ISRP (K) — BR — 1

V. Ninjoor

Use of Ionising Radiation for Food Processing Applications

1989

Indian Society for Radiation Physics

Kalpakkam Chapter

About ISRP and this Series

Ionising radiation is a powerful tool finding increasing applications in almost all walks of life, be it agriculture, medicine, industry or basic research. By the very nature of its diverse applications, the study of ionising radiations and their interaction with matter has diffused into various other scientific disciplines. It is with the primary objective of providing a common forum for the scientists and engineers working on different basic as well as applied aspects of ionising radiation that the Indian Society for Radiation Physics (ISRP) was formed in 1976. Its membership consists of professionals from national laboratories, universities and institutions of higher education, industry etc. In line with its basic objective, ISRP has been organising periodic national and regional seminars, topical meetings etc.

It is recognised that for an optimum utilization of any technology, a comprehensive appreciation of its problems and potentials must prevail not only amongst the scientists and engineers associated with the technology but amongst the general public also. In the case of ionising radiations while its hazard aspects seem to have been overplayed for historical or other reasons, its full potential in the service of mankind does not seem to have drawn the deserved attention of the general public. It is to fill up this gap and to develop an overall perspective ISRP (Kalpakkam Chapter) has launched this series of semi-popular brochures on various facets of ionising radiation.

We feel that for any programme to be relevant and successful a strong user-feed back is essential. We earnestly solicit suggestions with regard to the content and level of these brochures, topics to be included etc. The suggestions may please be sent to.

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ISRP(K)—BR—1

USE OF IONISING RADIATION FOR FOOD PROCESSING APPLICATION

V. NINJOOR

INDIAN SOCIETY FOR RADIATION PHYSICS
(Kalpakkam Chapter)
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FOREWORD

Thanks to the visionary and dynamic leadership provided by Dr. Homi Bhabha and the successive Chairmen of the Indian Atomic Energy Commission, there has been awareness and appreciation at the government level, in the scientific community and also in the minds of the general public, of the importance and potential of atomic energy development for the growth of the national economy. On the other hand, there has been till now no systematic effort on the part of the Department of Atomic Energy to publish books and monographs to project in detail the achievements in the field, and to disseminate information on all the various aspects of nuclear science and technology, in a style that is scientifically objective and at the same time intelligible to the general public. The need for such an effort has become imperative in the present juncture when the nuclear power programme and the applications of ionising radiations are poised for substantial growth, and when simultaneously anxieties about the safety of design and operation of nuclear power plants, management of radioactive waste, biological effects of radiation, and the impact of the nuclear programme on the environment, have become accentuated following the Chernobyl nuclear plant accident in USSR in 1986.

It is in this context that the series publication of monographs on selected themes, by the Kalpakkam Chapter of the Indian Society for Radiation Physics (ISRP), is to be welcomed. The Chapter is fortunate to have dedicated and enlightened members who have taken a leading interest in the information dissemination and organising educational programmes for the benefit of the general public.

One of the important applications of ionising radiation is in the processing and preservation of food articles. The extensive work carried out at BARC, Trombay, has demonstrated that irradiation can be effectively employed for inhibition of sprouting in onions and potatoes, insect disinfestation in grains, delayed ripening of fruits, shelf-life extension of fish and poultry, and microbial decontamination of spices. The monograph by Dr. Ninjoor is a very interesting presentation of the developments in the field, giving relevant information on radiation sources, and choice of dose for specific results, and also answers questions on the safety and nutritional adequacy of irradiated food.

The country has reached the stage of substantial increase in food production by adopting scientific means. Equal emphasis has now to be devoted to food preservation and transport, and the use of ionising radiation offers very good potential in this context.

I wish the Indian Society for Radiation Physics (Kalpakkam)'s Science Propagation Programme every success.

