicate. The alternative is to take the line of least resistance and to capitulate to temporary confusion, fear and caprice.

BIBLIOGRAPHY


COMMERCIAL DEVELOPMENTS:
PROGRAMMING AND FINANCING

(Session VII)

Chairman

H. GLUBRECHT
Federal Republic of Germany
IRRADIATION OF DRIED FRUITS AND NUTS

R.K. SWITZER
CH2M HILL,
Albuquerque, New Mexico,
United States of America

Abstract

IRRADIATION OF DRIED FRUITS AND NUTS.

The United States Department of Energy's Byproducts Utilization Program seeks to develop beneficial uses for nuclear waste materials. One potential application is the irradiation of dried fruits and nuts using caesium-137 for insect disinfestation. Irradiation is being investigated as an alternative to the current practice of fumigation, principally with methyl bromide. A programme developed by the United States Department of Agriculture (USDA), the United States Department of Energy (DOE), and CH2M Hill Consulting Engineers to determine the feasibility of this application is described. Elements of the feasibility study include efficacy, organoleptics, engineering/economics, and consumer acceptance.

INTRODUCTION

This research program is supported through the U.S. Department of Energy Byproducts Utilization Program. The U.S. Department of Energy, as part of its military production activities, has generated substantial amounts of radioactive byproduct materials. Because some of these materials decay with emission of a useful gamma ray and have a relatively long half-life, some byproducts have potential value as a radiation source.

The goal of DOE's Byproducts Utilization Program (BUP) is to identify ways in which these radioactive byproducts can be used beneficially and encourage the commercial development and application of technology that makes use of these isotopes. The four elements of the program used to promote this technology are:

- identification of potential applications
- determination of user requirements
- systems analysis
- technology transfer.

Research has shown irradiation to be effective as a quarantine or disinfestation treatment to rid a commodity of...
pests and as a preservation technique to retard or eliminate microbial food spoilage. The objective of this research program is to determine the feasibility of irradiating dried fruits and nuts for insect disinfestation.

For a project to be feasible, it must pass five tests. The test of technical feasibility is passed if the proposed project is physically capable of performing its intended function. The project is economically feasible if the benefits resulting from it exceed the costs and there is no cheaper method of accomplishing similar results. The test of financial feasibility is passed if sufficient funds can be raised to pay for project construction and operating costs. The project is politically feasible if the required regulatory approvals can be secured. Finally, the test of social feasibility is passed if the potential users (consumers) respond favorably to the product. These tests of feasibility are interrelated in many ways, but each must be passed individually if a project is to be successful.

In the first phase of this project, primary consideration has been given to the technical and economic feasibility of irradiating dried fruits and nuts for insect disinfestation. Consideration will be given to the financial, political, and social feasibility in the second phase of the project.

THE DRIED FRUIT AND NUT INDUSTRY

This study is concerned with the production of almonds, raisins, prunes, and walnuts in the State of California. California represents most of the United States production of these commodities, which are representative of the physical and chemical properties of most nuts and dried fruits.

Production estimates for these commodities are shown in Table I. Greater than 1 million tons are produced each year with peak-season deliveries approaching 24,000 tons per day.

Dried fruits and nuts are commonly infested by several insect species. Therefore, these commodities are fumigated after harvest once or several times to control these insects. The insects being considered in this study include the codling moth (Cydia pomonella), navel orangeworm (Amyelois transitella), Indianmeal moth (Plodia interpunctella), and one species of dried fruit beetle. Table II shows which of the four commodities are infested by these insects.

The current methods for insect disinfestation used by the dried fruit and nut industry primarily involve fumigation with either methyl bromide or phostoxin. Table III shows that methyl
TABLE I. TREE-NUTS AND DRY FRUIT PRODUCTION ESTIMATES

<table>
<thead>
<tr>
<th>Commodity</th>
<th>Annual total production (tons)</th>
<th>Tons/day at peak</th>
</tr>
</thead>
<tbody>
<tr>
<td>Almonds</td>
<td>350,000</td>
<td>8,000</td>
</tr>
<tr>
<td>Raisins</td>
<td>300,000</td>
<td>8,000</td>
</tr>
<tr>
<td>Prunes</td>
<td>150,000</td>
<td>4,000</td>
</tr>
<tr>
<td>Walnuts</td>
<td>225,000</td>
<td>4,000</td>
</tr>
<tr>
<td>TOTAL</td>
<td>1,025,000</td>
<td>24,000</td>
</tr>
</tbody>
</table>

Peaks => September through November.

TABLE II. INFESTATION OF STORED COMMODITIES

<table>
<thead>
<tr>
<th>Insect</th>
<th>Almonds</th>
<th>Raisins</th>
<th>Prunes</th>
<th>Walnuts</th>
</tr>
</thead>
<tbody>
<tr>
<td>Codling moth</td>
<td></td>
<td></td>
<td></td>
<td>x</td>
</tr>
<tr>
<td>Navel orange worm</td>
<td>x</td>
<td></td>
<td></td>
<td>x</td>
</tr>
<tr>
<td>Indian meal moth</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>Dried fruit beetle</td>
<td>x</td>
<td></td>
<td></td>
<td>x</td>
</tr>
</tbody>
</table>

bromide and phostoxin are used regularly in processing almonds and raisins. Prunes, on the other hand, are treated only with methyl bromide as a common practice, but could be treated with phostoxin if necessary. Walnuts are treated with methyl bromide as a standard practice and could be treated with phostoxin if sufficient treatment time is available. (Phostoxin treatment is too slow to meet the early market for walnuts.) Table III also indicates that a maximum of three methyl bromide treatments is allowed for almonds and walnuts to ensure that bromide residuals are low enough to meet export requirements.

The current fumigation practices have existing or may have future limitations with their continued use. Methyl bromide requires high doses and a long exposure time for some pests; it poses a hazard to human health in that death may result from pulmonary edema when exposed; and there is a great
TABLE III. CURRENT TREATMENT METHODS

<table>
<thead>
<tr>
<th>Commodity</th>
<th>Methyl bromide</th>
<th>Phostoxin</th>
</tr>
</thead>
<tbody>
<tr>
<td>Almonds</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>Raisins</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>Prunes</td>
<td>x</td>
<td>Ok</td>
</tr>
<tr>
<td>Walnuts</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Early Market</td>
<td>xa</td>
<td></td>
</tr>
<tr>
<td>Other</td>
<td>xa</td>
<td>Ok</td>
</tr>
</tbody>
</table>

*a Max. three treatments with methyl bromide for export.

detail of controversy within the scientific community regarding its carcinogenicity. In addition, the use of methyl bromide may be restricted or even phased out. Several government sources have indicated that methyl bromide is probably, at best, a short-term alternative and the Environmental Protection Agency is carefully reevaluating its future. Phostoxin requires a long exposure time; the dose and concentration are difficult to control; it is highly toxic although there is no evidence of carcinogenicity; and it is expensive.

The potential ban of methyl bromide and other fumigants provides a significant incentive for the dried fruit and nut industry to seek alternative disinestation methods. In the event that methyl bromide is not banned, the industry is also interested in ways to reduce the levels of residual bromide in the final product. For these reasons, the industry is evaluating irradiation technology as one of the alternative treatments.

The benefits of irradiation processing to the dried fruit and nut industry are that it provides instantaneous treatment; it provides effective treatment; there is no "residual"; there is no known insect resistance to the process; and there is a history of safe operation of irradiation processing facilities.

PROGRAM DESIGN

There are several elements that define the overall research program. These include efficacy, organoleptics, engineering, economics, and consumer acceptance.

The efficacy work is being conducted because irradiation technology is a commodity-specific and insect-specific process.
This work is being conducted by the U.S. Department of Agriculture Agricultural Research Service in Fresno, California, and Yakima, Washington. Efficacy at doses of 0, 150, 300, 600, and 900 Gy (0, 15, 30, 60, 90 krad) is being determined using artificially and naturally infested commodities. The questions of interest include the doses required to kill the insects immediately, those required to stop insect feeding, and those required to prevent growth and reproduction of insects.

The organoleptic evaluations are being conducted by the Department of Food Science at Oregon State University, Corvallis, Oregon. There is a possibility that irradiation could initiate free-radical reactions and that oxidation, especially oxidation of lipids, could produce off-flavors and odors. Taste panel testing is being conducted on the commodities with level of irradiation treatment and length of storage as variables. For each length of storage, the panel is given a "labeled" control, a "blind" control, and samples treated at the four levels of radiation. The panel members are asked to rate the unidentified treated samples versus the "labeled" control and indicate any difference in the samples as well as preferences.

The engineering and economic components of this study are intimately interrelated. The objective is to evaluate several scenarios that are practical, realistic, and acceptable to the industry. For this study, it is assumed that fumigants have been banned and that irradiation can be used in combination with other nonirradiation alternatives such as heat, refrigeration, and modified atmospheres. The factors being considered are the supply structure; domestic and export markets; potential engineering concepts for irradiators; trade-offs between facility costs and transportation costs; potential numbers, sizes, and locations of irradiators; supplementary demand for irradiation facilities by industries other than dried fruits and nuts; estimates of costs and benefits of implementing this technology; and a comparison of this cost/benefit with alternative disinfestation treatments. This work is being conducted by the U.S. Department of Agriculture Economic Research Service, Riverside, California, with the support of CH2M HILL Consulting Engineers, Albuquerque, New Mexico.

Activities in efficacy, organoleptics, engineering and economics have been ongoing for approximately one year. A significant factor in achieving the objectives in these areas has been the support, guidance, and active participation of industry leaders in this program since its inception. In planning this program, it was decided not to initiate consumer acceptance studies until after the results in these other areas indicated the likely success of implementing the technology.
SUMMARY

The purpose of this discussion has been to outline the problem facing the dried fruit and nut industry and to describe the approach developed by the USDA and DOE to evaluate irradiation as one solution. The results of work-to-date are preliminary and will be reported in the literature by the principal investigator of each activity when the work is complete.

The irradiation initiatives being pursued by the BUP underscore DOE's view that byproducts may indeed be productively utilized in industry. However, the potential can only be realized if clear technical, economic, or social advantages exist in the absence of insurmountable disadvantages for industry to adopt this technology on a widespread scale. DOE's Byproducts Utilization Program hopes to develop some of these advantages for using irradiation technology and to overcome some of the barriers that currently exist.
RESEARCH AND DEVELOPMENT OF FOOD IRRADIATION IN SHANGHAI, CHINA

Zhicheng XU
Shanghai Institute of Nuclear Research,
Academia Sinica,
Shanghai, China

Presented by Yin Dai

Abstract

RESEARCH AND DEVELOPMENT OF FOOD IRRADIATION IN SHANGHAI, CHINA.

Research and development of food irradiation in Shanghai have been listed as key projects by the Academia Sinica and the Shanghai Commission of Science and Technology. The Shanghai Irradiation Center (SIC), run by the Shanghai Institute of Nuclear Research (SINR), is scheduled to be operational by the end of 1985. A large number of preliminary studies in connection with this project are in progress. This project contains 25 research subjects. Ten institutes and corporations have been co-operating in this research. Research into food irradiation has included designing a commercial irradiation facility to suit various purposes, the technology of food irradiation (fruits and vegetables), studies of the wholesomeness of irradiated food, dose and dosimetry, and the mechanism of food irradiation, etc. The centre will have a $5 \times 10^5$ Ci cobalt-60 source; the initial loading will be a $2 \times 10^5$ Ci cobalt-60 source. The centre is mainly concerned with pilot-scale development and production and scientific research into food irradiation processing of fresh fruits and vegetables, together with the irradiation sterilization of medicine and medical supplies, the radiation modification of macromolecular materials, etc. The irradiation facility is designed to have a productivity of 20 t/h (potatoes), a radiation utilization ratio of 18.6% and a dose uniformity of 1.6. After the establishment of the Shanghai Irradiation Center, its formal processing ability will be 35,000 t/a of vegetables (potatoes, onions, garlic, etc.) or 2000–3000 t/a of fruits.

Food irradiation processing plays an important role in the peaceful uses of atomic energy. Research into food irradiation has been conducted for over three decades and the efficacy of a number of applications is well established, including the inhibition of the growth and maturation of fresh fruits and vegetables, microbial disinfection of spices and dry condiments, pathogen decontamination of frozen food of animal origin, control of insect infestation of food, and reduction of the number of microorganisms that spoil food. Above all, two major advances in food irradiation were achieved in 1980, when the Joint FAO/IAEA/WHO Expert Committee on the Wholesomeness of Irradiated Food (JEFCFI) recommended the acceptability of food irradiated up to an overall average dose of 10 kGy, and in 1983, when the Codex Alimentarius Commission adopted the Codex's General Standard for Irradiated Foods. These achievements have greatly promoted the commercialization of irradiated foods for human consumption. Therefore,
techniques of food irradiation are developing rapidly and have wide application at present. Research and development of food irradiation in Shanghai have been listed as key projects by the Academia Sinica and the Shanghai Commission of Science and Technology. The Shanghai Irradiation Center (SIC), run by the Shanghai Institute of Nuclear Research, Academia Sinica (SINRAR), is scheduled to be operational by the end of 1985. An economic gain is expected to be achieved. A large number of preliminary studies in connection with this project are in progress. This project comprises research into 25 subjects. Ten institutes and corporations co-operated in this research.

Research and development work in food irradiation in Shanghai includes the following:

(1) Design of a commercial irradiation facility for various purposes. This project includes studies of the technological design of a commercial irradiator, the physical design of a \( \gamma \)-irradiator, research into transmission system design and facility design of the irradiation source, microprocessing computer application, and the study of dose distribution throughout the product, etc.

(2) Technological research into the irradiation of fruits and vegetables. The key point of the research will be low-dose irradiation of various fresh fruits and vegetables, such as apples, strawberries, cauliflower, carrots, green peppers, winter bamboo shoots, red bayberries, etc. The aim is to minimize post-harvest losses, to control significant agricultural pests, to eliminate parasites and pathogens from food, to extend the shelf-life of fruits and vegetables, and to reduce microbial infections in dry vegetables (spices) and nuts. Optimal technological and irradiation processing conditions, and pilot-scale research on potato, onion, garlic, etc. have been performed.

(3) Studies of the wholesomeness of irradiated food. To clarify the wholesomeness of irradiated foods, nutrients, microorganisms, trace elements, and toxicology, etc., have been studied.

(4) Dose and dosimetry research. New methods for the determination of the dose absorbed by the food itself and dosimetry, and dose standardization have been studied.

(5) Research into the mechanism of food irradiation. This includes studies of radiation-induced intermediate and final chemical products and studies into the mechanism of plant physiology.

The Academia Sinica and the Shanghai Commission of Science and Technology have decided to build a radiation centre with a \( 5 \times 10^5 \) Ci cobalt-60 source in Shanghai. The centre is mainly concerned with pilot-scale production and developmental research into the irradiation of fresh fruits and vegetables, together with the irradiation sterilization of medicine and medical supplies, the radiation modification of macromolecular materials, etc.
The design and construction of the irradiation centre was undertaken by the Shanghai Institute of Nuclear Research, Academia Sinica.

The features of the centre are as follows:

(1) The centre is multi-purpose, but will chiefly be used for food irradiation preservation of vegetables and fruits. The initial loading will be $2.0 \times 10^5$ Ci; the target design can be reached later.

(2) Double source plaques and five passes have been adopted, so that it is advantageous to raise the utilization efficiency of the source and to simplify the mechanical structure. We are still considering the geometry of the irradiation field, and replacement and supplement of the $^{60}$Co source.

(3) A hanging chain conveyer with an accumulative loading style has been adopted for the transmission of the irradiation product. The overall technological arrangement is so designed that personnel and freight ducts are separated. The speed of the transmission chain ranges from 0.2 to 10 m/min.

(4) To ensure safety and reliability, standard electrical equipment and instruments have been adopted in the control and monitoring systems. At the same time we are still considering how to apply a microprocessor to the irradiation facility so that a higher level of automation can be achieved.

(5) The radiation source is stored in a water well. The design of the labyrinth has been improved. The ozone concentration in the radiation room should not exceed 0.3 mg/m³.

(6) Semi-mechanized equipment has been adopted for loading and unloading.

(7) The expected targets of the irradiation facility are as follows:

<table>
<thead>
<tr>
<th>Productivity</th>
<th>20 t/h (potatoes)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Radiation utilization ratio</td>
<td>18.6%</td>
</tr>
<tr>
<td>Dose uniformity</td>
<td>1.6</td>
</tr>
</tbody>
</table>

After the establishment of the Shanghai Irradiation Center, its formal processing ability will attain 35 000 t/a of vegetables (potatoes, onions, garlic, etc.) or 2000—3000 t/a of fruits.

Recently irradiation technology has been applied in the preservation of apples, strawberries and fresh and dry vegetables. Some results of these studies are as follows. The best irradiation dose to apples has been determined, and within this range, the storage period of irradiated apples can be extended to about 9 months. Irradiation inhibits the growth and maturation of apples, without significantly changing their hardness, water content, flavour, smell and appearance. The nutrients, including vitamins C, B₁, and B₂, amino acids and saccharides, etc., are not affected by irradiation. Furthermore, irradiating potatoes, onions, garlic, logan, red bayberries, oranges, cauliflower, carrots, green peppers and winter bamboo shoots has shown to prevent sprouting, decay, etc. Most of the research achieved the anticipated results. Animal feeding tests have shown no carcinogenic mutations or other harmful effects from irradiated diets.
APPLICABILITY OF FOOD IRRADIATION TECHNIQUES TO FOOD PRESERVATION IN DEVELOPING COUNTRIES

A.O. OLORUNDA
Department of Food Technology,
Faculty of Technology,
University of Ibadan,
Ibadan, Nigeria

Abstract

APPLICABILITY OF FOOD IRRADIATION TECHNIQUES TO FOOD PRESERVATION IN DEVELOPING COUNTRIES.

Collaborative studies with the International Facility for Food Irradiation Technology, Wageningen, Netherlands, have demonstrated that gamma radiation could be effective in: (1) Reduction of microbial contamination of Nigerian ground red pepper with a dose of not more than 5 kGy; (2) Sprout inhibition and extension of shelf-life of Nigerian onion cultivar Sokoto pink with a dose of 0.05 kGy; and (3) Prevention of mould during high humidity storage of Nigerian cowpeas (Ife Brown), with a dose of 4 kGy. Moving from this technical feasibility stage to the stage leading to commercialization may, however, pose some problems in Nigeria in view of the prevailing production and marketing patterns of these commodities. Hypothetical frameworks within which these problems could be overcome have been proposed and their possible implications for the current methods of processing, storage and distribution of these commodities in Nigeria and other developing countries with similar problems are discussed.

The bulk of the staple food, namely roots and tubers, fruits and vegetables, cereals and pulses, in many developing countries is produced by small-scale peasant farmers.

Production of these foods is seasonal and produce must be stored to meet requirements during the off-season. However, because of the prevailing climatic conditions in most developing countries within the humid tropics, together with the high incidence of pests and diseases, post-harvest losses experienced between the farm gate and the consumer’s table are very high [1] and could assume considerable economic and social importance in these countries. Several reports [1—8] put these losses at anything ranging from 10 to 80%, depending on the commodity, the location, and the time these losses were estimated. It is, however, interesting to note that most developing countries have now recognized that one of the major problems that needs attention in their drive towards self-sufficiency in food supply is not necessarily increased food production but rather ensuring that what is produced is conserved both in qualitative and quantitative terms. Scientific endeavour including the use of food irradiation techniques to reduce post-harvest
### TABLE I. FARMER POPULATION AND ARABLE LAND IN NIGERIA

<table>
<thead>
<tr>
<th>Location</th>
<th>Population density per km² (1980)</th>
<th>Farmer population (million)</th>
<th>Arable land (Mha)</th>
<th>Arable land per farmer (ha)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Anambra</td>
<td>401</td>
<td>0.608</td>
<td>0.723</td>
<td>1.189</td>
</tr>
<tr>
<td>2. Bauchi</td>
<td>233</td>
<td>0.660</td>
<td>1.350</td>
<td>2.045</td>
</tr>
<tr>
<td>3. Bendel</td>
<td>164</td>
<td>0.618</td>
<td>1.798</td>
<td>2.909</td>
</tr>
<tr>
<td>4. Benue</td>
<td>230</td>
<td>0.699</td>
<td>1.446</td>
<td>2.069</td>
</tr>
<tr>
<td>5. Borno</td>
<td>429</td>
<td>0.755</td>
<td>0.839</td>
<td>1.111</td>
</tr>
<tr>
<td>6. Cross River</td>
<td>340</td>
<td>0.961</td>
<td>1.346</td>
<td>1.401</td>
</tr>
<tr>
<td>7. Gongola</td>
<td>194</td>
<td>0.420</td>
<td>1.029</td>
<td>2.450</td>
</tr>
<tr>
<td>8. Imo</td>
<td>960</td>
<td>1.323</td>
<td>0.657</td>
<td>0.497</td>
</tr>
<tr>
<td>9. Kaduna</td>
<td>158</td>
<td>1.084</td>
<td>3.266</td>
<td>3.013</td>
</tr>
<tr>
<td>10. Kano</td>
<td>363</td>
<td>1.528</td>
<td>2.004</td>
<td>1.312</td>
</tr>
<tr>
<td>11. Kwara</td>
<td>58</td>
<td>0.424</td>
<td>3.455</td>
<td>8.149</td>
</tr>
<tr>
<td>12. Lagos</td>
<td>843</td>
<td>0.292</td>
<td>0.166</td>
<td>0.568</td>
</tr>
<tr>
<td>13. Niger</td>
<td>280</td>
<td>0.768</td>
<td>1.306</td>
<td>1.701</td>
</tr>
<tr>
<td>14. Ogun</td>
<td>178</td>
<td>0.384</td>
<td>1.024</td>
<td>2.667</td>
</tr>
<tr>
<td>15. Ondo</td>
<td>317</td>
<td>0.722</td>
<td>1.167</td>
<td>1.616</td>
</tr>
<tr>
<td>16. Oyo</td>
<td>495</td>
<td>1.378</td>
<td>1.325</td>
<td>0.962</td>
</tr>
<tr>
<td>17. Plateau</td>
<td>110</td>
<td>0.362</td>
<td>1.566</td>
<td>4.326</td>
</tr>
<tr>
<td>18. Rivers</td>
<td>231</td>
<td>0.409</td>
<td>0.844</td>
<td>2.064</td>
</tr>
<tr>
<td>19. Sokoto</td>
<td>111</td>
<td>0.362</td>
<td>1.551</td>
<td>4.285</td>
</tr>
</tbody>
</table>

*Source: Ref. [12].*

Food losses is now recognized in many of these countries and some of them including Nigeria have already established the technical feasibility for extending the shelf-life of most of their staple foods through the application of science and technology [1, 6–8, 9–11]. Moving from this technical feasibility stage to the stage that would lead to commercialization may, however, pose some problems in view of the production and post-harvest systems in these countries.

**ANALYSIS OF THE SITUATION: PRODUCTION AND POST-HARVEST HANDLING PATTERN IN NIGERIA**

The estimated farmer population per arable land, size of farm holding, and the output of modern versus rural holdings in Nigeria have been reported [12],
### TABLE II. ESTIMATED SIZE OF FARM HOLDINGS IN NIGERIA (1975/76)

<table>
<thead>
<tr>
<th>Commodities</th>
<th>Area of farm holdings (Mha)</th>
<th>Average size of farm per farmer (ha)</th>
<th>Size of farm as percentage of average arable land available per farmer</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Maize</td>
<td>0.971</td>
<td>0.072</td>
<td>1.31</td>
</tr>
<tr>
<td>2. Millet</td>
<td>5.478</td>
<td>0.407</td>
<td>7.39</td>
</tr>
<tr>
<td>3. Sorghum</td>
<td>5.721</td>
<td>0.426</td>
<td>7.73</td>
</tr>
<tr>
<td>4. Rice</td>
<td>0.261</td>
<td>0.019</td>
<td>0.34</td>
</tr>
<tr>
<td>5. Cassava</td>
<td>0.331</td>
<td>0.025</td>
<td>0.45</td>
</tr>
<tr>
<td>6. Potatoes</td>
<td>0.040</td>
<td>0.002</td>
<td>0.04</td>
</tr>
<tr>
<td>7. Yams</td>
<td>0.776</td>
<td>0.058</td>
<td>1.05</td>
</tr>
<tr>
<td>8. Cocoyams</td>
<td>0.113</td>
<td>0.008</td>
<td>0.15</td>
</tr>
<tr>
<td>9. Plantains</td>
<td>0.302</td>
<td>0.022</td>
<td>0.40</td>
</tr>
<tr>
<td>10. Groundnuts</td>
<td>1.472</td>
<td>0.110</td>
<td>2.00</td>
</tr>
<tr>
<td>11. Cowpeas</td>
<td>3.035</td>
<td>0.226</td>
<td>4.11</td>
</tr>
<tr>
<td>12. Soyabean</td>
<td>0.005</td>
<td>++</td>
<td>++</td>
</tr>
<tr>
<td>13. Benniseed</td>
<td>0.043</td>
<td>0.003</td>
<td>0.05</td>
</tr>
<tr>
<td>14. Melonseed</td>
<td>0.236</td>
<td>0.018</td>
<td>0.33</td>
</tr>
<tr>
<td>15. Vegetables</td>
<td>0.263</td>
<td>0.020</td>
<td>0.36</td>
</tr>
<tr>
<td>16. Tomatoes</td>
<td>0.023</td>
<td>0.001</td>
<td>0.02</td>
</tr>
<tr>
<td>17. Fruits</td>
<td>0.013</td>
<td>0.005</td>
<td>0.09</td>
</tr>
</tbody>
</table>

*Source:* Ref.[12].

*Note:* ++ = negligible or insignificant.

see Tables I—III. From these tables it can be seen that production of most of the staple food in Nigeria is in the hands of small-scale farmers with small holdings and as a result their production level is generally low. Because of this low level of production, improved systems of food conservation have not proved to be economically feasible, just as the absence of adequate systems of conservation has not effectively stimulated production.

The machinery of food distribution comprises three distinct systems, which are summarized in Fig.1. Storage losses resulting from physical, physiological and pathological factors are high in the post-harvest distribution system [3, 6, 8]. Theoretically, storage can be undertaken at three points in the distribution system: (i) at the farm gate, (ii) at the wholesale, and (iii) at the retail level. In practice, it is at the second and third stages that storage is undertaken in any
TABLE III. OUTPUT OF MODERN AND RURAL FARM HOLDINGS IN NIGERIA

<table>
<thead>
<tr>
<th>Crop</th>
<th>Total farm output (Mt)</th>
<th>Output of modern holdings(^a) (kt)</th>
<th>Output of modern holdings as percentage of total output</th>
<th>Residual output of rural holdings as percentage of total output(^b)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Maize</td>
<td>0.528</td>
<td>3.90</td>
<td>0.74</td>
<td>99.26</td>
</tr>
<tr>
<td>2. Millet</td>
<td>5.554</td>
<td>1.70</td>
<td>0.03</td>
<td>99.97</td>
</tr>
<tr>
<td>3. Sorghum</td>
<td>4.738</td>
<td>2.20</td>
<td>0.05</td>
<td>99.95</td>
</tr>
<tr>
<td>4. Rice</td>
<td>0.525</td>
<td>7.20</td>
<td>1.37</td>
<td>98.63</td>
</tr>
<tr>
<td>5. Cassava</td>
<td>3.582</td>
<td>20.70</td>
<td>0.57</td>
<td>99.43</td>
</tr>
<tr>
<td>6. Yams</td>
<td>7.160</td>
<td>5.20</td>
<td>0.07</td>
<td>99.93</td>
</tr>
<tr>
<td>7. Cocoyams</td>
<td>0.480</td>
<td>0.50</td>
<td>0.10</td>
<td>99.90</td>
</tr>
<tr>
<td>8. Groundnuts</td>
<td>1.948</td>
<td>1.80</td>
<td>0.09</td>
<td>99.91</td>
</tr>
<tr>
<td>9. Cowpeas</td>
<td>1.099</td>
<td>0.20</td>
<td>0.02</td>
<td>99.80</td>
</tr>
</tbody>
</table>


\(^a\) Modern holdings are defined as large-scale mechanized farms.

\(^b\) Rural holdings are defined as small-scale peasant farms usually less than 10 hectares in size.

significant amount and any innovation that could improve storage may have to focus on these stages. Existing marketing channels (Fig.2) are basically efficient in terms of the physical and financial resources available. One feature of these traditional marketing channels, however, is the relatively large number of market intermediaries located at strategic points, their number being a function of the distance and degree of isolation from the production area. As shown in Fig.2, the normal pattern is for producers to offer their small surpluses to traders in the first assembly or village market. These traders or individuals then move the accumulated produce along the channel often to secondary or tertiary assembly markets until they reach the central wholesale markets in the cities. With the emphasis now being placed on food production in Nigeria, together with the increased allocation of inputs into food production, concern is now being expressed as to whether the traditional marketing channels will be able to cope with the increasing supplies from the farmgate without any infrastructural or institutional improvements. The above analysis would be true for most of the staple foods that pass through the marketing system.
1. FARM GATE → CONSUMER

2. FARM GATE → WHOLESALER → CONSUMER
   |    ↓
   |    RETAILER
   |    ↓
   |    CONSUMER

3. FARM GATE → CORPORATION → CONSUMER
   |    ↓
   |    WHOLESALER
   |    ↓
   |    RETAILER
   |    ↓
   |    CONSUMER

**FIG. 1.** Schematic representation of the food distribution machinery.

**FIG. 2.** Schematic representation of the traditional marketing channels.
APPLICATION OF FOOD IRRADIATION TREATMENT TO EXTEND THE SHELF-LIFE OF FOOD IN NIGERIA

In the light of the above analysis of a typical post-harvest system, attempts should now be made to incorporate a food irradiation treatment/storage facility into the second stage (i.e. the wholesale level) of the theoretical distribution system. Any adjustments that might be necessary in the institutional setting would then be examined and discussed.

The staple foods envisaged are yams, onions, cowpeas and a dehydrated vegetable (ground red pepper). The technical feasibility of using food-irradiation techniques to extend the shelf-life of these staples has already been established under Nigerian conditions [6, 9, 10]. However, because of the low unit value of these commodities together with the prevailing farming and marketing systems in the country, it could be argued that the system may not be able to pay its way. In addition, there are also the technical and organizational constraints.

One practical approach might be to introduce an irradiation treatment facility into the second stage of the distribution system (i.e. at either the primary, secondary or tertiary assembly markets), see Fig.3. These facilities should, however, be located in the main areas of production of the commodities. This innovation should fit very well into the existing framework. On the other hand, one could encourage co-operative storage, which would involve an organization where the commodities yams, onions, cowpeas and dry red pepper are brought by producers to collection centres where they could be further treated or processed, sorted, graded and packaged before irradiation prior to storage or distribution through the existing network. An organization similar to the Potato Marketing Board in the United Kingdom or the British Columbia Tree Fruits in Canada might also be appropriate.

For this system to work on a commercial scale, further irradiation trials would still have to be carried out on the commodities on a reasonably large scale. These studies should, among other things, establish the optimum conditions to irradiate the produce, the best package/produce combination, and the best way to present irradiated produce for sale under Nigerian conditions. Consumers and people involved in the production, marketing and industrial processing of these commodities should be brought into the picture right from the onset and their opinion should be considered before coming out with any recommendations. From these trials useful information such as the optimum plant operating capacity and time, the optimum conditions to irradiate produce, the most efficient containers that would minimize handling, irradiation and transportation costs in addition to fulfilling their protective function, and the most efficient way to present the irradiated food under Nigerian conditions would be established.

Finally, consumers, producers and all those involved in the post-harvest system should be made aware of the fact that ionizing irradiation is a relatively cheap and very safe option for extending shelf-life.
CONCLUSION

In conclusion, the Government should initiate policies that would lead to improvement in the post-harvest marketing system of the major staple foods. They should include the following:

1. Price efficiency inducing policies designed to increase the responsiveness of the marketing system to consumer direction by improving market information and establishing consumer grades and standards.

2. Structural policies designed to modify the behaviour of the middlemen so as to improve market performance through the establishment of co-operatives.

3. System analysis of specific marketing procedures in order to determine cost and returns and economies of scale.

4. Infrastructural policies necessary for the development of capital-intensive (roads, silos, irradiation facilities, warehouses, processing equipment, etc.), capital-extensive (post-harvest market extension services, agricultural research, etc.), and institutional (subsidies, tax dispensation, etc.) infrastructures. These policies are necessary if we are to improve the efficiency of our
post-harvest marketing systems since they reflect the environment in which they operate. Thus with improved storage facilities, improved market knowledge and other ingredients of economic development many of the post-harvest marketing problems in Nigeria and many other developing countries would be solved.

REFERENCES

GUIDELINES FOR ASSESSING FOOD IRRADIATION TECHNOLOGY

N. FERRELL, J.S. SIVINSKI

CH2M HILL,
Albuquerque, New Mexico,
United States of America

Abstract

GUIDELINES FOR ASSESSING FOOD IRRADIATION TECHNOLOGY.

Irradiation is currently being considered throughout the world as a possible solution to varied problems. How does one proceed with conducting a formal assessment of the technology to determine if it can technically and economically meet a specific need? Numerous criteria are suggested in the literature for assessing the technology. However, many of these items are difficult to apply to particular situations. Furthermore, a comprehensive technical approach may be too consuming in both time and money. The basic guidelines and procedures presented in the paper are useful for early determination of project feasibility. Irradiation should be considered as part of a system—not as a stand-alone, isolated process. Consideration must be given to preceding and following processes and events. Comparisons between alternatives must be made on a system-wide basis to ensure uniformity and accuracy of conclusions. However, only a few key factors have a major impact on project feasibility. By concentrating on these factors, and staging the time at which they are considered, a reliable decision to proceed or not can be made at a minimum investment.

There is a universal need for new and better ways of producing and distributing food of higher quality for expanding populations. Some major concerns include:

- Control of infestation of crops by pests
- Quality preservation during transportation and storage from farm to market
- Developing new and better distribution methods
- Extending shelf-life of commodities to reduce the huge loss of spoilage
- Alternatives to processes under regulatory scrutiny
- Alternatives to high-energy consumption storage and preservation processes such as cold storage and frozen foods
- Better methods of disease and parasitic control in food processing.

There is a growing worldwide interest in irradiation of food stuffs as a possible solution to many of these concerns.
The introduction of irradiation into a given food processing system is a complex task. The success of irradiation as an integral part of a food processing system is dependent upon the cooperation and coordinated efforts of several facets of the system. Most important of these facets of the process system are the technical, product concerns, regulatory, social, consumer, industry, and financial. Each of these concerns have individual requirements which must be satisfied before the irradiation project can be an economic success. The process of analysis of the controlling or major concerns of an intended project to identify and address the requirements of each is usually called a detailed feasibility study. These studies can become cumbersome, expensive, and of long duration, often taxing the physical and financial resources of the promoters of the project.

The three major areas of project concern that are usually addressed in a feasibility study are the techno-economic, socio-economic, and commercial feasibility. These studies are tailored to the individual needs of each project, but there are some questions which are common to most feasibility efforts. These are listed below.

**TECHNO-ECONOMIC FEASIBILITY**

1. Does existing technology have proven solutions to project problems?

2. Can the existing research data which has been compiled in other applications of this technology be applied to the local area and commodities?

3. Is irradiation still the best solution to the project needs when compared to other existing technologies?

4. What are the total benefits to be derived from this technology, and what are its limitations and constraints?

5. What is the real economic value for the benefits and/or enhancement of the quality of the irradiated commodity and how does this compare to the estimated capital and operating costs of the facility over the expected life of the project? Investments and costs should include the time value or life-cycle cost analysis.

**SOCIO-ECONOMIC FEASIBILITY**

1. What is the present attitude of the local legal community and regulatory agencies toward the introduction of irradiation into the food process system?
2. Does the intended project exhibit a high degree of social soundness? This may include the effects of the project on the local work force. Is the intended project compatible with the social customs and practices of the population in the area?

3. What is the anticipated degree of public acceptance of an irradiation facility near the intended site, and will publicity be positive or negative to the project?

4. Are there serious environmental concerns and impacts to the environment and/or the economy of the region because of the project?

COMMERCIAL FEASIBILITY

1. Can the irradiation process be integrated into the present commercial structure of the local food industry and become a component of the existing process system?

2. What will be the marketability and consumer acceptance of the irradiated commodities?

3. Will this process increase the unit cost of the commodity to the consumer, or will increased shelf-life and/or opening of new markets for the commodity offset the increased costs, if any?

4. What will be the effects of the irradiation process on the pre- and post-harvest process activities?
   - commodity turnaround time;
   - increased handling and transportation to deliver the commodity to a central irradiation facility;
   - if commodity is seasonal in nature, how will the peak production be handled, and are there "fill in" commodities for the off season?
   - other process system effects such as cold storage and packaging changes;
   - assess the impacts to existing markets and the processing of related commodities due to increased shelf-life and/or increased market potential.

5. Can a monetarily favorable value added-to-process volume ratio be achieved and maintained within the established process and distribution system for the commodity to be processed?

6. Is the affected food industry a firm supporter for the irradiation processing of this commodity?
7. What is the present attitude of market area public health agencies toward food irradiation and what imposed regulations, such as labeling, could be anticipated in the future?

Many of the developing countries, as well as local or private interests do not have the resources to initiate a complete feasibility study as outlined above without the help of other interests. There are a few key factors that may be examined as indicators of feasibility in the early stages of project development. Accurate analysis of these factors can form the basis for a reliable decision to proceed or not to proceed with a detailed feasibility study with a minimum investment. Successful completion of this preliminary feasibility analysis will also stimulate the interest of potential partners or investors who then can share the burden of a complete feasibility study.

Some of the facets of irradiation technology that can be considered as key indicators of project feasibility are listed below:

1. Technical Elements:
   - High capital cost favors a larger, centrally located facility; this could result in additional cost to the process of some commodities for such items as transportation, refrigeration and storage, commodity turnaround time, increased handling, and special packaging.
   - Is there sufficient valid data on the effect of irradiation on the physical properties of commodities under consideration?
   - Does the local industry have valid data on combination processes for commodities being considered?
   - Compatibility or incompatibility of the food irradiator facility to other potential applications in the area.

2. Social Elements
   - Public awareness and attitude toward irradiation as a process.
Local customs and traditions which could be at variance with the proposed project activities.

Anticipated positive or negative media publicity.

Labor availability and economic and social impact on the local area.

Present attitude of government and regulatory agencies toward food irradiation.

3. Commercial Elements

Seasonality of commodities and harvest production peaks as related to effective use of the facility.

Is there an accepted national standard and accepted practice for commissioning and process validation for food irradiation?

Has the Codex and code of practice for food irradiation been adopted in this state or area, and is it adequate for industry use?

The status of marketability and consumer acceptance of irradiated foods in the market area.

Is there an accepted policy on labeling requirements for irradiated foods?

The history of food irradiation technology in the local industry as reflected by industry confidence.

Has commercial scale viability of the process been clearly established for the commodities being considered?

Is there sufficient interest and resources to support a detailed feasibility study and, if necessary, a demonstration facility?

4. Economic and Financial Elements

Obtain "ballpark" estimates of capital cost from existing facilities in that area similar in basic concept.
What ultimate financial resources are available to be applied to the project if it were found to be feasible and desirable?

The success of food irradiation processing where the facility is properly sized and located is inseparably connected to the eyes and perception of the marketplace, the consumer, and the financial institutions. The technology is in place. Therefore, it is imperative that each new venture into food irradiation be successful in its application which will build confidence in the industry, the marketplace, the consumer, and, finally, the financial institutions.