1/6/89

C. V. SUNDARAM
Director
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USE OF IONISING RADIATION FOR FOOD PROCESSING APPLICATIONS

1. Introduction

With the bulging world population, the need for increased food production to feed the millions is growing incessantly. While the advances in agricultural methods have ensured food production keeping pace with the rapidly growing requirements, unchecked processing and storage losses of food commodities pose serious problems for the world food supply. It is estimated that one quarter to one third of world food production is lost due to pests, insects, bacteria, fungi and enzymes which eat, degrade or destroy the crops. In Africa, even more than 50% is ost after harvest depending on the product. Apart from food losses, the problem of contamination has to be encountered which includes pathogens and parasites that lead to food borne diseases. The incidence of food borne disease has shown a dramatic spurt in recent years and currently it is one of the most widespread health problems not only in developing but also in industrialized countries with relatively high standard of hygiene The report of a Joint FAO/WHO Expert Committee on Food Safety has identified contaminated food as the most important cause for the widespread health problems in the world which also adversely affects the economic productivity of several countries. In addition, a variety of food items, such as poultry, meat and meat products, seafood, frog legs and spices are often rejected on the ground of poor hygienic quality including contamination with pathogens. The potential economic loss due to food borne disease and rejection of food contaminated with pathogenic microorganisms is apparently enormous and could significantly hamper international trade.

A number of methods for the preservation of food are currently being employed universally. While thermal processing, cold storage, sun drying, salting, smoking and pickling are as old as mankind itself, modern preservation techniques like canning, pasteurising, deep freezing, vacuum drying and preservation by chemical additives have considerably extended the shelf life of several food products. However, some of the chemicals that have been used in the past for decontamination, storage and quarantine treatment (eg. fumigants, ethylene dibromide EDB, and ethylene oxide) are under review because of their potential danger to the mankind and the environment. The most recent addition to the long list of preservation techniques is the food irradiation. It is essentially a technique of exposing food products to ionising radiations such as X-rays, *γ-rays* or high energy electrons to deactivate the undesirable organisms in the food matrix and thereby enhance its preservation.

2. Historical background

The use of ionizing radiation for preservation of food by employing X-rays was first patented in France in 1930. During 1940-53 exploratory research in food irradiation in United States was sponsored by the Department of Army, the Atomic Energy Commission and private industry. Amongst different types of radiations employed for the preservation of food, X-rays were considered to be impractical because of very low conversion efficiency from electron to X-ray during that period (1951). Ultraviolet light and alpha particles were found to be having limited ability to penetrate matter. Neutrons, though exhibited great penetration and were quite effective in the destruction of bacteria, were considered inappropriate for use because of their potential for inducing radioactivity in the treated food. Early studies also pointed out that bacteria such as *Salmonella paratyphi, Salmonella typhimurium and Salmonella senftenberg* in whole egg could be inactivated by cathode ray radiation. By 1958 several factors affecting the radiation sensitivity of microorganisms such as nature of the suspending medium, temperature during irradiation, availability of free water, irradiation atmosphere (nitrogen, air, vacuum), stage of development (vegetative cell or spore) and physiological injury had been identified The removal of oxygen was found to suppress the undesirable changes in the organoleptic properties of the food. Similar studies on the application of ionizing radiation in the processing and preservation of foods were initiated in the

1960s in several countries including India and by 1968 there were 76 countries with food irradiation programmes. In 1970, 24 countries collaborated under the "International Project in the Field of Food Irradiation" and joint activities were overseen by the Food and Agricultural Organization (FAO) the International Atomic Energy Agency (IAEA) and the World Health Organization (WHO). Soon, advantage of irradiation as a means of reducing food losses due to microbial and insect spoilage was recognized all over the world. Extensive researches on the technological, nutritional and safety aspects of irradiated foods have since been carried out on an unprecedented scale in most of the industrialized countries and some developing countries including India.

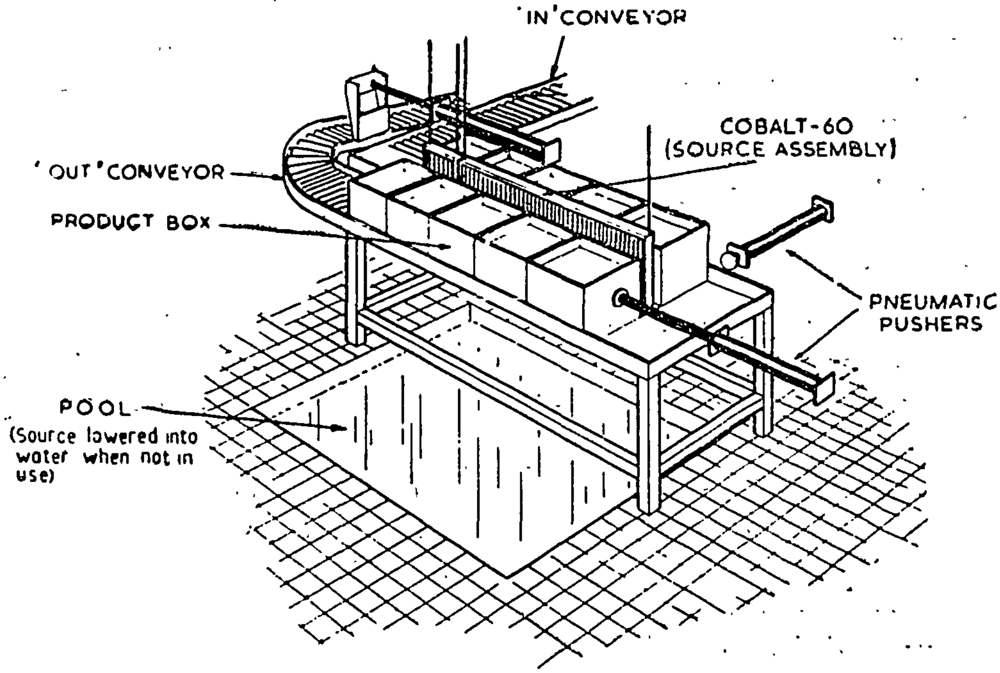
3. Radiations, sources and plants

X-rays, *γ-rays* and electrons knock out electrons from the neutral molecules or atoms of the material through which they pass thereby creating positive ions and free electrons (hence the name ionising radiations). The electrons and positive ions eventually recombine leading to excited species which will bring out subsequent chemical changes in the material. In the process of ionisation these radiations deposit part of their energy in the material. The overall chemical change is to a large extent proportionate to the energy thus absorbed by the material. While the electrons are capable of ionising directly, in the case of X and *γ-rays,* it is essentially the secondary electrons resulting from the interaction of these radiations with the material through which they pass which are responsible for ionisation. X-rays and *γ-rays* are electromagnetic radiations similar to light or radio waves except that they are of much shorter wavelength and possess much higher energies.

Gamma rays are emitted during the decay of radioactive nuclides and for the purposes of food irradiation, the radionuclides cobalt-60 and cesium-137 are used as gamma ray sources. While cobalt-60 which has a halflife of 5.27 years and emits a *γ-ray* of 1.33 MeV, has to be specially prepared starting from the naturally occuring cobalt-59, cesium-137 with a half life of 30 years and emitting a *γ-ray* of 0.66 MeV is obtained as a fission product from nuclear reactors. The radiations from these sources possess good penetrating power and therefore are useful in irradiating bulky packets of food products. However good penetrating power also means smaller energy deposited per unit length along their path. This has the disadvantage that more time is required for the deposition of a given amount of energy by these radiations.

Alternatively, X-rays or accelarated electrons are also used for food irradiation. These radiations are produced by machines and it is possible to obtain them with very high intensities. An additional advantage with these radiations is that their production can be stopped when not required by switching off the machine. A major limitation with electrons is its low penetrability restricting its applications to foods which can be treated in thin layers such as foodgrains.

Irradiation plants generally consist of: a radiation source, either an isotope or a machine, housed in an area fitted with elaborate safety devices to prevent accidental exposures to radiation and surrounded by concrete walls upto 2m thick and a variable speed conveyor system to carry the material around the radiation source. A typical gamma irradiator is shown in Fig. 1.



CONTINUOUS IRRADIATOR (PRODUCT BOX TYPE)

SUITABLE FOR ONIONS, POTATOES, FRUITS AND PACKAGED FOODS

Fig. 1

In a gamma irradiation facility, the cobalt-60 source is housed in a 6m deep water well, built inside a special chamber with thick concrete walls During irradiation, the source is raised from the pool of water by remote control and the food packed in pouches, cartons or barrels sent through the conveyors, is exposed to gamma radiation to a predetermined dose regulated by time of exposure.