Proper execution of preliminary feasibility analysis and complete feasibility studies will help to ensure that new ventures will be successful.
CARIBBEAN AREA FOOD IRRADIATION FEASIBILITY STUDY

R.F. MORRIS
Office of Agriculture,
Agency for International Development,
The United States Department of State,
Washington, D.C.,
United States of America

Abstract

CARIBBEAN AREA FOOD IRRADIATION FEASIBILITY STUDY.

The US Agency for International Development funded the Caribbean Area Food Irradiation Feasibility Study (CAFI) through the US National Food Processors Association and with the collaboration of the US Department of Energy. This study focused on the economic, technical, financial, political and social feasibility of transferring food irradiation technology to the Caribbean area. The study focuses on three areas including the benefits to small farmers and nations interested in the export of crops, including non-traditional tropical commodities. The Feasibility Study Team conducted field work in Guatemala, Haiti, and Trinidad. The benefits of irradiation technology have been shown to have an impact particularly on the small farmer who is more capable of producing non-traditional crops intended for international export marketing. In Haiti, the anthropologists working on the CAFI study found that 74,000 individuals will be directly affected by the ban on the postharvest fumigant ethylene dibromide. Irradiation technology can not only provide the quarantine security needed to allow crops requiring quarantine treatment to move into international trade, but it can promote international co-operation in technology transfer. Training and safety issues related to the transfer, operation, and disposal of nuclear materials must be considered and point out the need for adequate regional co-operative programmes. Research and training programmes will be needed to augment the implementation of food irradiation processing by the private sector. Irradiation firms planning facilities in developing countries may need to provide crop production information, international marketing intelligence, and other assistance needed to integrate an irradiator into the overall postharvest food system.

The Agency for International Development has primary responsibility for the United States Government programme of international development assistance. As such, we at AID have been concerned about the impact that the US ban on ethylene dibromide (EDB) may have on developing countries. It appears that in the Caribbean and Central American region, also called the Caribbean Basin, many countries with USAID assistance have developed or are developing strong export marketing projects and also non-traditional crop production projects. Because
the intent of President Reagan's Caribbean Basin Initiative is to promote trade in this region and exports to US markets, we have recently initiated research to evaluate alternative quarantine treatment to EDB, including chemical, hot water dips, and cold storage. In another effort, our Office of Agriculture has funded the Caribbean Area Food Irradiation, or CAFI, Feasibility Study. The CAFI study is being implemented through a grant to the National Food Processors Association and includes the collaboration of the Department of Energy.

The CAFI study is intended to assess the technical, economic, political, social, and financial feasibility of transferring food irradiation technology to the Caribbean area.

The team has been working under the guidance of Dr. Mussman, the keynote speaker, from the National Food Processors Association and under the leadership of J. Sivinski, an internationally known food irradiation specialist. The team also includes D. Jackson, a trade and agribusiness specialist; G. Cavin, an entomologist; J. Knapp, an economist and financial analyst; K. Priester, an anthropologist/sociologist; S. O'Rourke, an anthropologist stationed in Haiti, and J. Ingersoll, as senior anthropologist.

We are currently anticipating receipt of the first draft by the end of March. At that point we plan to distribute copies for review and comment. It is anticipated that the final CAFI Feasibility Study Report will be ready for distribution by September 1985.

I would like to highlight a few of the points which have been relayed to me by the CAFI Feasibility Study Team.

Early in the discussions about strategy for this Feasibility Study there was general agreement that the technical feasibility of food irradiation has been adequately demonstrated.

This conclusion is based on the long history of laboratory studies and global pilot-scale demonstrations in over 30 countries. When I say long history, I mean over eighty years. The first US patent I know of is #788480 issued to a Mr. H. Lieber on 25 April 1905. Early research and development efforts in the USA can therefore be documented to the turn of the century. The team therefore felt that, because of the long international R&D efforts, the technical feasibility has been over demonstrated. Why then has food irradiation not been universally accepted? Is it lacking feasibility in another area?

The CAFI team in their final report will address the economic and financial feasibility, but I wish to emphasize a major focus: the people issues: acceptability, safety, social benefit, etc. If irradiation technology is not perceived by our fellow humans as being acceptable and feasible for them, we scientists will have failed. Indeed, I personally believe that one of the major reasons we are not discussing the widespread acceptance today, but are still trying to get the technology out of the laboratory, has been due to our inability to communicate and demonstrate the benefits of this technology to people. What role will this AID funded CAFI Feasibility Study play?
The CAFI team has been spending good brain power and social and anthropological expertise on the examination of the human impact of the transfer of irradiation technology to the Caribbean. With three sociology or anthropology experts participating in this effort, we hope to clearly focus on the human impact. The following are some of their early findings.

First, within the Caribbean, agriculture's share of Gross Domestic Product represents from 8—40 per cent, while in the USA it is only 3 per cent of GDP. Agricultural activities are very important to the Caribbean region.

Second, agricultural exports from the Caribbean countries, particularly Haiti and Belize, are a major provider of foreign exchange earning and a principal source of employment.

The team has also noted the importance of the postharvest system in relation to production agriculture. Marketing costs normally exceed production costs, so improvements in the postharvest system can not only save the value of agricultural production input costs, but can dramatically increase the economic efficiency as well. The costs for marketing melons and cantaloupes from Central America are almost twice their production costs.

Irradiation used for quarantine treatment could help maintain existing levels and kinds of exports which had required EDB fumigation to enter US markets. New production areas being planted to crops requiring quarantine treatment could also benefit if irradiation technology were transferred to the region.

Also of note is the possibility for irradiation to play a major role in non-traditional crop exports, not only to meet quarantine requirements but also to prolong shelf-life. Many of the tropical crops have a very short marketing shelf-life. If irradiation can extend the life only a few days, this could have significant impact on expanding the market range, and for a few crops could open opportunities for marketing these perishables in Europe.

There are many crops which grow well in the Caribbean, but which have not seen great export market activity. Tomatoes, avocados, eggplant, bell peppers, and chili peppers exhibit phytotoxic damage if treated with EDB replacement chemicals such as methyl bromide. Because these crops require quarantine treatment to enter the USA and often other markets but do not tolerate fumigation with methyl bromide, they could dramatically and quickly enter international marketing if irradiation processing is accepted by US (or other) regulatory agencies and if irradiators were available. These and many other non-traditional crops can tolerate the low doses required for quarantine security, and may also benefit from market shelf-life prolongation by irradiation.

The CAFI team is spending considerable effort in evaluating the social impact of the transfer of food irradiation technology to the Caribbean. The traditional view that small farmers in Central America and the Caribbean are conservative and resistant to change is not supported in Guatemala, at least. Subsistence and small farmers there have shown their willingness to take advantage of perceived opportunities to boost income. In the highlands of Guatemala, farmers do not want to move to the lowlands where malaria is present. They also do not want to
Their desire to adopt non-traditional crops that can bring added income is real, as evidenced by the increases in non-traditional crop production and export. Irradiation could give them expanded market opportunities for these non-traditional crops.

If farmers perceive a secure market at a price which would at least cover costs, they are eager to shift production to new crops. The CAFI team reports that small farmers have a competitive advantage over large farmers in the production of non-traditional labour-intensive export crops. A small farming family can contribute cost-saving labour while larger farmers must depend on hired labour. Also, the time and attention needed to ensure export quality of agricultural commodities is more easily attained by the small farmer.

Although it seems that small farmers are willing to produce more of the non-traditional crops, this trend is limited by the necessity of the very small farmers to meet subsistence requirements. Farmers will produce non-traditional crops only after food needs for the family have been met.

The land available to each farm family therefore limits capacity to fulfil subsistence requirements and the secondary potential to produce export crops which may benefit from irradiation. Therefore, the smallest and poorest of farmers will be the least able to benefit from expanded market capabilities made possible by food irradiation.

Then who would benefit? Because small commercial farmers have been more able than larger farmers to compete in production of labour-intensive crops, they are likely to be the major beneficiaries of commercial food irradiation. Small farmers with access to irrigation could benefit even more. The landless labourers who are available to help produce expanded export production through employment opportunities and secondary economic growth will also benefit.

What is the CAFI team saying about the impacts of irradiation technology transfer to the Caribbean?

1. Can maintain present export production, even with the EDB ban;
2. Could expand export potential particularly for novel non-traditional crops;
3. Particularly help small farmers;
4. Reduce hazards to applicators, handlers, and consumers from toxic chemicals which have been used for quarantine treatment. However, the potential safety hazards of radiation injury to workers in the irradiation facility cannot be ignored or minimized. Irradiation must be carefully controlled at a central facility and safety measures and appropriate training must be provided to minimize the possibility of accidents involving the use, transport and replenishment of nuclear materials;
5. Can promote quality improvement of produce by channelling it through a central irradiation facility. Control of grades and standards at a central facility can promote international market acceptance. The increased shelf-life potential may also promote added economic incentive and the image of superior quality of irradiated produce.
(6) Can expand domestic marketing area. For example, with marine fish irradiation, the interior domestic markets may for the first time have fresh fish available.

The team is still working on many other aspects of the CAFI study including a model horticultural produce irradiator design. The team has supplied one important calculation of particular interest. It appears that 7000 t of produce per year is needed to justify the construction of an irradiator facility. Because the costs of treatment are directly related to the tonnage processed, these data are important. Small Caribbean islands may not have sufficient production to justify irradiator construction, but for areas where the combination of crops can approximate 20 t of throughput per day, it is likely that capital costs can be amortized in a reasonable amount of time.

Dr. D.T. Luckey's exciting ideas about radiation hormesis and the potential for stimulating increased production may offer tremendous new opportunities to more fully utilize irradiation facilities by treating seeds and other plant and animal material at very low doses. Because seed planting time and the harvest occur at different seasons, this may help balance and more fully utilize irradiation trained personnel if appropriate seed irrigation equipment were available.

Because it seems that an irradiator has the greatest potential to help small farmers who produce non-traditional crops for export, the management behind an irradiator must truly serve the needs of the small farmers. This suggests that the facility, and its organization and management, must be integrated well into the production and postharvest system.

This means that appropriate non-traditional crop production guidance, marketing intelligence, co-operative formation expertise, grades and standards development assistance, agricultural credit, adequate transportation facilities, packaging containers and systems, etc., must be readily available.

In other words, the irradiator cannot be isolated — it must fit within the existing production and postharvest system. Those who are really going to successfully transfer irradiation technology are those who will be willing to succeed over the long haul. If the management of irradiator firms does its homework and integrates its irradiation operation into a two-way information flow to and from the producers, these firms can succeed. Private sector firms interested in the international opportunities food irradiation technology offers will be well advised to consider providing marketing and production information help to the individual producers or co-operatives, perhaps even radiation stimulated seeds.

In the USA, where a sophisticated agricultural marketing chain is accustomed to highly specialized service industries, an irradiator service need only be marketed well. In a developing country, for a service irradiator to survive, it may need to work directly with farmers and co-operatives. It may also have to ensure fair access to irradiation facilities since this access may imply the only access to markets.

Before closing, I want to mention a few interesting observations made by the CAFI team while in Haiti. Although Haiti's major export crop is coffee, mangoes are the second most important earner of foreign exchange.
The anthropologists working with the CAFI team have discovered that there are 74,000 Haitians directly involved in mango export. This includes 72,000 peasant producers, 1,000 intermediaries, and 1,000 managers and employees of mango export firms. If one assumes that the average number of persons per household is 5, then 360,000 or roughly 6% of Haiti's 5.5 million population could be affected if alternative quarantine treatments are not in place by the 1st of September 1985, when a zero EDB residue tolerance for mangoes goes into effect.

The CAFI team has also been looking into the responsibility that the transfer of this nuclear technology will entail. The team has identified a need for a Caribbean regional research and training facility. People must be trained to safely operate facilities and research programmes.

Many of the tropical crops which might someday benefit most from irradiation have never been tested. The US Department of Agriculture has stated that quarantine treatment protocols are required for each commodity to ensure quarantine security. Treatment protocols must therefore be developed for each individual crop.

Many fruits benefit most if irradiated close to the point of harvest. It seems logical that the best place, ultimately, for an irradiator is within the tropical Caribbean, close to an adequate supply of produce. The most feasible location will need to be identified and agreed upon by the countries interested in pursuing this technology.

I wish to close with two quotes, one from perhaps the most important international treaty in existence and the other from the most famous scientist who made the treaty a necessity.

The first quote is from the Treaty on the Non-Proliferation of Nuclear Weapons which was proclaimed by the United States President and entered into force fifteen years ago, on 5 March 1970. The quote is from Article IV, Paragraph 2:

"All the Parties to the Treaty undertake to facilitate, and have the right to participate in, the fullest possible exchange of equipment, materials and scientific and technological information for the peaceful uses of nuclear energy. Parties to the Treaty in a position to do so shall also cooperate in contributing alone or together with other States or international organizations to the further development of the applications of nuclear energy for peaceful purposes, with due consideration for the needs of the developing areas of the world."

The second quote is a statement made by Albert Einstein in 1945:

"Since I do not foresee that atomic energy is to be a great boon for a long time, I have to say that for the present it is a menace. Perhaps it is well that it should be. It may intimidate the human race into bringing order into its international affairs, which, without the pressure of fear, it would not do."

The Feasibility study has shown that Carribean entrepreneurs are ready for the transfer of food irradiation technology. The choice of using this technology for the benefit of human kind is ours.
NEW CONSIDERATIONS FOR RADIATION-TECHNOLOGY TRANSFER PROGRAMMES FOR DEVELOPING COUNTRIES*

M.C. LAGUNAS-SOLAR
Radioisotope Program,
Crocker Nuclear Laboratory,
University of California,
Davis, California,
United States of America

Abstract

NEW CONSIDERATIONS FOR RADIATION-TECHNOLOGY TRANSFER PROGRAMMES FOR DEVELOPING COUNTRIES.

For more than three decades of research on food irradiation, radionuclides (¹³⁷Cs, but (mostly ⁶⁰Co) have been the type of radiation sources employed in the majority of efforts world wide. This is currently continuing as a trend in the planning of new large-scale commercial facilities for processing food. At the same time, machine sources of ionizing radiation are generally being ignored, although it appears that newly developed electron beam accelerators of sufficient beam power and reliability of operation can offer many technical and economic advantages over the use of radionuclide sources. Many developing countries motivated by potential economic gains, or by the need to overcome new trade restrictions, are moving rather fast to incorporate radiation processing facilities. Therefore, an analysis and a comparison of the different radiation sources currently available, and the new machine (accelerator) sources being developed and tested seems appropriate and timely.

I. INTRODUCTION

Despite the efforts of many international organizations, local governments, research institutions, and the commercial sector, losses of the world's food supply still reaches one-quarter to one-third of the total food production. Losses occur to different extents in all of the different phases of the overall food chain. The relative extent of harvesting; post-harvesting; distribution; storage; processing; market display; and consumer-handling losses varies widely due to technical, operational, and environmental factors. In many regions, but particularly in developing countries located in tropical zones, these losses are further compounded by the lack of technical resources and facilities for effective food preservation. Known methods (i.e. temperature and environmental controls; drying; freezing; canning; fermentation; etc.) are either not available or are insufficient in capacity.

* Supported by the University of California Nuclear Sciences Fund.
In 1975, during the Seventh Special Session of the United Nations General Assembly, the need for a concerted effort to reduce post-harvest food losses in developing countries was given a high priority. However, and despite many initiatives by international agencies, many countries are still producing food below their needs and suffering from large shortages. Insufficient food production, when coupled with the lack of proper facilities for preservation, and some political and/or economical factors, almost invariably results in hunger and social unrest.

It is generally accepted today that food irradiation can help minimize some of these losses if the technology is established, as expected, in the developed countries, and if it is timely and appropriately transferred to all of the different regions of the world. The general response of the scientific, regulatory, and food-industry communities to the 1981 WHO/FAO/IAEA "Wholesomeness of Irradiated Food" report (1), has been to accelerate the regulatory process in order to promote the worldwide use of radiation in food processing. As a result, many engineering, technical, operational, and economical factors regarding a large-scale operation are being analyzed. In most developing countries, food production and exports are significant national and economic resources. Therefore, the choice, transfer, and implementation of a new technology is an essential and determining factor in the nation's progress.

As with many other technical developments, the transfer of new techniques to developing countries is a time-consuming process. For the most part is generally carried out by private-industry counterparts, although in the majority of cases an important role is played by the developing country's government agencies by sanctioning, commissioning, and licensing the process and its facilities.

The introduction and/or marketing of food-irradiation facilities has already started very aggressively in many developing countries. However, as a result of almost three decades of research on food irradiation, and on its scientific/technological base using radionuclide sources (Cs-137, but mostly Co-60), these types of sources are strongly considered as the radiation source of choice for most planned facilities. Today, many facilities under construction or in the planning stages, are being designed to house radionuclide sources, primarily Co-60. This is despite the fact that the international regulations based upon the WHO/FAO/IAEA report, also include machine (accelerator) sources (1), and that both the availability and the cost of the future Co-60 production are being questioned (2). On the contrary, and in particular in the case of most developing countries, the diffusion of the necessary information on the performance and status of current accelerators is far from reaching the level of knowledge and familiarity achieved with the use of radionuclide sources. This is despite the fact that in the last two decades, and due to the
applications in medical therapy; solid-state physics; several industrial processes; and defense programs; accelerator technology has evolved considerably and at a greater rate than most believe.

For many years, the day-to-day operational reliability for accelerators with adequate beam energy and power, was thought as a serious drawback for machine sources. However, the advances in solid-state electronics; the development and operation of low-gradient accelerator modules with high-frequency magnetic switches, have resulted in accelerator systems which seem to offer many advantages for establishing large-scale, portable, multi-purpose radiation-processing facilities (3,4).

The present work will then evaluate the different advantages and disadvantages of technology-transfer programs based upon the different radiation sources; and suggest a criteria with which to ascertain the requirements, potential value, and current interest of technology-transfer efforts.

II. RADIATION SOURCES FOR DEVELOPING COUNTRIES

A. General Observations

The choice of radiation sources for developing countries must compare the economics of installation; day-to-day cost of operation and maintenance; food processing costs; impact on consumer prices; and also the potential for other applications. The latter can be a factor to rationalize operational costs. In addition, and due to the needs to satisfy the peak demands of various food products likely from distant production locations, the potential for source portability becomes an important feature with great influence in the overall economic assessment.

The characteristics, availability, and the present status of radionuclides and accelerator (machine) sources have been recently reviewed (2). A comparative economic cost analysis for pest control for raisins, using chemical and irradiation methods was also recently reported (5). The latter report demonstrated that irradiation could be quite cost competitive with several other treatments (i.e. temperature and environmental controls; chemical fumigation), and that electron-beam accelerator facilities can provide even less costly alternatives than radionuclide sources.

In order to facilitate further analysis of the different alternatives as radiation sources, the equivalency of radiation processing capabilities for radionuclides and electron-beam accelerator sources is given in figure 1.

Both Cs-137 (30.17 a) and Co-60 (5.27 a) have been used in more than 50 countries as sources for food irradiation research,
applications in cancer radiotherapy (mostly Co-60), and as sources for industrial applications. There is considerable worldwide experience in the handling and operation of these facilities, particularly in those developing countries which participated in feasibility, testing, and demonstration projects under the auspices of the Atoms for Peace, IAEA, or other R&D programs. This experience, however, was obtained with relatively low-level sources (0.2 to 0.5 MCi) and mainly through academic/government programs under the general direction of the countries's Atomic or Nuclear Energy Agencies. However, because of the amounts of food involved in a commercial size operation, larger sources would be needed at centralized locations. In certain regions of the world, it is also conceivable that smaller sources may be necessary for dealing with specific local needs.