4. The language of irradiation

Dose : The quantity of radiation energy absorbed by the matter.

Exposure time : The amount of time taken for the food to pass around the source - this controls the dose.

Rad : The unit of dose. One rad equals 100 ergs of energy/g. The scaled up units are : 1 kilorad (krad) = 1000 rads, 1 megarad (Mrad) = 1 million rads.

Gray (Gy) : This unit supercedes the rad in the S.I. system. A radiation dose of one Gy involves the absorption of 1 Joule of energy by each kg of matter. One Gy is equivalent to 100 rads.

Curie (Ci) : The unit of radioactivity is defined as that amount of radioactivity which corresponds to 3.7×10^{10} disintegrations per sec.

Becquerel : The unit of radioactivity which supercedes the curie in the S.I. system. It is defined as the amount of radioactivity corresponding to one disintegration per second.

Radurization (also referred to as radiation pasteurization) : Exposure of food to ionizing radiation to reduce populations of organisms and delay onset of spoilage. The dose range is 75-250 krad.

Radicidation : Generally employed for sanitation of frozen products Exposure of food to ionizing radiation at doses necessary to kill all nonspore forming pathogens and/or parasites. The dose range is 250-1000 krad.

Radappertization or radiation sterilization : Exposure of food in hermetically sealed packings at doses necessary to kill all organisms of food spoilage or public health significance. Doses employed are greater than 1 Mrad (3·5 Mrad generally).

5. Applications

As mentioned earlier, ionising radiations enhance the food preservation by deactivating the undesirable organisms. In Table 1 is given the radiation doses required for deactiva-

Table 1 : Lethal doses of radiation

Organism	Dose range (krad)
Man and higher animals	0.5
Insects	5 - 100
Parasites	10 - 400
Salmonella	200 - 800
Aerobic spores	1000 - 3000
Clostridium botulinum	1000 - 4500
Viruses	1000 - 5000

ting different organisms. It can be seen from the table that the dose required for deactivating is inversely proportional to the complexity of the organism. Thus, viruses are about 10000 times more resistant than man to the lethal effects of radiation. Radiation resistance can also vary upto 500-fold between species and even between strains of a species. The effect of radiation is also influenced markedly by environmental factors such as gas phase, medium, temperature and water activity.

Uses of gamma irradiation in food preservation could be broadly categorised as follows :

1. destruction of insects infesting stored cereals, grains, cereal products and fruits,
2. inhibition of sprouting in tubers and bulbs thus extending their shelf life,
3. control of physiological processes to delay post harvest ripening in fruits,
4. the reduction in spoilage organisms in fish and meat to retard spoilage (radurization),

5. elimination of pathogens posing public health hazards from frozen sea foods (radicidation)

6. microbial decontamination of spices and

7. radappertization - the total elimination of food spoilage or disease causing organisms, thus making the prepacked food stable without refrigeration.

It is customary to divide the above under three heads depending on the dose applied as indicated in Table 2. Fig-6 depicts the advantages of radurization in prolonging the storage stability of some tropical fish varieties at 0-2°C. Some pathogens, especially *Salmonella sp.* could be eliminated from frozen sea foods, frog legs, poultry and meat products. Microorganisms surviving irradiation are more sensitive to heat, salt, acidity and moisture and therefore several combination treatments have also been attempted to improve the quality of flesh foods. Spices are expensive food ingredients, commonly infested with bacteria and pests. A dose of 750-1000 krad disinfests the spice products. Sterilization of material requires the highest doses. Examples of such applications are sterilization of meat food products, food regimen for hospital patients, space food, feed for laboratory animals, food packaging materials and containers and enzymes. It is customary to sterilize packed precooked foods under vacuum and subzero temperature (—40° C) in order to minimize radiolytic changes and suppress alteration in food quality attributes. Sterilized food items can be stored at room temperature for years. A major advantage of irradiation as a preservation technique is that the treatment can be given after packing and the recontamination is prevented unless the package is opened. Also, irradiation retains freshness of foods (especially fruits and meat products), obviates the need for using hazardous chemical additives and fumigants, improves food hygiene and is less energy demanding.