The non-food radiation-processing industry, has recently experienced a vigorous growth in numerous developed countries. These countries have already incorporated low-energy, low-power electron-beam accelerators for the processing of wood products; for cross-linking of plastics; for the treatment of plastic coated wires; and other applications (6-10). An infrastructure for the support and expansion of this industry is also being established. The private sector in many developing countries is also investigating this new process which requires almost an identical infrastructure to radiation processing of food.
B. On the Use of Radionuclide Sources

Although the operation of radionuclide sources throughout the world has been conducted safely and efficiently, there are several drawbacks that make them less attractive alternatives, in particular for developing countries:

1) Present and Future Supply

The current world supply of both Cs-137 and Co-60 is insufficient to support food irradiation processing as is expected to expand worldwide. The US government is the only producer of Cs-137 and at present has about 77 M Ci in inventory (11). The current Co-60 production level (from a single company) is about 20–25 M Ci per year, and is assigned to resupply irradiation facilities (mostly non-food) on a worldwide basis. However, it has been announced that the availability of Co-60 may be increased to 60–70 M Ci/year (11).

2) Expected Demand

According to fig. 1, a 1.0 M Ci Co-60 source used at 30% efficiency can process in a 24-h operational day, 400 metric tons of food per day, at a nominal 100 krad (1 kGy) dose. Also, 6.9 M Ci of Cs-137 would be needed for the same output/dose level per day. If the product's intended technical effect requires higher doses, the amount of food treated per day would decrease accordingly. The expected future Co-60 availability would only represent a net increase of about 35–40 M Ci, because part of the production is already committed to resupply current sources (estimated as 22– to 25-M Ci per year) and part (about 12%) must be committed to resupply the new facilities. This would represent 35 to 40 new 1.0 M Ci Co-60 sources for the entire world demand, with a capability to process only 14 000 to 16 000 metric tons of food per day at a nominal 100 krad (1 kGy) dose. Because both developed and developing countries are expected to implement radiation processing of food in the near future, the processing capacity on a daily basis is estimated as several million metric tons per day. Clearly the future prospects for adequate radionuclide source supply can provide only a small fraction of the estimated needs.

3) Future Cost

Developing countries are typically troubled with fluctuating (normally decreasing) currency values, a trend that in most cases is expected to continue. Therefore, a major economic concern in the planning of a facility with radionuclide sources is the long-term commitment to a mandatory Co-60 resupply program. It is also to be expected that an increased availability of Co-60 (and the assumed increased demand) will also result in a considerably higher price than the current US $ 1.00/Ci. An increase of many-fold in Co-60 prices would greatly deteriorate the economic value of radionuclide source installations in developing countries.
From this standpoint, it appears that Cs-137 with a 30.17 a half-life, and a much reduced cost of US $ 0.10/Ci, could alleviate this problem. However, the world supply of Cs-137 is even more restricted (77 Ci, see above). Even if the US government would expand a reprocessing and encapsulation program for Cs-137 (a fission product from the operation of nuclear reactors) so as to increase its availability many-fold, a Cs-137 radiation source has other limitations (due to its low-energy 662 keV photons) making its use only applicable to thin foods. Even if its use is justifiable in certain developed countries for specific applications (i.e. Sludge Irradiation, Pork Irradiator Facility, etc.), its use in developing countries is questionable.

4) Potential Applications

Even under the best of circumstances, facilities housing radionuclide sources will provide few opportunities for flexible or variable applications. Processing of food can be performed for any of the intended low-, medium, and high-dose applications as defined in the WHO/FAO/IAEA report (1). However, product selection and handling will have to be done in such a way as to assure that the product-package geometries would provide adequate dose ratios allowing the necessary control of the product's response. On the other hand, sterilization of many products (specially medical supplies) can be performed with few concerns for dose ratios.

C. Accelerator Sources for Radiation Processing of Food

Electron-beam accelerators have been used in research for several decades. Converting electron beams to X radiation (Bremsstrahlung radiation) allows these accelerators to be used in processing large, dense targets. A water-cooled metallic plate is used to convert the electron beam energy into X-rays and heat. The process is relatively inefficient (8% at 5 MeV), but the conversion increases with electron beam energy (15% at 10 MeV). Therefore, photons created in this form can provide a more penetrating radiation allowing the processing of larger food packages with acceptable (in most cases better) dose distributions in the package (2).

According to fig. 1, 9 kW of X-radiation are equivalent to 1.0 MCi of Co-60 or 6.9 MCi of Cs-137. This power can be obtained from either a 5-MeV (112-kW, 8%), or a 10 MeV(60-kW, 15%) electron-beam accelerator. The types of current and future accelerators which can provide a fraction or all of the needed power are given in table I.

A well-established non-food radiation-processing industry already exists in developed countries. As mentioned earlier, many developing countries are considering the radiation processing of plastics (crosslinking; polymerization; grafting;
### TABLE I. PRESENT AND FUTURE ELECTRON BEAM ACCELERATORS FOR RADIATION PROCESSING OF FOOD

<table>
<thead>
<tr>
<th>Accelerator</th>
<th>Beam Energy (MeV)</th>
<th>Beam Power (kW)</th>
<th>Beam Type</th>
<th>Basis of Operation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Linear</td>
<td>1 to 50</td>
<td>0.3 to 20</td>
<td>Pulsed CW</td>
<td>High Voltage, RF wave</td>
</tr>
<tr>
<td>Dynamitron</td>
<td>4.5 (max.) up to 150</td>
<td>Direct Current</td>
<td>Cockroft-Walton technology</td>
<td></td>
</tr>
<tr>
<td>Resonant Transformer</td>
<td>4.0 (max.) up to 40</td>
<td>Direct Current</td>
<td>High-voltage, ins. core transformer</td>
<td></td>
</tr>
<tr>
<td>Van der Graff</td>
<td>3 (air)</td>
<td>low</td>
<td>Direct</td>
<td>Moving-belt discharge</td>
</tr>
<tr>
<td></td>
<td>10 (press.)</td>
<td></td>
<td>Current</td>
<td></td>
</tr>
<tr>
<td>RF Linac</td>
<td>10</td>
<td>500 kW</td>
<td>Pulsed CW</td>
<td>Conceptual Design</td>
</tr>
<tr>
<td>Induction</td>
<td>10</td>
<td>Megawatts</td>
<td>Pulsed CW</td>
<td>Testing at LLNL</td>
</tr>
</tbody>
</table>

a CW = continuous wave.

b University of California Lawrence Livermore National Laboratory.

cable and wire coatings), rubber products (coating; shrinking; crosslinking), as well as applications in medical-product sterilization, as new areas of technology.

In general, the design, operation, and maintenance of radiation-processing facilities using an accelerator source are more favorable because electrically-driven accelerators are more compatible with existing food processing facilities. Even though a more technically capable staff is needed, once the capability exists, the system is capable of providing other resources in the treatment of a variety of targets (non-food). This versatility is a major factor for developing countries.

Because of the amounts of food involved, the variations of production levels (reaching peak levels over short periods); the geographical separation of major agricultural centers; and the lack of good transportation systems; most developing countries will need to maximize the use of radiation processing facilities simply for economic reasons. Therefore, a major feature of accelerator sources is the construction of portable systems capable of high throughput. This is possible with accelerators in contrast to the need to move multi-Curie radionuclide sources. The design features for such a portable system are shown in figures 2 and 3.
The potential operation of electron beam accelerators in developing countries offers also many unique advantages over the operation of radionuclide sources. These are:

1) Radiation Energy Spectrum

A 5-MeV (as presently being proposed) photon spectrum provides higher average energy than Co-60 or Cs-137. This allows processing larger-size packages to within the same dose ratios with no increased labor. In addition, variable beam energies are available to treat a wider range of density foods. The average beam energy can also be increased by "hardening" the photon spectrum with the use of thin metal shields which will stop the lower energy photons.

2) Beam Directionality

The X-radiation has a forward direction allowing for a more efficient utilization of the available beam power. At the same time it reduces some of the need for massive all-direction shielding as is required with radionuclide sources.

3) Beam Steering Capabilities

The photon field can be scanned, and focused or defocused, by using electromagnets. This tuning allows a better use of photon power by the proper adjustments to the size of the food packages.
FIG.3. Close-up view of a radiation processing facility for food. Facility operates based upon two portable 5-MeV electron beam accelerators mounted on a 40 ft truck. Soil and concrete are used as radiation shield.

4) Beam On/Off Capabilities

Radiation safety and environmental concerns in the use of high-energy ionizing radiation are much reduced due to this capability. System maintenance and repair can also be conducted rather easily once the source has been turned off.

III. CONCLUSIONS

The implementation of radiation processing of food in developing countries should be made with a strong consideration to many potential short- and long-term impacts. Selecting the type of radiation source is an important decision with many potential economic and technical risks. Radionuclide sources seem less desirable to developing countries due to economic (initial and resupply costs; future price uncertainty; single major supplier) and technical (lower energies, limited useful power, higher dose ratios in large packages) reasons. On the other hand, the accelerator industry is likely to be a very competitive domain of
multiple ventures in the private sector. Accelerators with versatility of operation (food and non-food processing) and portability, reduce installation costs, and on/off operation can provide systems which can greatly enhance the use of radiation in different areas of technology. These systems can satisfy many of government/private sector needs and help support many beneficial efforts for the countries's progress.

The international agencies must play a much needed role in helping this decision by prompt and up-to-date diffusion of information, and by suggesting, supporting, and helping the many different phases of any technology-transfer effort. The right technology in the hand of developing countries can always be a factor in closing the gap between nations.

REFERENCES

SIGNIFICANT MILESTONES OF PROGRESS TO DATE IN FOOD IRRADIATION AND IDENTIFICATION OF AREAS OF FUTURE ADVANCES

W.M. URBAIN
Michigan State University,
East Lansing, Michigan,
United States of America

Abstract

SIGNIFICANT MILESTONES OF PROGRESS TO DATE IN FOOD IRRADIATION AND IDENTIFICATION OF AREAS OF FUTURE ADVANCES.

A review of the progress in food irradiation as marked by significant accomplishments since the 1940s is presented and the current status noted. Future needs and probable developments are identified. Suggestions for particular activities are given.

The first international symposium on food irradiation sponsored by the International Atomic Energy Agency and the Food and Agriculture Organization was held in Karlsruhe, Federal Republic of Germany, in 1966. To hold an international symposium at that time, there had to be substantial on-going activity in food irradiation. That this was so is clearly established from the fact that 69 papers from 17 nations were presented and 209 persons attended this first symposium.

Today, 19 years later, we are meeting again. Not only is there continued activity in food irradiation, but we are seeing the attainment of the goal of many years of effort — commercial irradiation of foods. To have kept that activity going through the past decades has required a conviction that the effort is worthwhile, that food irradiation is a useful process and that it will take its place in our food supply system. To have arrived where we are today must mean that accomplishments of significance have been secured — milestones along the path of progress.

As we look at the future of food irradiation, it is worthwhile to recall some of these milestones, and, with this background, to attempt to foresee what is ahead and what we need to do in the future. This fifth international symposium seems to be a good occasion for undertaking this task.
MILESTONES OF PROGRESS TO DATE IN FOOD IRRADIATION

Any attempt to identify certain past events as especially significant is not without hazard to the individual who does this. I offer only my views, but hope that some, at least, will be found acceptable. I have had the good fortune to have been present for many of the activities since the beginning of serious interest in food irradiation and to have known personally many of the participants. Hopefully, this experience may be helpful in my attempt to identify milestones of progress.

There are some genuine and generally recognized milestones that I believe we do not need to discuss to any great extent at present for the reason that they are so basic as to be obvious. I am referring to the discoveries before 1900 of X-rays and radioactivity; that is, to the discovery of ionizing radiation itself. I would also omit discussion of a number of observations made in the early decades of the twentieth century. They are noteworthy, but they did not accomplish anything of significance in the development of food irradiation. These were the observations on the lethal action of ionizing radiation on the various forms of life, including the microbial contaminants of foods, as reported by a number of investigators. Such knowledge was not much more than a curiosity of science without practical meaning in the preservation of foods by radiation, for one very important reason: there was no way to obtain the ionizing radiation in the quantity needed and at supportable costs for the commercial treatment of foods.

In my listing of milestones I identify as the first one the development of radiation sources that provide what is needed for commercial food irradiation. In the 1940s two types of sources were developed. These are the machine sources, mainly particle accelerators, and the man-made radionuclides such as $^{60}$Co. With these new sources, theoretically unlimited quantities of ionizing radiation are available and the costs are in accord with commercial usage.

This availability of radiation stimulated and launched the serious investigation of its use for the treatment of foods. As best I can determine, the first work in this new era was done in 1943 by the late Professor Bernard E. Proctor of the Massachusetts Institute of Technology in the United States of America. He demonstrated the preservation of hamburger meat by X-rays. It probably was no accident that this experiment was performed at MIT, since it was there that the electron accelerator named after him was invented by Professor Robert van de Graaff. The X-rays used by Proctor were obtained with a van de Graaff accelerator. This first experiment of Proctor was the beginning of the period of sustained development of food irradiation that has continued through all the years since 1943 until today, and I believe deserves identification as a milestone of progress.

I believe that this first milestone rightfully should be shared with another early investigator, who also was active in the 1940s. Arno Brasch developed another accelerator, the Capacitron. He did this in the USA after some earlier
work in Europe. Working with US industry he expanded the knowledge of food irradiation, and was the first to report the value of irradiation at subfreezing temperatures in limiting indirect action of radiation.

These very early activities resulted in the establishment of two separate programmes of research and development by the United States government, one by the Atomic Energy Commission (AEC) and one by the Army. The AEC was interested in peaceful uses of atomic energy and saw in food irradiation an excellent opportunity for utilizing gamma radiation from radionuclides such as $^{60}$Co and $^{137}$Cs. The Army's interest centred on a problem it had. The experience of two wars, World Wars I and II, with thermally sterilized combat rations indicated that these products had unsatisfactory sensory characteristics. The Army programme was directed toward the development of radiation-sterilized counterparts which would have improved troop acceptance.

These two US government programmes have to be regarded as important milestones of progress. The AEC programme was concerned with low-dose applications and explored diverse product areas such as marine and fresh-water animal foods, fresh meats and poultry, fruits and vegetables, with objectives including radurization, insect disinfestation and delay of ripening and senescence. The Army programme, aimed at the high-dose process of radappertization, attacked a number of problems including the sterilization dose requirement, the radiation-induced off-flavour in meats and other foods, wholesomeness evaluation, and technological aspects such as product development, packaging, etc. Important contributions to basic aspects of food irradiation were made by both the AEC and Army programmes, especially in microbiology and radiation chemistry. These two programmes contributed much to our understanding of food irradiation.

Interest in food irradiation developed in other countries, too. A tabulation made in 1968 showed that 76 countries had such programmes. Among the countries that participated in this early work were the United Kingdom, the Union of Soviet Socialist Republics, Canada, France, Belgium, the Netherlands, Denmark, Hungary, Italy, the Federal Republic of Germany, Israel, Greece, India, the Philippines, Pakistan, South Korea, Thailand, Japan, Argentina and Chile.

Other programmes and group activities came into being in these early years that had a very large impact on the progress in food irradiation. What became the joint FAO/IAEA programme started in 1963 under the leadership of Dr. Harry Goresline. The Commission of the European Communities and the Organization for Economic Co-operation and Development sponsored research and assisted in information transfer. The countries in Europe with centrally planned economies formed a programme under the Council for Mutual Economic Assistance. In 1970 approximately 25 nations established the International Project in the Field of Food Irradiation. It is my view that this spread of interest in food irradiation and the investigational work it generated, essentially on a worldwide basis, constitutes another milestone of progress.
Still another milestone came into being as a result of the research carried out on almost every food. This milestone is the recognition that food irradiation is a broadly applicable process. Irradiation proved to be yet another means for treating foods — for solving many problems, for innovation, with unique aspects to challenge the imagination — a process that in some manner can benefit almost every food.

Fruits can be preserved, freed of insects, their ripening delayed and senescence inhibited. Similar benefits occur with vegetables. Cereal grains and legumes can be freed of insects. Meats and poultry can be radappertized to match thermal sterilization, but with superior results. Radurization extends the shelf-life of fresh meats. Meat parasites can be inactivated. Results with seafood parallel those with meats. Animal feeds can be freed of Salmonellae. The list of potential uses in treating foods with radiation seems endless. The accomplishments of the research of the past four decades proving the broad applicability of irradiation in treating foods surely is another milestone of progress.

Right from the beginning one area of great effort was directed toward providing an answer to the question: Are irradiated foods safe to eat? Unlike other food processes whose origin is in the past, irradiation has had to prove that it is safe before it can be used. This is a requirement of the scientifically sophisticated era we are in today. Additionally, and unfortunately, emphasis on the need for proof of safety is the result of association of food irradiation with radiation, which has become something to be feared in our times.

Since the changes irradiation produced in foods were not understood in the early years, the question regarding the safety of irradiated foods was difficult to answer. Under these circumstances the only available approach for evaluating safety was to feed irradiated foods to test animals and to observe their performance. This technique was an adaptation of one used to evaluate the safety of chemical food additives but there is a major problem in applying it to irradiated foods. Unlike a chemical food additive, the test material itself is the irradiated food and this imposes a limitation on how much can be fed to the test animal. There is no way to magnify its action by feeding large quantities as is done with food additives.

Despite this problem, many animal feeding studies on irradiated foods were conducted. Important is the finding that, when properly carried out, none of these studies revealed any health hazards associated with the consumption of irradiated foods. Nonetheless, additional testing was required by regulatory government agencies, in particular the US Food and Drug Administration.

As time went on, although the required testing remained basically animal feeding, it became more and more complex, requiring a great deal of effort, time and money. One very severe requirement was that each and every food that was to be irradiated had to be tested separately under the specific conditions it was to be irradiated. This requirement added enormously to the burden of the evaluation of safety.

This situation became a morass. Progress was held up for more than ten years. Some nations terminated their programmes. One important effect was
that the food industry refused to invest development money in a process that they were not certain they would ever be permitted to use.

I am sure that we would be bogged down still today, and perhaps food irradiation would even be a lost cause were it not for another development that appeared at a crucial time.

One problem with radappertized meats is the development of a characteristic off-flavour. This problem spurred studies to determine what substances are produced in irradiated foods in order to account for the undesired flavour. Unfortunately in the early years no analytical technique was available that was able to provide the information needed on the radiolytic products in meats.

The breakthrough came with the availability of gas chromatography and associated techniques which were developed about this time and which proved to have the sensitivity and discrimination needed to identify the volatile radiolytic products formed in meats at magnitudes of the order of parts per million. The first paper on work of this kind, of which I am aware, was reported in the first IAEA/FAO International Symposium on Food Irradiation in 1966 by Dr. Charles Merritt, Jr., of the US Army Natick Laboratories. Strangely, information useful in identifying the cause of the off-flavour in meats was not provided by this work, although it did reveal what substances are formed by radiation. The real value of this work is that it opened up the approach of using radiation chemistry in evaluating the toxicological safety of irradiated foods.

In this period radiation chemistry had been developing as a separate discipline, but it had not been concerned very much with food irradiation. In the years succeeding Merritt's initial work there developed a good understanding of the radiation chemistry of foods. This understanding has provided clear evidence that, from a toxicological point of view, irradiated foods contain no substance as a result of irradiation that constitutes a consumer health hazard. Certainly the evidence of radiation chemistry combined with all the information derived from animal testing leads to such a conclusion.

This is a very important milestone. In fact, if there is such a thing as a keystone among milestones, this is it. In passing it we emerged from the morass of the early and midyears of frustration and dilemma. It has brought us into the period where we are seeing the issuance of regulatory approvals for the commercial use of food irradiation.

In the attainment of this milestone recognition must be given to contributions of many individuals and organizations. Among the organizations we can identify the International Project in the Field of Food Irradiation, which from its inception in 1971 until 1981 carried out a programme to evaluate the safety of irradiated foods. Major factors in the total activity were also the IAEA, FAO and WHO. The culmination of these efforts was the declaration by the Joint FAO/IAEA/WHO Expert Committee that:

"... the irradiation of any food commodity up to an overall average dose of 10 kGy presents no toxicological hazard: hence, toxicological testing of food so treated is no longer required."
The result of our passing this milestone is that we are at the stage of beginning commercialization of food irradiation. It is already underway in some countries, notably Japan, South Africa, the Netherlands, Belgium, the Union of Soviet Socialist Republics and the United States of America. As regulatory approvals increase in number and scope we can anticipate increased commercial use of food irradiation as it takes its place among the standard food processes and is put to use where it applies.

In looking back to the beginnings of the serious interest in food irradiation we see a record of advances for about 40 years. The goal of this effort — commercial use on a broad basis — is at hand.

Yet we know that work remains to be done. Can we foresee our needs? Can we plan now for future activities?

My belief is that these questions should be answered affirmatively. I realize that anyone who attempts to foresee the future does so at considerable risk. Yet I believe that there is value in attempting to seek guidance from past events to help us with future activities. For that reason, for what they may be worth, I offer a few ideas on future activities that I believe will prove important.

MAXIMUM DOSE

The Joint FAO/IAEA/WHO Expert Committee stated that all foods irradiated with doses up to 10 kGy present no toxicological hazard. Except for spices and dried vegetable seasonings, national regulatory agencies so far have limited doses to below 10 kGy, in conformity with the statement of the FAO/IAEA/WHO expert committee. Yet for some uses of food irradiation doses greater than 10 kGy are needed. I suggest that a part of our future activities needs to be concerned with the obtaining of approvals for doses greater than 10 kGy, perhaps up to 50 kGy. We need not delay the taking of such action. Steps in this direction can be initiated now. I urge that this be done.

RADIATION SOURCES

Today two kinds of radiation sources for food irradiation are available: machines and radionuclides. In the future, I believe, we will move away from radionuclides and go to machine sources. Radionuclide sources present problems we would like to avoid, problems almost entirely associated with the fact that we cannot ‘turn off’ these sources. We recognize environmental problems, problems in the handling and operation of these sources and also economic problems.

Today the machine sources are primarily electron beam generators. Unfortunately the 10 MeV upper energy limit for electron beams used to irradiate foods
does not provide adequate penetration for treating many foods. The limit for X-rays is 5 MeV. This provides more penetration than we get with the gamma rays of $^{137}$Cs and $^{60}$Co. The use of a machine source, such as an X-ray generator, which can be turned off, will permit avoidance of the particular problems that radionuclide sources have and at the same time provide the needed penetration capabilities.

New developments in X-ray generators encourage the belief that X-ray machines will be the radiation sources of choice in the future.

**FACILITY EFFICIENCY**

With the commercialization of food irradiation, greater attention will have to be paid to facility efficiency. This will involve not only improved source efficiency, but also overall facility efficiency, such as may be obtained by computer-controlled programming and operation of the facility. The beginnings of this can be seen in existing facilities.

As the use of food irradiation increases it can be anticipated that fewer general-purpose irradiators will be employed and, instead, special-purpose facilities will be used for particular types of operations. One aspect of this specialization will be improved efficiency.

**FRUIT AND VEGETABLE IRRADIATION**

It is my view that more research is needed into the irradiation of fresh fruits and vegetables. These foods can be sensitive to radiation and some potential uses have not been achieved because of various phytotoxic effects of radiation. We have tended to accept these limitations and have done without some potential uses. A better understanding of the relationship between irradiation and the post-harvest pathology, physiology and biochemistry of these living foods is needed.

Most efforts to apply irradiation to fruits and vegetables have been based on acceptance of present practices for handling them. What may be needed in order to use irradiation more effectively in some cases is to modify these established practices. I would include in this approach the gamut of culturing, harvesting, storage, transport and handling procedures. Additionally modification of the foods themselves through genetic changes may be important.

Finally, I believe that radappertization of fruits and vegetables deserves more attention than it has been given so far.

Hopefully, additional research will solve some of the problems that are preventing broader use of irradiation of fruits and vegetables.
REPLACEMENT OF CHEMICALS

It is recognized that irradiation can replace some chemicals now used with foods. It appears to me, however, that we have generally waited for the chemicals to encounter problems before suggesting the use of irradiation. Yet in some situations we can argue for irradiation's superiority — no toxic residues; inactivation of insects regardless of the stage of development, egg or adult or any stage in between; effective wherever the insect is, on the surface or in the interior of the food. I suggest a more aggressive approach be undertaken in order to determine where irradiation is better than a chemical substance. This may uncover uses for irradiation hitherto not considered.

One possibility along this line is the problem of farm soils which are contaminated with insects. At present such soils are treated with chemical pesticides, for example, ethylene dibromide. These chemical pesticides can transfer to the food crop and become a consumer health hazard. Could not irradiation be applied to the fallow soil and succeed where chemicals now are used? A not very large dose would serve to inactivate the insects and there would be no toxic chemicals to contaminate the foods.

FOOD INDUSTRY PARTICIPATION

There is another milestone in the offing that I believe could be of major importance. Up to now virtually none of the research and development concerned with food irradiation did involve food industry participation. With the issuance of government regulations permitting use of the process it can be anticipated that industry will become active. When this occurs we look forward to a very much enlarged discovery of ways that irradiation can be used. Only industry knows of many of its problems in food processing. Industry is best able to appraise opportunities for product development.

The input of industry should greatly enlarge the scope of the usefulness of food irradiation.

DEVELOPING COUNTRIES

There has been a general understanding that the usefulness of food irradiation may be different in developed and in developing countries. Developed countries usually have less need for food irradiation because they have in place now food supply systems that effectively fulfil their requirements. Irradiation may succeed in these countries only by replacing something else that is already present.

In developing countries there may not be an effective procedure available to aid in food preservation and distribution. Not only is improvement needed to
reduce food losses and to facilitate distribution, but with no effective system in place, irradiation can be installed without having to overcome an existing competitive process. One can conclude that opportunities and need for food irradiation may be greater in the developing countries.

As I understand it, the FAO/IAEA/WHO programme in food irradiation has been oriented to giving more assistance to the developing countries than to developed countries. Other programmes, such as those of individual nations, could provide similar assistance to the developing countries. In some countries barriers to such assistance exist, however, and are the result of lack of approval for the use of food irradiation in those countries. In the United States of America, for example, the Agency for International Development, which is the federal government agency for foreign aid, is prohibited from assisting another nation in food irradiation until the Food and Drug Administration has approved the process for use in the USA.

In the belief that such barriers to assistance are soon to be removed, there is reason to anticipate that greater assistance may be made available to less developed countries.

Such assistance may take a number of forms. The joint FAO/IAEA programme has been directed primarily toward sponsoring research and to providing training. Additional meaningful assistance aimed at implementing food irradiation could include measures which provide facilities for commercial operations. Business ventures for the domestic or foreign marketing of irradiated foods likewise could be assisted.

I suggest that a productive activity in this direction would be a proper future milestone target.

CONSUMER EDUCATION

The last future area I will mention is concerned with consumer acceptance of irradiated foods. While we may have confidence that the consumer will accept irradiated foods, we know that there can be problems in this area. There are already experiences on record that point to controversy and resistance. We cannot take a position of ignoring this aspect of food irradiation.

If one holds the view that the problems in gaining consumer acceptance are the result of lack of information, or even of his having received misinformation, and if one has confidence that presenting him with the true facts regarding the safety of irradiated foods will lead to his acceptance, then I believe that what is needed is consumer education.

How to get the facts to the consumer, what to tell him, who is to tell him — these are questions for which we need answers. This is a programme we should organize now and put into action soon. Perhaps action should be timed to coincide with the issuance of regulations for food irradiation in each nation.
We must recognize that there are those who oppose food irradiation and that there are some who will be active in their opposition. Regardless of the motivation for their opposition, we know that they are in error. Unless we challenge them, they could prevail.

The time for developing a consumer education programme is now. It should not be postponed. It is a job for all of us.

We need leadership to organize such an effort. A recent statement of the World Health Organization suggests we can get help from that organization and from the FAO and IAEA. I quote:

“This outline of WHO’s involvement in the field of food irradiation indicates that the Organization is confident that this technology can properly be utilized in an attempt to promote food safety. WHO will therefore continue to collaborate with its sister organizations, IAEA and FAO, in its efforts to secure for food irradiation technology its appropriate place in helping increase a safe food supply for mankind.”1

May I suggest that there be organized an active effort regarding consumer education. I suggest, additionally, that each of us in his own way and with his own capability accept a role in consumer education.

The accomplishment of consumer education, and thereby, consumer acceptance, can be yet another milestone of progress.

---

EXPERT PANEL REPORTING

(Session VIII)

Chairman

D.A.A. MOSSEL
Netherlands
In association with the Symposium, the sponsoring organizations invited an Expert Panel to discuss topics related to the implementation of food irradiation in developing countries, and to report its conclusions and recommendations for discussion at the final session of the Symposium. Each member of the Panel attended in an individual capacity and not as a representative of his or her affiliated organization.

The Panel met on a number of occasions during the Symposium. It was agreed that the question of implementation of food irradiation in developing countries could not be considered in isolation, since many aspects were common to all countries and progress in one country often depended on progress in another. Nevertheless, the needs of developing countries were given particular attention in the recommendations which form the final section of this report.

The Panel first considered the principal requirements which had to be met before implementation of the food irradiation process could take place, and identified those which currently needed the most attention.

**Tasks substantially achieved**

- Demonstrate technological efficacy
- Demonstrate absence of harmful side effects.
Tasks requiring completion

- Demonstrate economic feasibility
- Establish legislative framework
- Secure consumer acceptance.

Once all the objectives listed had been satisfactorily achieved, the Panel considered that commercial introduction of the process, while still requiring the expenditure of considerable resources both financial and technological, would nevertheless be relatively straightforward.

DEMONSTRATION OF ECONOMIC FEASIBILITY

Three areas were considered to offer the greatest prospects of economic benefit from the introduction of food irradiation, while at the same time giving rise to immense potential benefits to humanity. These areas are:

1. Reduction in post-harvest losses
2. Promotion of international trade
3. Improvement in public health.

(1) Reduction in post-harvest losses

Losses during storage and transportation of staple foodstuffs in some developing countries may be considerable, often up to 30 or even 50% of the total crop. This can have a serious effect on the standard of nutrition of large numbers of people. The monetary value of the losses may be increased by the fact that replacement food supplies may have to be bought at greater cost. The detriment of such a situation may be further enhanced by other factors; for example, development of a food processing industry is hampered through lack of continuity of supplies of raw materials.

(2) Promotion of international trade

Irradiation of food has the potential to facilitate international trade in a number of ways. First, by preventing post-harvest losses, application of the process may result in food commodities becoming available for export which would otherwise not be in surplus. The avoidance of spoilage during transportation maintains the value of the consignment and may prevent rejection by the importing country. Particular applications of this concept include the possibility of food irradiation to satisfy quarantine requirements for fruit and vegetables, and thus permit an important expansion of international trade. Similar oppor-
tunities arise in respect of satisfaction of hygiene regulations concerning food of animal origin.

(3) Improvement in public health

The incidence of food-borne disease due to pathogenic and parasitic microorganisms is exceedingly widespread in both developed and developing countries. Irradiation of food could play an important part in reducing this incidence, with consequent advantages both economic and in terms of reduction of human suffering.

Other potential improvements in human health which would stem from the introduction of food irradiation include the possibility of reducing the quantity of nitrate and nitrite used in the preservation of certain meat products, and the replacement of chemical fumigants and pesticides used for the treatment of bacterial contamination and insect infestation of foods.

The Panel agreed that all aspects of economic feasibility had to be taken into account and quantified if possible. In addition to the cost of the radiation facility itself, there was a need for an associated infrastructure of services and facilities which might or might not already be in existence, for example:

- Adequate transportation and storage facilities for product
- Adequate power supplies for plant
- Suitable packaging materials for product
- Availability of trained operating and supervisory staff
- Provision of dosimetric services.

On the other hand, the total value of benefits accruing from the provision of an irradiation facility also needed quantification and not just the visible value of components such as food losses avoided or international currency earned. It might not be easy to ascribe a value to improve public health and quality of life, but such socio-economic factors cannot be ignored.

A complete analysis also required that a similar study be made of the costs and benefits of achieving the same or similar objectives by alternative means, including an assessment of any associated detriment. Thus the cost of alternative treatments such as the use of chemicals for fumigation or food preservation must include an allowance for possible public health effects (which in the extreme case could ultimately result in the future non-availability of the alternative).

Selection of the most suitable type and size of irradiation plant was identified as being of vital importance in achieving economic viability. The requirement for low unit cost of treatment leads towards a large, centrally located facility capable of high throughput and requiring intensive utilization. The variable pattern of food production in many developing countries is, however, not suitable for such large-scale operation and a smaller, less highly automated plant may be preferable. In either case it is considered probable that a multi-purpose plant will prove most
likely to be needed, at least in the initial period of introduction of the food irradiation process.

Selection of the type of irradiation facility and radiation sources depends not only on the physical characteristics of the differing types available (cobalt, caesium or machine), but also on their cost and availability both now and in the future.

It was considered essential that economic feasibility studies in developing countries should be supported by adequate pilot plant studies. Ideally, these should be carried out locally in order to assess fully the impact of local environmental conditions and, at the same time, to facilitate the process of technology transfer. The part which could be played (and already had been played in some cases) by Regional Aid programmes was considered to be of immense value, as was the contribution made by the International Facility for Food Irradiation Technology at Wageningen.

ESTABLISHMENT OF LEGISLATIVE FRAMEWORK

The Panel noted that introduction of the food irradiation process is critically dependent on the existence of a satisfactory system of regulatory control. While national legislation is of primary importance, international harmonization of food irradiation legislation is an essential factor in the development of international trade. In some cases, therefore, national and international considerations were of comparable significance.

It was agreed that the current disharmony of existing and proposed national legislation constitutes a significant obstacle to the economic introduction of the food irradiation process. The Codex General Standard for Irradiated Foods and the associated Code of Practice were considered to constitute a suitable basis for international harmonization of food irradiation legislation. While the reasons why individual countries were reluctant immediately to enact legislation based on the Codex Standard were appreciated, the Panel expressed the hope that acceptance of the Standard will eventually be universal.

CONSUMER ACCEPTANCE OF FOOD IRRADIATION

Acceptance of the concept of food irradiation by the consumer was recognized as being an essential prerequisite to the introduction of the process. All available methods of achieving this objective should be exploited; the production of both written and audio-visual material by international agencies, governments, and representatives of industry should be encouraged. The aim should be to inform and educate the public as to the benefits to be derived from introduction of the process, as well as its lack of harmful side effects.
It was agreed that marketing development played a useful part in the educative process, and it was satisfactory to note that where marketing promotion had taken place, consumer reaction was almost always favourable.

RECOMMENDATIONS

Arising from the Panel's deliberations, certain positive recommendations of a general nature were identified.

— There is far more knowledge concerning the safety of food irradiation as a physical process, supported by many years of research and development, than is available concerning most other food preservation techniques. It is recommended that all government agencies be urged to recognize this fact, and to take all possible steps to facilitate its introduction on a commercial scale, so that this technology can be made available for the benefit of mankind. It is suggested that parliamentarians, professional and trade associations and consumer groups should all play an important part in influencing government policy and should be encouraged to do so.

In particular, the following recommendations are considered to be those which, when implemented, will confer the greatest benefit to developing countries:

— Programmes to achieve radiation disinfestation of stored food should be expedited. Such programmes hold out the best prospect of immediate economic advantage, as well as improvement in public health by raising nutritional standards and substituting for the use of chemicals.

— Programmes to achieve radiation disinfestation of fruit as a means of satisfying quarantine requirements should also be assigned a high degree of urgency. Here the benefits are principally economic by promotion of international trade, with secondary advantages in reduction of post-harvest losses, and improvement in public health by replacement of chemicals.

— Another important area should be the introduction of irradiation as a means of reducing food-borne disease resulting from contamination by pathogenic microorganisms. The principal benefit would stem from the improvement in public health, although the promotion of international trade would also be of considerable importance.

— The establishment of Regional Aid programmes by international and national agencies should be given every encouragement. Such programmes form a very effective means of carrying out feasibility studies, including the adaptation of the process to local conditions and effecting technology transfer. FAO/IAEA should be encouraged to develop uniform guidelines for conducting economic feasibility studies so that the results of such studies can be compared.

— Potential users of the food irradiation process should be encouraged to bring to the attention of their national authorities the key role which could be
played by the adoption of a uniform legislative framework for control of the process based on the Codex General Standard for Irradiated Foods. The advantages in promoting international trade with its consequent economic and other benefits cannot be overemphasized.

- The possibility of compiling and maintaining an up-to-date inventory of existing requirements for radiation sources (isotopes and machines) for treating food and non-food items should be considered by FAO/IAEA. Such considerations should include requirements for such sources in facilities under construction or planned; projected figures for future utilization would also be useful in reconciling estimates of supply and demand.

- Every encouragement should be given to the production of educational and publicity material by national and international organizations and industry, with the aim of achieving the widest possible acceptance of the process by consumers.

- It is recommended that this report should be circulated to responsible national authorities of Member States party to FAO/IAEA. It is recognized that the International Consultative Group On Food Irradiation of which 20 countries are members could play an important role in bringing several of the recommendations stated above to fruition.
CHAIRMEN OF SESSIONS

Session I  J. FARKAS  Hungary
Session II  H.M. ROUSHDY  Egypt
Session III F.K. KÄFERSTEIN  WHO
Session IV  T. RUBIO  Chile
Session V  L. SAINT-LÈBE  France
Session VI  R.F. MORRIS  United States of America
Session VII H. GLUBRECHT  Federal Republic of Germany
Session VIII D.A.A. MOSSEL  Netherlands

SECRETARIAT OF THE SYMPOSIUM

Scientific Secretary:  J. VAN KOOIJ
Joint FAO/IAEA Division of Isotope and Radiation Applications of Atomic Energy for Food and Agricultural Development, IAEA, Vienna

Administrative Secretary:  E. PILLER
Division of External Relations, IAEA, Vienna

Editor:  B. KAUFMANN
Division of Publications, IAEA, Vienna
LIST OF PARTICIPANTS

Adamantiades, A.
Mitre Corp.,
1820 Dolley Madison Blvd,
McLean, VA 22102, United States of America

Adams, D.
The Carver Research Foundation,
Tuskegee Institute,
Tuskegee, AL 36088, United States of America

Ahlstrom, S.B.
CH2M HILL,
6121 Indian School Road, NE, Suite 206,
Albuquerque, NM 87110, United States of America

Ahmed, M.S.H.
Nuclear Research Centre,
P.O. Box 765, Baghdad, Iraq

Andreski, R.E.
Miramar Industries Incorporated,
8260 Greensboro Drive/Penthouse,
McLean, VA 22102, United States of America

Andreski, S.
Miramar Industries Incorporated,
8260 Greensboro Drive/Penthouse,
McLean, VA 22102, United States of America

Astier-Dumas, M.
Centre de recherches Foch,
45, rue des Saints-Pères, F-75006 Paris, France

Auda, H.
Nuclear Research Centre,
P.O. Box 765, Baghdad, Iraq

Badel, D.
CEA, Centre d'études scientifiques et techniques
d'Aquitaine,
B.P. 2, Le Barp, F-33830 Belin Beliet, France

Ballantine, D.S.
United States Department of Energy,
Office of Energy Research, ER-74,
Washington, DC 20545, United States of America

Banditsing, C.
Biological Science Division,
Office of Atomic Energy for Peace,
Vibhavadi Rangsit Road, Bangkhen,
Bangkok 10900, Thailand

Basker, D.
Agricultural Research Organization,
The Volcani Center,
P.O. Box 6, 50250 Bet Dagan, Israel

Batchelor, T.A.
Department of Scientific and Industrial Research,
Entomology Division, Private Bag,
Auckland, New Zealand

Beacham, L.M.
National Food Processors Association,
1401 New York Avenue,
Washington, DC 20005, United States of America

Beck, J.A.
Johnson and Johnson,
Ethicon, Inc., Route 22,
Somerville, NJ 08876, United States of America
Beghian, L.E.  
University of Lowell,  
1 University Avenue,  
Lowell, MA 01854, United States of America

Blumenthal, H.  
Center for Food Safety and Applied Nutrition,  
Food and Drug Administration,  
Room 5014, HFF-150, 200 C Street, S.W.,  
Washington, DC 20235, United States of America