It is to be noted that not all foods are suitable for irradiation just as not all foods are suitable for processing by canning, freezing, drying etc. Irradiation can induce undesirable changes in flavour, colour and texture of several food materials. For example, while milk is susceptible to the

Table 2 : Applications of food irradiation

Dose range	Process	Examples	Dose applied (krad)
Low (5-100 krad)	Sprout inhibition	Onion, potatoes* garlic, ginger	5 - 15
	Insect disinfestation	Grains, dried fish**, fruits, vegetables	20 - 80
	Delayed ripening	Mango, banana, papaya	25 - 80
Medium (100-1000 krad)	Shelf life extension (radurization)	Poultry, fish shellfish strawberries, mushrooms	100 - 300
	Pathogen elimination (Radicidation)	Salmonellae, E. coli, Pseudomonas sp. staph. sp. Campylobacter etc.	300 - 800
	Microbial decontamination of spices	Pepper, turmeric, chilli, dry ginger, (spices & condiments)	500 - 1000
High (1000 - 5000 krad)	Sterilization	Processed meat, pork, poultry, animal diets, finfish.	2300 - 4500

* See Figures 2 and 3

** See Figures 4 and 5

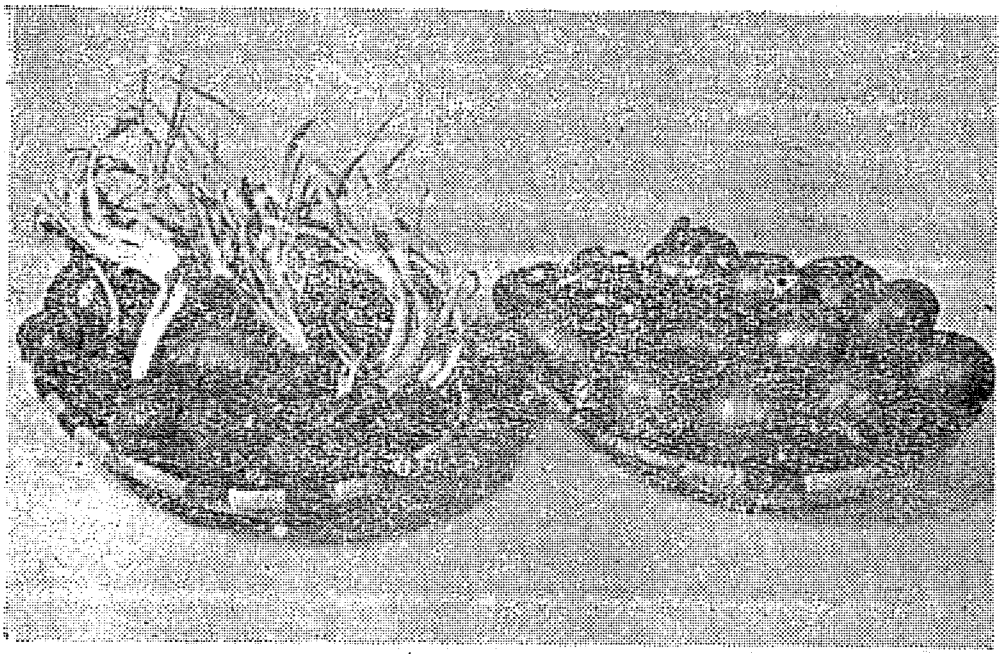


Fig. 2 : Sprouting inhibition in potatoes. Unirradiated (left); irradiated (right)