Bögl, W.  
Federal Health Office,  
Institute for Radiation Hygiene,  
Ingolstädter Landstrasse 1, D-8042 Neuherberg,  
Federal Republic of Germany

Bomer, S.  
United Fresh Fruit and Vegetable Assoc.,  
P.O. Box 1417 E35,  
Alexandria, VA 22313, United States of America

Boone, W.  
Varian Associates, Inc.,  
611 Hansen Way,  
Palo Alto, CA 94303, United States of America

Borsa, J.  
Atomic Energy of Canada Ltd,  
Chalk River, Ontario K0J 1J0, Canada

Bradford, W.R.  
Ministry of Agriculture, Fisheries and Food,  
65 Romney Street, London SW1P 3RD,  
United Kingdom

Braud, M.  
UNISABI,  
B.P. 7, F-45550 Saint-Denis de l'Hôtel, France

Brooker, J.R.  
National Marine Fisheries Service,  
NOAA,  
3300 Whitehaven Street, NW,  
Washington, DC 20235, United States of America

Brynjolfsson, A.  
Department of Applied Biological Sciences,  
Massachusetts Institute of Technology,  
Cambridge, MA 02139, United States of America

Burditt, A.K.  
Yakima Agricultural Research Laboratory,  
Agricultural Research Service,  
United States Department of Agriculture,  
3706 West Nob Hill Boulevard,  
Yakima, WA 98902, United States of America

Burns, T.F.  
American Spice Trade Association,  
P.O. Box 1267, 580 Sylvan Avenue,  
Englewood Cliffs, NJ 07632, United States of America

Bustamante, R. R.  
Argatom ICSA,  
Maipu 939 PB, Buenos Aires, Argentina

Buyle, R.  
Institut national des radioéléments (IRE),  
B-6220 Fleurus, Belgium

Carter, E.  
The Carver Research Foundation,  
Tuskegee Institute,  
Tuskegee, AL 36088, United States of America
Carty, W.  Americas Magazine Organization of American States, Administration Building, 19th and Constitution Avenue, Washington, DC 20006, United States of America

Casey, M.W.  Brand Group, Inc., 640 N. LaSalle Street, Suite 655, Chicago, IL 60610, United States of America

Cayle, T.  Kraft, Inc., 801 Waukegan Road, Glenview, IL 60025, United States of America

Chang, C.N.  The Carver Research Foundation, Tuskegee Institute, Tuskegee, AL 36088, United States of America

Chawes, J.  General Foods Corp., 250 North Street, White Plains, NY, United States of America

Chishya, B.E.  National Council for Scientific Research, P.O. Box CH 158, Chelston, Lusaka, Zambia

Chung, R.A.  The Carver Research Foundation, Tuskegee Institute, Tuskegee, AL 36088, United States of America

Clavelli, V.L.  Gamma Technology International Inc., 8260 Greensboro Drive, McLean, VA 22102, United States of America

Cleland, M.R.  Iotech, Inc., 5995 South Syracuse Street, Suite 201, Englewood, CO 80111, United States of America

Cochran, R.  United States Department of Energy, Washington, DC 20545, United States of America

Cohen, H.  EBASCO Services Inc., 2 World Trade Centre, New York, NY 10048, United States of America

Collins, C.  Radiation Law Reporter, 236 Mass. Avenue, NE, Washington, DC, United States of America

Conners, C.C.  Rockwell International, Rocketdyne Division - LB II, 6633 Canoga Avenue, Canoga Park, CA 91304, United States of America

Copple, P.  Atomic Energy of Canada Ltd, Radiochemical Company, 413 March Road, P.O. Box 13500, Kanata, Ontario K2K 1X8, Canada

Dai, Yin  Institute of Food Safety Control and Inspection, Ministry of Public Health, 29 Nan-wei Road, Beijing, China
LIST OF PARTICIPANTS

Dawes, M.A. The Carver Research Foundation, 
Tuskegee Institute, 
Tuskegee, AL 36088, United States of America

De Franceschi, L. Università di Pisa, 
Pisa, Italy

De Wet, W.J. Nuclear Development Corporation of 
South Africa (Pty) Ltd, 
Private Bag X256, Pretoria 0001, South Africa

DeGraff, E.D. Neutron Products, Inc., 
P.O. Box 68, 
Dickerson, MD 20842, United States of America

Denny, C.B. National Food Processors Association, 
1401 New York Avenue, NW, 
Washington, DC 20005, United States of America

Dobkin, R.A. Atomic Industrial Forum, 
7101 Wisconsin Avenue, 
Bethesda, MD 20814, United States of America

Doores, S. 111 Borland Laboratory, 
Department of Food Science, 
The Pennsylvania State University, 
University Park, PA 16802, United States of America

Doyen, J.-B. CEA, Oris Industrie, 
B.P. 21, F-91190 Gif-sur-Yvette, France

Ehlermann, B. Bundesforschungsanstalt für Ernährung, 
Institut für Verfahrenstechnik, 
Engesserstrasse 20, D-7500 Karlsruhe, 
Federal Republic of Germany

Ehlermann, D. Bundesforschungsanstalt für Ernährung, 
Institut für Verfahrenstechnik, 
Engesserstrasse 20, D-7500 Karlsruhe, 
Federal Republic of Germany

Eiss, M. McCormick & Co., 
202 Wight Avenue, 
Hunt Valley, MD 21231, United States of America

El-Kady, E.A. Department of Plant Protection, 
Faculty of Agriculture, Ain Shams University, 
Shoubra El Kheima, Cairo 13769, Egypt

El-Zawahry, Y.A. National Centre for Radiation 
Research and Technology, 
P.O. Box 29, Nasr City, Cairo, Egypt

Engel, R.E. United States Department of Agriculture, 
Room 402-Annex, 
300 12th Street, SW, 
Washington, DC 20250, United States of America

Eukel, W.W. Brobeck Corp., 
1235 Tenth Street, 
Berkeley, CA 94710, United States of America
LIST OF PARTICIPANTS

Fabech, B. Statens Levnedmiddelinstitut,
Mørkhøn Bygade 19, D-2860 Seborg, Denmark

Farkas, J. Central Food Research Institute,
Herman Ottó ut 15, H-1022 Budapest, Hungary

Fiddler, W. Eastern Regional Research Center,
Agricultural Research Service,
United States Department of Agriculture,
600 East Mermaid Lane,
Philadelphia, PA 19118, United States of America

Fisher, F.R. National Academy of Sciences,
Washington, DC, United States of America

Fiszer, W. Laboratory of Nuclear Methods in Agriculture,
Akademia Rolnicza,
Mazowiecka 41, 60-623 Poznań, Poland

Fitte, R. A. Argatom ICSA,
Maipu 939 PB, Buenos Aires, Argentina

Frank, R. United States Department of Agriculture,
Food and Nutrition Information Center,
National Agricultural Library,
Beltsville, MD 20705, United States of America

Franklin, R.W. Pico Processing Inc.,
11618 20th Street, SE,
Everett, WA 98205, United States of America

Fraser, P. Atomic Energy of Canada Ltd,
Radiochemical Company,
413 March Road, P.O. Box 13500,
Kanata, Ontario K2K 1X8, Canada

Friedman, S.T. Ionizing Energy Company of Canada Ltd,
P.O. Box 393, Station A,
Fredericton, New Brunswick E3B 4Z9, Canada

Gardner, K.J. MARS Ltd,
Corporate Services,
Banbury Road, Slough, Buckinghamshire,
United Kingdom

Gasper, K.A. Rockwell Hanford Operations,
P.O. Box 800,
Richland, WA 99352, United States of America

Giachetti, I. Secrétariat d'État à la consommation,
13, rue Saint-Georges, F-75009 Paris, France

Giddings, G.G. Isomedix, Inc.,
11 Apollo Drive,
Whippany, NJ 07981, United States of America

Glubrecht, H. Institut für Biophysik, Universität Hannover,
Herrenhäuser Strasse 2, D-3000 Hannover 21,
Federal Republic of Germany
LIST OF PARTICIPANTS

Goebel, J.N. 
NUKEM GmbH, 
Rodenbacher Chaussee 6, 
Postfach 110080, D-6450 Hanau 11, 
Federal Republic of Germany

Grant, R.B. 
Department of Commerce, 
14th and Constitution Avenue, NW, Room 4878, 
Washington, DC 20230, United States of America

Green, E.R. 
National Food Processors Association, 
1401 New York Avenue, NW, Suite 400, 
Washington, DC 20005, United States of America

Gschwend, W. 
Inter American Operations, 
United States Peace Corps, 
806 Connecticut Avenue, NW, 
Washington, DC 20526, United States of America

Hannah, K.W. 
Columbia Research Corporation, 
1 Metropolitan Grove Court, 
Gaithersburg, MD 20878-4097, 
United States of America

Hecht, M.M. 
Fusion Energy Foundation, 
304 West 58th Street, 
New York, NY 10019, United States of America

Heldman, D.R. 
Campbell Institute for Research and Technology, 
Campbell Soup Company, 
Campbell Place, 
Camden, NJ 08101, United States of America

Henderson, A.M. 
Castle and Cooke Inc., 
P.O. Box 3080, 2300 Glades Blud, 
Boca Raton, FL 33431, United States of America

Henon, Y. 
CEA, Centre d'études nucléaires de Cadarache, 
B.P. 1, F-13115 Saint-Paul-lex-Durance, France

Holzapfel W.H. 
Department of Microbiology, 
University of Pretoria, 
ZA-0002 Pretoria, South Africa

Hungate, F.P. 
Battelle Northwest, 
P.O. Box 999, 
Richland, WA 99352, United States of America

Hunter, B. 
Western Industries, 
P.O. Box 419, 475 Prospect Avenue, 
West Orange, NJ 07052, United States of America

Ikuby, P. 
The Carver Research Foundation, 
Tuskegee Institute, 
Tuskegee, AL 36088, United States of America

Ito, H. 
Takasaki Radiation Chemistry Research Establishment, 
Japan Atomic Energy Research Institute, 
1233 Watanuki-machi, 
Takasaki-shi, Gunma-ken 370-12, Japan
LIST OF PARTICIPANTS

Iverson, S.L.  Atomic Energy of Canada Ltd,
Whitewell Nuclear Research Establishment,
Pinawa, Manitoba ROE 1L0, Canada

Jaddou, H.  Nuclear Research Centre,
P.O. Box 765, Baghdad, Iraq

Jaffan, R.  Agency for International Development,
S&T/AGR/APS-18,
Washington, DC 20523, United States of America

Jarboe, A.  United States Department of Agriculture,
Technology Transfer and Assessment,
Room 4911 South Building,
Washington, DC 20250, United States of America

Jarrett, R.  United States Department of Agriculture,
RSS, R226, B001, BARC - W,
Beltsville, MD 20705, United States of America

Jorgensen, M.P.  Queensland Department of Primary Industries,
P.O. Box 46, Brisbane QLD 4001, Australia

Josephson, E.S.  Department of Applied Biological Sciences,
Massachusetts Institute of Technology,
77 Massachusetts Avenue,
Cambridge, MA 02139, United States of America

Kálmán, B.  AGROSTER Irradiation Company,
Jászberényi ut 5, H-1106 Budapest, Hungary

Kasaoka, G.S.  Technology Transfer and Assessment Staff,
Food Safety and Inspection Service,
United States Department of Agriculture,
Room 4911-South Building,
14th and Independence Avenue, SW,
Washington, DC 20250, United States of America

Katušin-Ražem, B.  "Ruder Boškovié" Institute,
Bijenicka cesta 54, P.O. Box 1016,
YU-41000 Zagreb, Yugoslavia

Katz, A.  Agrolife S.A.,
8-K Oakhill Estates,
Gladwyn, PA, United States of America

Kauffman, F.L.  United States Food and Drug Administration,
HFF-214, 200 'C' Street, SW,
Washington, DC 20204, United States of America

Kaylor, J.D.  National Marine Fisheries Service,
Gloucester Laboratory,
Emerson Avenue,
Gloucester, MA 01930, United States of America

Keehn, W.T.  Gaines Foods, Inc.,
1551 E. Willow Street,
Kankakee, IL 60901, United States of America
LIST OF PARTICIPANTS

Kelly, J.L.  
University of Virginia,  
Department of Nuclear Engineering  
and Engineering Physics,  
Reactor Facility,  
Charlottesville, VA 22901, United States of America

Keraron, Y.  
Société générale pour les techniques nouvelles  
(SGN),  
F-78184 Saint-Quentin-en-Yvelines Cédex, France

Kerin, D.  
Univerza v Mariboru,  
Visjá Agronomjska Sola,  
Vrbanska 30,  
YU-62000 Maribor, Yugoslavia

Khán, I.  
Nuclear Institute for Food and Agriculture,  
P.O. Box 446, Peshawar, Pakistan

Klein, B.  
University of Illinois,  
Department of Foods and Nutrition,  
386 Bevier Hall, 905 S. Goodwin,  
Urbana, IL 61801, United States of America

Knight, K.  
Energy Pathways Inc.,  
251 Laurier Avenue West, Suite 304,  
Ottawa, Ontario K1P 5J6, Canada

Kovács, E.  
Central Food Research Institute,  
Herman Ottó ut 15, H-1022 Budapest, Hungary

Krishnamurthy, K.  
Bhabha Atomic Research Centre,  
Trombay, Bombay 400 085, India

Kunstadt, P.  
Atomic Energy of Canada Ltd,  
Radiochemical Company,  
413 March Road, P.O. Box 13500,  
Kanata, Ontario K2K 1X8, Canada

Kuznesof, P.M.  
United States Food and Drug Administration,  
Center for Food Safety and Applied Nutrition,  
HFF-458, 200 C Street, SW,  
Washington, DC 20204, United States of America

Lagunas-Solar, M.C.  
Crocker Nuclear Laboratory,  
University of California,  
Davis, CA 95616, United States of America

Laizier, J.  
CEA, Centre d'études nucléaires de Saclay,  
B.P. 21, F-91190 Gif-sur-Yvette, France

Langguth, S.  
Bund für Lebensmittelrecht und  
Lebensmittelkunde eV,  
Godesberger Allee 157, D-5300 Bonn 2,  
Federal Republic of Germany

Lapidot, M.  
Soreq Nuclear Research Center,  
Yavne 70600, Israel

Lastarria Tapia, H.J.  
Universidad Nacional Agraria la Molina,  
Av. La Universidad s/n, Apartado 456,  
La Molina, Lima, Peru
LIST OF PARTICIPANTS

Lauer, B.H.  
Division of Chemical Evaluation,  
Bureau of Chemical Safety,  
Health Protection Branch,  
Department of Health and Welfare,  
Ottawa, Ontario K1A 0L2, Canada

Leaf, M.  
Food Chemical News,  
1101 Pennsylvania Avenue, SE,  
Washington, DC 20003, United States of America

Leemhorst, J.G.  
GAMMASTER BV,  
Postbus 4250, NL-6710 Ede, Netherlands

Leembitu, Reio  
The National Food Administration of Sweden,  
P.O. Box 622, S-751 26 Uppsala, Sweden

Leone, F.A.  
United States Department of Energy,  
Washington, DC 20545, United States of America

Lewis, P.F.  
United States Department of Commerce,  
Room 4510,  
Washington, DC 20230, United States of America

Licciardello, J.J.  
National Marine Fisheries Service,  
Gloucester Laboratory,  
Gloucester, MA 01930, United States of America

Lipman, W.  
William F. Lipman & Associates,  
223 Woodlawn Road,  
Baltimore, MD 21210, United States of America

Loretan, P.A.  
The Carver Research Foundation,  
Tuskegee Institute,  
Tuskegee, AL 36088, United States of America

Lu, J.Y.  
The Carver Research Foundation,  
Tuskegee Institute,  
Tuskegee, AL 36088, United States of America

Luckey, T.D.  
1009 Sitka Court,  
Loveland, CO 80537, United States of America

Lustre, A.F.  
Food Processing Department,  
Food Terminal Inc.,  
East Service Road, South Superhighway,  
Taguig, Metro Manila, Philippines

Machurek, J.  
The Machurek Group, Inc.,  
5922 Anniston Road,  
Bethesda, MD 20817, United States of America

MacQueen, K.F.  
724 Courtenay Avenue,  
Ottawa, Ontario K2A 3C1, Canada

Maddox, J.N.  
United States Department of Energy,  
Washington, DC 20545, United States of America

Maha, M.  
Centre for the Application of Isotopes and Radiation,  
P.O. Box 2, Kebayoran Lama,  
Jakarta Selatan, Indonesia
LIST OF PARTICIPANTS

Mahmoud, A.A.  
National Centre for Radiation Research and Technology,  
P.O. Box 29, Nasr City, Cairo, Egypt

Mallett, J.C.  
Department of Biological Sciences,  
University of Lowell,  
Lowell, MA 01854, United States of America

Manalo, J.A.  
The Philippine Women's University,  
Taft Avenue, Manila, Philippines

Manoto, E.  
Philippine Atomic Energy Commission,  
Atomic Research Centre,  
Dilliman, Quezon City, Philippines

Marin, H.  
Compagnie d'aménagement des Coteaux de Gascogne,  
B.P. 21, F-65001 Tarbes, France

Maros, P.G.  
E.I. DuPont de Nemours and Company, Inc.,  
Concord Plaza - Springer Building,  
Wilmington, DE 19898, United States of America

Martín Cutinella, V.J.  
Centro de Investigaciones Nucleares,  
Universidad de la República O. del Uruguay,  
Rambla Euskalerría s/n,  
Casilla de Correo 860, Montevideo, Uruguay

Martin, R.E.  
National Fisheries Institute,  
2000 Main Street, NW,  
Washington, DC 20036, United States of America

Marulli, A.S.  
Western Industries,  
P.O. Box 419, 475 Prospect Avenue,  
West Orange, NJ, United States of America

Matin, M.A.  
Institute of Food and Radiation Biology,  
Bangladesh Atomic Energy Commission,  
P.O. Box 3787, Ganakbari, Savar, Dhaka 2, Bangladesh

Matthews, S.M.  
Lawrence Livermore National Laboratory,  
L-389, P.O. Box 808,  
Livermore, CA 94550, United States of America

Mattson-Cotter, F.L.  
Crescent Foods Co.,  
P.O. Box 3026,  
Seattle, WA 98004, United States of America

Mayo, W.L.  
Atomic Industrial Forum,  
7101 Wisconsin Avenue, 12th Floor,  
Bethesda, MD 20814-4805, United States of America

McAllister, L.  
E. Bruce Harrison Company,  
605 14th Street, NW,  
Washington, DC 20005, United States of America

McCabe, N.  
National Food Processors Association,  
1401 New York Avenue, NW, Suite 400,  
Washington, DC 20005, United States of America
McKay, R.  
Department of Consumer & Corp. Affairs,  
Place du Portage,  
Hull, Quebec K1A 0C9, Canada

McLaughlin, W.L.  
National Bureau of Standards,  
Building 245, Room C216,  
Gaithersburg, MD 20899, United States of America

McMain, A.T., Jr.  
Radiation Technology Development,  
GA Technologies Inc.,  
P.O. Box 85608,  
San Diego, CA 92138, United States of America

McMullen, W.  
United States Department of Energy,  
Albuquerque Office,  
P.O. Box 5400,  
Albuquerque, NM 87115, United States of America

McMurray, C.H.  
Department of Agriculture and Food Chemistry,  
Newfordge Lane, Belfast BT9 5PX,  
United Kingdom

McNamara, R.C.  
Emergent Technologies, Inc.,  
Drawey 3218,  
San Jose, CA 95156, United States of America

Mercader, J.P.  
Asean Food Handling Bureau,  
8th Floor, Syed Kechik Foundation Building,  
Bangsar, Kuala Lumpur, Malaysia

Metzger, C.J.  
USA/AID,  
Multinational Agribusiness Systems, Inc.,  
1401 Wilson Blvd.,  
Arlington, VA 22209, United States of America

Milburn, B.  
United States Department of Agriculture,  
Office of International Cooperation and Development,  
14th and Independence Avenue, 3110 - Aud.,  
Washington, DC 20250, United States of America

Mills, S.  
Science Council of Canada,  
16th Floor, 100 Metcalfe,  
Ottawa, Ontario K1P 0M5, Canada

Modderman, J.P.  
United States Food and Drug Administration,  
Division of Chemistry and Physics,  
200 C Street, SW,  
Washington, DC 20204, United States of America

Montesalvo, M.  
University of Lowell,  
1 University Avenue,  
Lowell, MA 01854, United States of America

Morris, R.F.  
Agency for International Development,  
Office of Agriculture,  
Room 413A SA-18,  
Washington, DC 20523, United States of America
LIST OF PARTICIPANTS

Morrison, R.M. Economic Research Service, United States Department of Agriculture, 500 12th Street, SW, Room 128, Washington, DC 20250, United States of America

Morrison, T.A. Jack Faucett Associates, 5454 Wisconsin Avenue, Suite 115S, Chevychase, MD 20815, United States of America

Mosse, D. CEA, Laboratoire de métrologie des rayonnements ionisants (LMRI), B.P. 21, F-91190 Gif-sur-Yvette, France

Mossel, D.A.A. Faculty of Veterinary Medicine, Department of the Science of Food of Animal Origin, The University of Utrecht, P.O. Box 175, NL-3508 TD Utrecht, Netherlands

Moy, J.H. Department of Food Science and Human Nutrition, University of Hawaii at Manoa, 1920 Edmondson Road, Honolulu, HI 96822, United States of America

Multon, J.L. Institut national de la recherche agronomique (INRA), Rue de la Géraudière, F-44072 Nantes Cédex, France

Muñoz, R. Instituto de Ciencias Nucleares de la Escuela Politécnica Nacional, Quito, Ecuador

Murphy, J.D. ANEFCO, Inc., 904 Ethan Allen Hwy., Ridgefield, CT 06877, United States of America

Mussman, H.C. National Food Processors Association, 1401 New York Avenue, NW, Room 400, Washington, DC 20005, United States of America

Nelson, D. Gaines Foods, Inc., 1551 E. Willow Street, Kankakee, IL 60901, United States of America

Niemand, J.G. ISO-STER (Pty) Ltd, P.O. Box 3219, 1620 Kempton Park, South Africa

O'Sullivan, E. International Nutronics, Inc., 1237 North San Antonio Road, Palo Alto, CA 94303, United States of America

Olorunda, A.O. Department of Food Technology, Faculty of Technology, University of Ibadan, Ibadan, Nigeria

Olson, D.G. Iowa State University, 215 Meat Laboratory, Ames, IA 50011, United States of America

Oosterheert, W.F. RIKILT, P.O. Box 230, NL-6700 AE Wageningen, Netherlands
LIST OF PARTICIPANTS

Ouwerkerk, T.  
Energy Pathways Inc.,
251 Laurier Avenue West, Suite 304,
Ottawa, Ontario K1P 5J6, Canada

Paakkanen, H.J.  
Ministry of Trade and Industry,
Aleksanterinkatu 10, SF-00170 Helsinki, Finland

Parry, R.M.  
United States Department of Agriculture,
Agricultural Research Service,
BARC Bldg. 005,
Beltville, MD 20705, United States of America

Pauli, G.H.  
Center for Food Safety and Applied Nutrition,
Food and Drug Administration,
200 C Street, SW,
Washington, DC 20204, United States of America

Peaco, J.W., Jr.  
National Oceanic and Atmospheric Administration,
Office of the General Counsel,
United States Department of Commerce,
Page 2, Room 386,
3300 Whitehaven Street, NW,
Washington, DC 20235, United States of America

Pearce, S.R.  
Atomic Energy of Canada Ltd,
275 Slater Street,
Ottawa, Ontario K1A 0S4, Canada

Petruzzello, M.  
E. Bruce Harrison Company,
605 14th Street, NW,
Washington, DC 20005, United States of America

Phan, D.  
Laboratoire national d'essais,
1, rue Gaston Boissier, F-75015 Paris, France

Pickering, H.C.  
F.W. Energy Applications, Inc.,
110 S. Orange Avenue,
Livingston, NJ 07039, United States of America

Poirier Drucker, D.  
CNFTSV,
Rue du Vercors,
ZI de Corbas-Montmartin, F-69960 Corbas, France

Pollard, S.  
United States Department of Agriculture,
300 12th Street, SW,
Washington, DC 20250, United States of America

Porter, W.  
United States Department of Energy,
International Affairs,
Washington, DC 20585, United States of America

Post, A.  
United States Department of Agriculture,
300 12th Street,
Washington, DC 20250, United States of America

Pretanik, J.S.  
National Broiler Council,
1155 15th Street, NW,
Washington, DC 20005, United States of America
Pritchard, T.W., III. Atomic Industrial Forum,  
7101 Wisconsin Avenue,  
Bethesda, MD 20814, United States of America

Prusik, T.P. Allied Corporation,  
P.O. Box 1021R,  
Morristown, NJ 07960, United States of America

Quevedo, F. Panamerican Health Organization,  
525 23rd Street, NW,  
Washington, DC 20037, United States of America

Ramm, R.A. Department of Health,  
P.O. Box 48, Brisbane QLD 4001, Australia

Ransohoff, J.A. Neutron Products, Inc.,  
301 + 349 + 5001,  
Dickerson, MD 20842, United States of America

Rao, R.D. Alabama A & M University,  
Department of Food Science,  
Box 264,  
Normal, AL 35762, United States of America

Raymond, N. 2101 22nd Street, NW,  
Washington, DC 20437, United States of America

Remini, W.C. United States Department of Energy,  
Washington, DC 20545, United States of America

Reyes Lujan, J. Instituto Nacional de Investigaciones  
Nucleares (ININ),  
Benjamín Franklin 161, 6 Piso,  
Col. Escandón, Salazar, Mexico 11, D.F., Mexico

Reynolds, A.B. University of Virginia,  
Department of Nuclear Engineering and  
Engineering Physics,  
Reactor Facility,  
Charlottesville, VA 22901, United States of America

Richman, J.W. Canadian Fusion Fuels Technology Program,  
Ontario Hydro,  
2700 Lakeshore Road, West,  
Mississauga, Ontario L5J 1K3, Canada

Rigney, C.J. Gosford Horticultural Postharvest Laboratory,  
P.O. Box 355, Gosford NSW 2250, Australia

Riley, G.E. Columbia Research Corporation,  
1 Metropolitan Grove Court,  
Gaithersburg, MD 20870-4097,  
United States of America

Riordan, M.J. Department of Health,  
P.O. Box 5013, Wellington, New Zealand

Risvik, E. Norwegian Food Research Institute,  
PB 50, N-1432 AAS-NLH, Norway
LIST OF PARTICIPANTS

Roberts, T.
Economic Research Service, 
United States Department of Agriculture, 
500 12th Street, SW, Room 112, 
Washington, DC 20250, United States of America

Rocchi, A.-M.
CEA, Centre d'études nucléaires de Cadarache, 
B.P. 1, F-13115 Saint-Paul-lez-Durance, France

Rodrigues, A.M.
RPC Industries, 
P.O. Box 3306, 
Hayward, CA 94540, United States of America

Rosenberg, L.J.
PCI, 
604 Clear Spring Road, 
Great Falls, VA 22066, United States of America

Ross, G.D.
Ionizing Energy Company of Canada Ltd, 
P.O. Box 393, Station A, 
Fredericton, New Brunswick E3B 4Z9, Canada

Roushdy, H.M.
National Centre for Radiation 
Research and Technology, 
101, Kasr El-Eini Street, Cairo, Egypt

Rubio, T.
Comisión Chilena de Energía Nuclear, 
Amunategui No. 95, Casilla 188-D, Santiago, Chile

Ruprecht, G.V.
Griffith Laboratories Ltd, 
757 Pharmacy Avenue, 
Scarborough, Ontario M1L 3J8, Canada

Sadat, T.
CGR MeV, 
551, rue de la Minière, F-78530 Buc, France

Saini, R.S.
The Carver Research Foundation, 
Tuskegee Institute, 
Tuskegee, AL 36088, United States of America

Saint-Lèbe, L.
CEA, Centre d'études nucléaires de Cadarache, 
B.P. 1, F-13115 Saint-Paul-lez-Durance, France

Schilt, L.
Ralston Purina Company, 
Checkerboard Square, 
St. Louis, MO 63164, United States of America

Schubert, J.
University of Maryland, 
Baltimore County Campus, 
Department of Chemistry, 
Catonsville, MD 21228, United States of America

Schubiger, G.
Comité suisse du codex alimentarius, 
Case Postale 88, 
CH-1814 Latour de Peilz, Switzerland

Sellers, D.B.
Gaines Foods, Inc., 
1551 E. Willow Street, 
Kankakee, IL 60901, United States of America
LIST OF PARTICIPANTS

Shibko, S.I. Center for Food Safety and Applied Nutrition, Food and Drug Administration, 200 'C' Street, SW, Washington, DC 20204, United States of America

Shieh, J.J. Eastern Regional Research Center, Agricultural Research Service, United States Department of Agriculture, 600 East Mermaid Lane, Philadelphia, PA 19118, United States of America

Shore, C. United States Department of Agriculture, National Agricultural Library, NAL Building, Room 304, Beltsville, MD 20705, United States of America

Simic, M. National Bureau of Standards, Building 245, Room C216, Gaithersburg, MD 20899, United States of America

Singh, H. Atomic Energy of Canada Ltd, Whiteshell Nuclear Research Establishment, Pinawa, Manitoba R0E 1L0, Canada

Sivinski, J.S. CH2M HILL, 6121 Indian School Road, NE, Suite 206, Albuquerque, NM 87110, United States of America

Slavin, J.W. Joseph W. Slavin and Associates, 8203 Ascalibur Court, Annandale, VA 22003, United States of America

Soemartaputra, M.H. Centre for the Application of Isotopes and Radiation, National Atomic Energy Agency, P.O. Box 2, Kebayoran Lama, Jakarta Selatan, Indonesia

Spencer, C. United States Department of Agriculture, FSIS/MPITS/TTA, Room 4911 - South, Washington, DC 20250, United States of America

Stapell, D. United Fresh Fruit and Vegetable Association, 727 N. Washington Street, Alexandria, VA 22314, United States of America

Stersky, A.K. Canadian International Development Agency, 200 Promenade du Portage, Hull, Quebec K1A 0G4, Canada

Stone, C.D.* M+M/MARS, High Street, Hackettsstown, NJ 07840, United States of America

Strickland, D. Department of Health and Human Services, Washington, DC, United States of America
LIST OF PARTICIPANTS

Subbaraman, G.
Rockwell International Corporation,
Rocketdyne Division-NA02,
6633 Canoga Avenue,
Canoga Park, CA 91304, United States of America

Switzer, R.K.
CH2M HILL,
6121 Indian School Road, NE, Suite 206,
Albuquerque, NM 87110, United States of America

Takeguchi, C.A.
Center for Food Safety and Applied Nutrition,
Food and Drug Administration,
200 C Street, SW,
Washington, DC 20204, United States of America

Tallent, W.H.
United States Department of Agriculture,
Room 358A,
Washington, DC 20250, United States of America

Tape, N.W.
Agriculture Canada,
Food Research Institute,
Ottawa, Ontario K1A 0C6, Canada

Taylor, J.M.
Queensland Consumer Affairs Bureau,
P.O. Box 252, Brisbane QLD 4000, Australia

Thayer, D.W.
Eastern Regional Research Center,
Agricultural Research Service,
United States Department of Agriculture,
600 East Mermaid Lane,
Philadelphia, PA 19118, United States of America

Thiebaut, C.
Direction des industries agricoles et alimentaires,
Ministère de l'agriculture,
35, rue Saint-Dominique, F-75007 Paris, France

Timsit, M.-P.
GEM, Société d'études Engineering IAA,
59A, rue du Dessous des Berges,
F-75013 Paris, France

Tingey, G.L.
Battelle Northwest,
P.O. Box 999,
Richland, WA 99352, United States of America

Toloday, D.
Singleton Seafood Company,
P.O. Box 2819,
Tampa, FL 33601, United States of America

Tubino, M.
Intec-Chile,
P.O. Box 667, Santiago 1, Santiago, Chile

Urbain, W.M.
Michigan State University,
East Lansing, MI 48824, United States of America

Van der Linde, H.J.
Nuclear Development Corporation of South Africa (Pty) Ltd,
Private Bag X256, Pretoria 0001, South Africa

Van Houweling, C.D.
National Pork Producers Council,
1015 15th Street, NW, Suite 200,
Washington, DC 20005, United States of America
LIST OF PARTICIPANTS

Van Kempen, R.J.  Ministry of Welfare, Public Health and Culture, Dr. Reyersstraat 12, NL Leidschendam, Netherlands
Vanheusden, R.G.  Tremayne Corporation, 1611 N. Kent Street, Arlington, VA 22209, United States of America
Vuilleme, R.  Commissariat à l'énergie atomique, 31-33, rue de la Fédération, B.P. 510, F-75752 Paris Cédex, France
Wallace, T.  University of Lowell, 1 University Avenue, Lowell, MA 01854, United States of America
Wanless, R.H.  The Procter and Gamble Company, W5S09 WHTC, 6250 Center Hill Road, Cincinnati, OH 45224, United States of America
Wegener, R.H.  The Austin Company, 3650 Mayfield Road, Cleveland, OH 44121, United States of America
Weinstein, J.  Center for International Development, University of Maryland, 1106 Mowill Hall, College Park, MD 20742, United States of America
Weitzen, W.  Tectran, Inc., 1911 N. Ft. Myer Drive, Arlington, VA 22209, United States of America
West, G.  Ansell International, P.O. Box 347, Dandenong, Victoria, Australia
Wethington, J.  University of Florida, Department of Nuclear Engineering, Gainesville, FL 32605, United States of America
Wetzel, G.K.  Zentralinstitut für Isotopen- und Strahlenforschung, Akademie der Wissenschaften der DDR, Permoserstrasse 15, DDR-7050 Leipzig, German Democratic Republic
White, S.  The Carver Research Foundation, Tuskegee Institute, Tuskegee, AL 36088, United States of America
Whitehead, D.W.  Anderson and Pendleton, Suite 707, 1000 Connecticut Avenue, NW Washington, DC 20036, United States of America
Wierbicki, E.  Eastern Regional Research Center, Agricultural Research Service, United States Department of Agriculture, 600 East Mermaid Lane, Philadelphia, PA 19118, United States of America
LIST OF PARTICIPANTS

Wiesner, L.  
BGS Beta-Gamma-Service,  
Pritz Kotz-Strasse, D-5276 Wiehl-Bomig,  
Federal Republic of Germany

Wills, P.  
Irradiation Research and Technology Section,  
Australian Atomic Energy Commission,  
Canberra, Australia

Wilson, B.K.  
Atomic Energy of Canada Ltd,  
Radiochemical Company,  
413 March Road, P.O. Box 13500,  
Kanata, Ontario K2K 1X8, Canada

Wilson, G.D.  
American Meat Institute,  
P.O. Box 3556,  
Washington, DC 20007, United States of America

Wongchinda, N.  
c/o State Institute for Quality Control of Agricultural Products,  
Bornseesteeeg 45, Wageningen, Netherlands

Wood, D.F.  
Agriculture Canada,  
Research Branch,  
Sir John Carling Building,  
Ottawa, Ontario K1A 0C5, Canada

Xie, Liqing  
c/o Accelerator Department,  
Risø National Laboratory,  
DK-4000 Roskilde, Denmark

Xu, Zhicheng  
Shanghai Institute of Nuclear Research,  
Academia Sinica,  
P.O. Box 8204, Shanghai, China

Yang, Renli  
Institute of Applied Nuclear Technology of Sichuan Province Sha He Bao,  
Chengdu, Sichuan, China

Yemin, L.  
EBASCO Services, Inc.,  
2 World Trade Center,  
89th Floor, West,  
New York, NY 10048, United States of America

Yuval, N.  
SOR-VAN Radiation Ltd,  
P.O. Box 214, Yavne 70600, Israel

Zaratzian, V.  
United States Department of Agriculture,  
Cotton Annex - Room 510,  
300 12th Street, SW,  
Washington, DC 20250, United States of America

PARTICIPANTS DESIGNATED BY INTERNATIONAL ORGANIZATIONS

AFRICAN REGIONAL CENTRE FOR TECHNOLOGY (ARCT)

Chinsman, B.  
The African Regional Centre for Technology,  
B.P. 2435,  
Route de Ouakam, Dakar, Senegal
LIST OF PARTICIPANTS

AMERICAN NUCLEAR SOCIETY (ANS)
Manowitz, B.
Department of Applied Science,
Brookhaven National Laboratory,
Upton, NY 11973, United States of America

ASSOCIATION INTERNATIONALE D'IRRADIATION INDUSTRIELLE (AIII)
Vidal, P.E.
59, route de Paris
F-69260 Charbonnières-les-Bains, France

CODEX ALIMENTARIUS COMMISSION (CAC)
Kimbrell, E.
United States Department of Agriculture,
Room 3064,
Washington, DC, United States of America

COMMISSION OF THE EUROPEAN COMMUNITIES (CEC)
Haigh, M.R.
Rue de la Loi 200,
B-1049 Brussels, Belgium

FOOD AND AGRICULTURE ORGANIZATION OF THE UNITED NATIONS (FAO)
Al-Suleiman, S.
FAO Programme,
Co-ordinator in Saudi Arabia,
Ministry of Agriculture and Water,
Hassa Irrigation and Drainage Authority,
Al-Hassa Date Factory, P.O. Box 279,
Riyadh, Saudi Arabia

Mikki, M.S.
FAO Programme,
Dates Processing Expert,
c/o UNDP, P.O. Box 558,
Riyadh, Saudi Arabia

INTERNATIONAL ATOMIC ENERGY AGENCY (IAEA)
Elbaradei, M.
United Nations
IAEA Liaison Office,
Room DC-1-1155,
New York, NY 10017, United States of America

Loaharanu, P.
Food Preservation Section,
Joint Division of Isotope and Radiation Applications of Atomic Energy for Food and Agricultural Development,
Wagamerstrasse 5,
A-1400 Vienna, Austria
LIST OF PARTICIPANTS

INTERNATIONAL BANK FOR RECONSTRUCTION AND DEVELOPMENT (IBRD)

Brown, J.G. CGIAR, World Bank, 1818 H Street, NW, Washington, DC 20433, United States of America

Hill, N.K. CGIAR, World Bank, 1818 H Street, NW, Washington, DC 20433, United States of America

ORGANIZATION OF AMERICAN STATES (OAS)

Herrera, H. 1889 F Street NW, Washington, DC 20006, United States of America

WORLD HEALTH ORGANIZATION (WHO)

Käferstein, F.K. Food Safety Programme, CH-1211 Geneva 27, Switzerland
AUTHOR INDEX

Numerals refer to the first page of paper(s) or poster(s) by the author concerned

Ahlstrom, S.B.: 335
Ahmed, M.: 163
Ahmed, M.S.H.: 151
Amin, M.R.: 17
Andersen, R.: 336
Appiah, V.: 244, 245
Auda, H.: 317
Aziz, N.H.: 236
Baer, M.: 35
Bagiawati, S.: 171
Banditsing, C.: 365
Basker, D.: 233
Bhuiya, A.D.: 163
Blanco, L.R.: 167
Bongirwar, D.R.: 353
Brodrick, H.T.: 137
Brower, J.H.: 235
Buchanan, R.L.: 246
Burditt, A.K., Jr.: 3
Canee, M.: 340
Carvacho, O.F.: 338
Chalwe, K.D.: 127
Chinsman, B.: 185
Chishya, B.E.: 127
Chon, Qixun: 160
Chosdu, R.: 170
Cleland, M.R.: 397
Curbelo, S.: 379
Dai, Yin: 234
Dawes, M.A.: 235
De Wet, W.J.: 323
Deliçée, H.: 348
Deng, Huachuan: 160
Doma, M.B.: 156
Du Plessis, T.A.: 341
Dvornik, I.: 69
Ehlermann, D.A.E.: 348, 349
Eisenberg, E.: 233
El-Rady, E.A.: 164
El-Zawahry, Y.A.: 236
Engel, R.E.: 297
Farkas, Cs.: 165
Farkas, J.: 159, 215
Farrar IV, H.: 335
Ferrell, N.: 237, 336, 487
Fiddler, W.: 238
Fiszer, W.: 101
Gates, R.A.: 238
Giddings, G.G.: 451
Goebel, J.N.: 161
Grünewald, T.: 348, 349
Hameed, A.A.: 151
Harris, L.J.: 338
Haryadi, R.S.: 170
Hegazy, R.A.: 156
Henon, Y.: 9, 311
Holzapfel, W.H.: 239, 243
Horváth, Ny.: 165
Horváth-Mosonyi, M.: 165
Hossain, M.A.: 17
Hossain, M.M.: 17
Huda, S.M.S.: 163
Hungate, F.P.: 3
Hussein, M.A.: 156
Ito, H.: 171
Izard, M.: 169
Jáksó, Gy.: 165
Jan, M.: 152
Jenkins, R.K.: 238, 246
Kadhum, A.A.: 151
Kálmán, B.: 109
Kalus, W.: 348
Kaneshiro, K.Y.: 168
Kardha, S.: 170
Katušin-Ražem, B.: 69
Kaylor, J.D.: 241, 429
Kékesi, E.: 109
Keresztes, Á.: 154
Khan, I.: 152
Kiss, I.: 165
Klinger, Y.: 117, 233
Kovács, E.: 154, 165
Kovács, J.: 154
Krishnamurthy, K.: 353
Lagunas-Solar, M.C.: 337, 338, 499
Langerak, D.I.: 244, 245
Lastarria-Tapia, H.J.: 55
Learson, R.J.: 429
Licciardello, J.J.: 241
<table>
<thead>
<tr>
<th>Author Name</th>
<th>Page Numbers</th>
</tr>
</thead>
<tbody>
<tr>
<td>Liu, Shupei</td>
<td>160</td>
</tr>
<tr>
<td>Loaharanu, P.</td>
<td>175</td>
</tr>
<tr>
<td>Loretan, P.A.</td>
<td>235</td>
</tr>
<tr>
<td>Maha, M.</td>
<td>162</td>
</tr>
<tr>
<td>Mahmoud, A.A.</td>
<td>47, 156</td>
</tr>
<tr>
<td>Malek, M.A.</td>
<td>17</td>
</tr>
<tr>
<td>Mallett, J.C.</td>
<td>241</td>
</tr>
<tr>
<td>Manoto, E.C.</td>
<td>167</td>
</tr>
<tr>
<td>Martin, V.J.</td>
<td>379</td>
</tr>
<tr>
<td>Matić, S.</td>
<td>69</td>
</tr>
<tr>
<td>Matin, M.A.</td>
<td>17</td>
</tr>
<tr>
<td>Matthews, S.M.</td>
<td>337, 338</td>
</tr>
<tr>
<td>Meisinger, D.</td>
<td>281</td>
</tr>
<tr>
<td>Mendoza, A.B.</td>
<td>167</td>
</tr>
<tr>
<td>Mihokovič, V.</td>
<td>69</td>
</tr>
<tr>
<td>Miller, A.</td>
<td>347</td>
</tr>
<tr>
<td>Moffitt, H.R.</td>
<td>3</td>
</tr>
<tr>
<td>Molco, M.</td>
<td>155</td>
</tr>
<tr>
<td>Montalban, A.</td>
<td>379</td>
</tr>
<tr>
<td>Morris, R.P.</td>
<td>493</td>
</tr>
<tr>
<td>Morrison, R.M.</td>
<td>407</td>
</tr>
<tr>
<td>Mosse, D.</td>
<td>340</td>
</tr>
<tr>
<td>Mossel, D.A.A.</td>
<td>159, 251</td>
</tr>
<tr>
<td>Moy, J.H.</td>
<td>61, 157, 168</td>
</tr>
<tr>
<td>Mróz, J.</td>
<td>101</td>
</tr>
<tr>
<td>Muhamad, L.J.</td>
<td>171</td>
</tr>
<tr>
<td>Mullen, M.A.</td>
<td>235</td>
</tr>
<tr>
<td>Mustafa, D.</td>
<td>162</td>
</tr>
<tr>
<td>Nagai, N.Y.</td>
<td>168</td>
</tr>
<tr>
<td>Nahar, G.</td>
<td>163</td>
</tr>
<tr>
<td>Niemand, J.G.</td>
<td>239, 243, 341</td>
</tr>
<tr>
<td>Noochapramoool, K.</td>
<td>365</td>
</tr>
<tr>
<td>O'Sullivan, E.</td>
<td>157</td>
</tr>
<tr>
<td>Odamttten, G.T.</td>
<td>244, 245</td>
</tr>
<tr>
<td>Ohta, A.T.</td>
<td>168</td>
</tr>
<tr>
<td>Olorunda, A.O.</td>
<td>479</td>
</tr>
<tr>
<td>Padova, R.</td>
<td>155</td>
</tr>
<tr>
<td>Pageau, G.M.</td>
<td>397</td>
</tr>
<tr>
<td>Palumbo, S.A.</td>
<td>246</td>
</tr>
<tr>
<td>Parker, G.</td>
<td>157</td>
</tr>
<tr>
<td>Parker, J.G.</td>
<td>157</td>
</tr>
<tr>
<td>Pensabene, J.W.</td>
<td>238</td>
</tr>
<tr>
<td>Piadang, S.</td>
<td>365</td>
</tr>
<tr>
<td>Prachasitisakdi, Y.</td>
<td>365</td>
</tr>
<tr>
<td>Prachasitthisakdi, Y.</td>
<td>159</td>
</tr>
<tr>
<td>Prinksulka, V.</td>
<td>365</td>
</tr>
<tr>
<td>Prusik, T.</td>
<td>342</td>
</tr>
<tr>
<td>Purwanto, Z.I.</td>
<td>170</td>
</tr>
<tr>
<td>Rahayu, A.</td>
<td>170</td>
</tr>
<tr>
<td>Rahman, S.</td>
<td>17</td>
</tr>
<tr>
<td>Ražem, D.</td>
<td>69</td>
</tr>
<tr>
<td>Resilva, S.S.</td>
<td>167</td>
</tr>
<tr>
<td>Rezaur, R.</td>
<td>163</td>
</tr>
<tr>
<td>Rigney, C.J.</td>
<td>169</td>
</tr>
<tr>
<td>Rokeya, B.</td>
<td>17</td>
</tr>
<tr>
<td>Rosenberg, R.</td>
<td>155</td>
</tr>
<tr>
<td>Ross, I.</td>
<td>117, 155</td>
</tr>
<tr>
<td>Roushdy, H.M.</td>
<td>47, 156, 236</td>
</tr>
<tr>
<td>Rubio, T.</td>
<td>203</td>
</tr>
<tr>
<td>Rudolf, M.</td>
<td>349</td>
</tr>
<tr>
<td>Saini, R.S.</td>
<td>235</td>
</tr>
<tr>
<td>Saint-Lèbe, L.</td>
<td>9</td>
</tr>
<tr>
<td>Sánta, R.</td>
<td>109</td>
</tr>
<tr>
<td>Sattar, A.</td>
<td>152</td>
</tr>
<tr>
<td>Sequeiros, N.</td>
<td>55</td>
</tr>
<tr>
<td>Shieh, J.J.</td>
<td>246, 343</td>
</tr>
<tr>
<td>Siddiqui, A.K.</td>
<td>17</td>
</tr>
<tr>
<td>Simoen, J.P.</td>
<td>340</td>
</tr>
<tr>
<td>Sivinski, J.S.</td>
<td>487</td>
</tr>
<tr>
<td>Slaughter, D.R.</td>
<td>337, 338</td>
</tr>
<tr>
<td>Slavin, J.W.</td>
<td>429</td>
</tr>
<tr>
<td>Sloan, D.P.</td>
<td>237</td>
</tr>
<tr>
<td>Soemartaputra, M.H.</td>
<td>170</td>
</tr>
<tr>
<td>Stegeman, H.</td>
<td>159</td>
</tr>
<tr>
<td>Subbaraman, G.</td>
<td>335</td>
</tr>
<tr>
<td>Sudatis, B.</td>
<td>169</td>
</tr>
<tr>
<td>Sutantawong, M.</td>
<td>365</td>
</tr>
<tr>
<td>Switzer, R.K.</td>
<td>469</td>
</tr>
<tr>
<td>Tamura, N.</td>
<td>171</td>
</tr>
<tr>
<td>Thayer, D.W.</td>
<td>246</td>
</tr>
<tr>
<td>Thery, V.</td>
<td>9</td>
</tr>
<tr>
<td>Urbain, W.M.</td>
<td>509</td>
</tr>
<tr>
<td>Van der Linde, H.J.</td>
<td>137, 243</td>
</tr>
<tr>
<td>Van Houweling, C.D.</td>
<td>281</td>
</tr>
<tr>
<td>Wahid, M.</td>
<td>152</td>
</tr>
<tr>
<td>Wallace, T.</td>
<td>342</td>
</tr>
<tr>
<td>Wang, Yongzhi</td>
<td>160</td>
</tr>
<tr>
<td>Watanabe, H.</td>
<td>171</td>
</tr>
<tr>
<td>Wetzel, K.</td>
<td>35</td>
</tr>
<tr>
<td>Wierbicki, E.</td>
<td>79, 238, 343</td>
</tr>
<tr>
<td>Wiesner, L.</td>
<td>437</td>
</tr>
<tr>
<td>Wongchinda, N.</td>
<td>159</td>
</tr>
<tr>
<td>Xie, Lijing</td>
<td>347</td>
</tr>
<tr>
<td>Xu, Zhicheng</td>
<td>475</td>
</tr>
<tr>
<td>Yang, Renli</td>
<td>160</td>
</tr>
<tr>
<td>Youssef, Y.A.</td>
<td>236</td>
</tr>
<tr>
<td>Zabielski, J.</td>
<td>101</td>
</tr>
</tbody>
</table>
INDEX OF PAPERS AND POSTERS BY NUMBER

(The letter P indicates a poster presentation)

<table>
<thead>
<tr>
<th>IAEA-SM-271/</th>
<th>Page</th>
<th>IAEA-SM-271/</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>4</td>
<td>17</td>
<td>61P</td>
<td>241</td>
</tr>
<tr>
<td>6</td>
<td>47</td>
<td>62</td>
<td>493</td>
</tr>
<tr>
<td>7P</td>
<td>156</td>
<td>63</td>
<td>407</td>
</tr>
<tr>
<td>9P</td>
<td>236</td>
<td>64P</td>
<td>157</td>
</tr>
<tr>
<td>10P</td>
<td>340</td>
<td>65</td>
<td>61</td>
</tr>
<tr>
<td>11</td>
<td>311</td>
<td>66P</td>
<td>342</td>
</tr>
<tr>
<td>12</td>
<td>9</td>
<td>67P</td>
<td>343</td>
</tr>
<tr>
<td>13P</td>
<td>348</td>
<td>68</td>
<td>487</td>
</tr>
<tr>
<td>14P</td>
<td>349</td>
<td>70</td>
<td>469</td>
</tr>
<tr>
<td>15</td>
<td>437</td>
<td>72</td>
<td>281</td>
</tr>
<tr>
<td>16</td>
<td>35</td>
<td>73</td>
<td>79</td>
</tr>
<tr>
<td>17P</td>
<td>244</td>
<td>74P</td>
<td>246</td>
</tr>
<tr>
<td>18P</td>
<td>245</td>
<td>75</td>
<td>69</td>
</tr>
<tr>
<td>19P</td>
<td>154</td>
<td>76</td>
<td>127</td>
</tr>
<tr>
<td>21</td>
<td>109</td>
<td>80</td>
<td>251</td>
</tr>
<tr>
<td>24</td>
<td>353</td>
<td>82P</td>
<td>337</td>
</tr>
<tr>
<td>27</td>
<td>317</td>
<td>83P</td>
<td>338</td>
</tr>
<tr>
<td>28P</td>
<td>233</td>
<td>84P</td>
<td>335</td>
</tr>
<tr>
<td>30P</td>
<td>155</td>
<td>85</td>
<td>499</td>
</tr>
<tr>
<td>31P</td>
<td>339</td>
<td>87</td>
<td>475</td>
</tr>
<tr>
<td>32</td>
<td>117</td>
<td>88P</td>
<td>160</td>
</tr>
<tr>
<td>34</td>
<td>479</td>
<td>89P</td>
<td>234</td>
</tr>
<tr>
<td>36</td>
<td>55</td>
<td>90</td>
<td>175</td>
</tr>
<tr>
<td>37</td>
<td>101</td>
<td>91</td>
<td>185</td>
</tr>
<tr>
<td>38P</td>
<td>341</td>
<td>92</td>
<td>203</td>
</tr>
<tr>
<td>39P</td>
<td>243</td>
<td>93</td>
<td>215</td>
</tr>
<tr>
<td>40P</td>
<td>239</td>
<td>95P</td>
<td>152</td>
</tr>
<tr>
<td>41</td>
<td>323</td>
<td>100P</td>
<td>151</td>
</tr>
<tr>
<td>42</td>
<td>137</td>
<td>101P</td>
<td>163</td>
</tr>
<tr>
<td>44</td>
<td>365</td>
<td>102P</td>
<td>164</td>
</tr>
<tr>
<td>47P</td>
<td>159</td>
<td>103P</td>
<td>165</td>
</tr>
<tr>
<td>49</td>
<td>379</td>
<td>104P</td>
<td>167</td>
</tr>
<tr>
<td>51</td>
<td>451</td>
<td>105P</td>
<td>168</td>
</tr>
<tr>
<td>52</td>
<td>3</td>
<td>107P</td>
<td>169</td>
</tr>
<tr>
<td>54</td>
<td>397</td>
<td>108P</td>
<td>170</td>
</tr>
<tr>
<td>55P</td>
<td>235</td>
<td>109P</td>
<td>347</td>
</tr>
<tr>
<td>56</td>
<td>297</td>
<td>110P</td>
<td>171</td>
</tr>
<tr>
<td>57P</td>
<td>336</td>
<td>111P</td>
<td>162</td>
</tr>
<tr>
<td>58P</td>
<td>237</td>
<td>114</td>
<td>509</td>
</tr>
<tr>
<td>59P</td>
<td>238</td>
<td>116P</td>
<td>161</td>
</tr>
<tr>
<td>60</td>
<td>429</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
HOW TO ORDER IAEA PUBLICATIONS

An exclusive sales agent for IAEA publications, to whom all orders and inquiries should be addressed, has been appointed in the following country:

UNITED STATES OF AMERICA UNIPUB, P.O. Box 433, Murray Hill Station, New York, NY 10157

In the following countries IAEA publications may be purchased from the sales agents or booksellers listed or through your major local booksellers. Payment can be made in local currency or with UNESCO coupons.

ARGENTINA Comisión Nacional de Energía Atómica, Avenida del Libertador 8250, RA-1429 Buenos Aires
AUSTRALIA Hunter Publications, 58 A Gipps Street, Collingwood, Victoria 3066
BELGIUM Service Courrier UNESCO, 202, Avenue du Roi, B-1060 Brussels
CHILE Comisión Chilena de Energía Nuclear, Venta de Publicaciones Amunategui 95, Casilla 188-D, Santiago
CZECHOSLOVAKIA S.N.T.L., Mikulandska 4, CS-116 86 Praha 1
FRANCE Office International de Documentation et Librairie, 48, rue Gay-Lussac, F-75240 Paris Cedex 05
HUNGARY Kultura, Hungarian Foreign Trading Company P.O. Box 149, H-1389 Budapest 62
INDIA Oxford Book and Stationery Co., 17, Park Street, Calcutta-700 016
ISRAEL Heiliger and Co., Ltd., Scientific and Medical Books, 3, Nathan Strauss Street, Jerusalem 94227
ITALY Libreria Scientifica, Dott. Lucio de Biasio "aeiou", Via Meravigli 16, I-20123 Milan
JAPAN Maruzen Company, Ltd., P.O. Box 5050, 100-31 Tokyo International
NETHERLANDS Martinus Nijhoff B.V., Booksellers, Lange Voorhout 9-11, P.O. Box 269, NL-2501 The Hague
PAKISTAN Mirza Book Agency, 65, Shahrah Quaid-e-Azam, P.O. Box 729, Lahore 3
POLAND Ars Polona-Ruch, Centrala Handlu Zagranicznego, Krakowskie Przedmiescie 7, PL-00-068 Warsaw
ROMANIA Ilexim, P.O. Box 136-137, Bucuresti
SOUTH AFRICA Van Schalk Bookstore (Pty) Ltd., P.O. Box 724, Pretoria 0001
SPAIN Díaz de Santos, Lagasca 95, E-28006 Madrid
SWEDEN AB Fritz Kungl. Hovbokhandel, Fredsgatan 2, P.O. Box 18356, S-103 27 Stockholm
UNITED KINGDOM Her Majesty’s Stationery Office, Publications Centre, Agency Section 51 Nine Elms Lane, London SW8 5DR
U.S.S.R. Mezhdunarodnaya Kniga, Smolenskaya-Sennaya 32-34, Moscow G-200
YUGOSLAVIA Jugoslovenska Knjiga, Terazije 27, P.O. Box 36, YU-11001 Belgrade

Orders from countries where sales agents have not yet been appointed and requests for information should be addressed directly to:

Division of Publications
International Atomic Energy Agency
Wagramerstrasse 5, P.O. Box 100, A-1400 Vienna, Austria
It would greatly assist the International Atomic Energy Agency in its current review of its publications programme if you could kindly fill in one of the attached postcards and return it to the address shown. Your co-operation is greatly appreciated.

1. Title of book: .................................................................

2. Did you purchase the book? [ ]
Did you borrow it from a library? [ ]

3. By what means did you learn of its existence?
A book notice [ ]; a book review [ ]; the IAEA publications catalogue [ ];
IAEA meetings [ ]; IAEA newsletters [ ]; a professional colleague [ ]; scientific
literature [ ]; other means (please specify) [ ]:

4. How do you rate the usefulness of the content?
Very useful, not found elsewhere [ ]; useful as a survey [ ]; useful for reference [ ];
useful because of its international character [ ]; useful for training or study
purposes [ ]; not very useful [ ].

5. How do you normally purchase IAEA publications?
Through booksellers [ ]; through direct purchase [ ]; through your national
Atomic Energy Commission or similar body [ ].

6. Would you like to have a free subscription to the IAEA publications catalogue?
Yes [ ] No [ ]
International Atomic Energy Agency
Sales and Promotion Unit
P.O. Box 100
Wagramerstrasse 5
A-1400 Vienna
Austria
It would greatly assist the International Atomic Energy Agency in its current review of its publications programme if you could kindly fill in one of the attached postcards and return it to the address shown. Your co-operation is greatly appreciated.

1. Title of book: ..................................................................................................................................................................................................................................................

2. Did you purchase the book? [ ]
   Did you borrow it from a library? [ ]

3. By what means did you learn of its existence?
   A book notice [ ]; a book review [ ]; the IAEA publications catalogue [ ];
   IAEA meetings [ ]; IAEA newsletters [ ]; a professional colleague [ ]; scientific
   literature [ ]; other means (please specify) [ ]: ............................................................

4. How do you rate the usefulness of the content?
   Very useful, not found elsewhere [ ]; useful as a survey [ ]; useful for reference [ ];
   useful because of its international character [ ]; useful for training or study
   purposes [ ]; not very useful [ ].

5. How do you normally purchase IAEA publications?
   Through booksellers [ ]; through direct purchase [ ]; through your national
   Atomic Energy Commission or similar body [ ].

6. Would you like to have a free subscription to the IAEA publications catalogue?
   Yes [ ] No [ ]