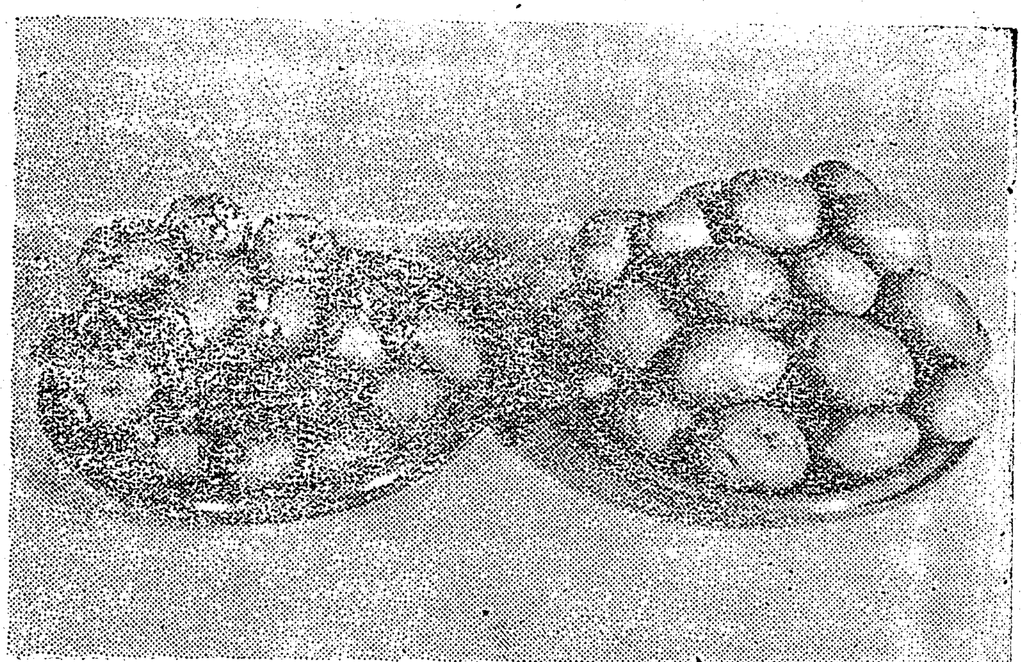


Fig. 3 : Sprouting inhibition in onions. Unirradiated (left); irradiated (right)

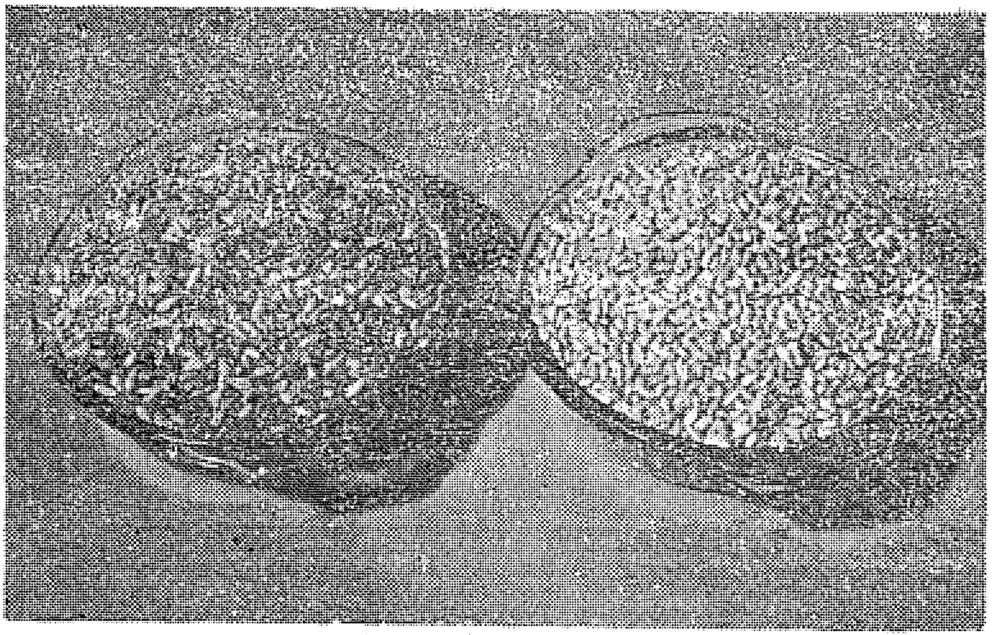


Fig. 4: Disinfestation of wheat. Unirradiated (left); irradiated (right)

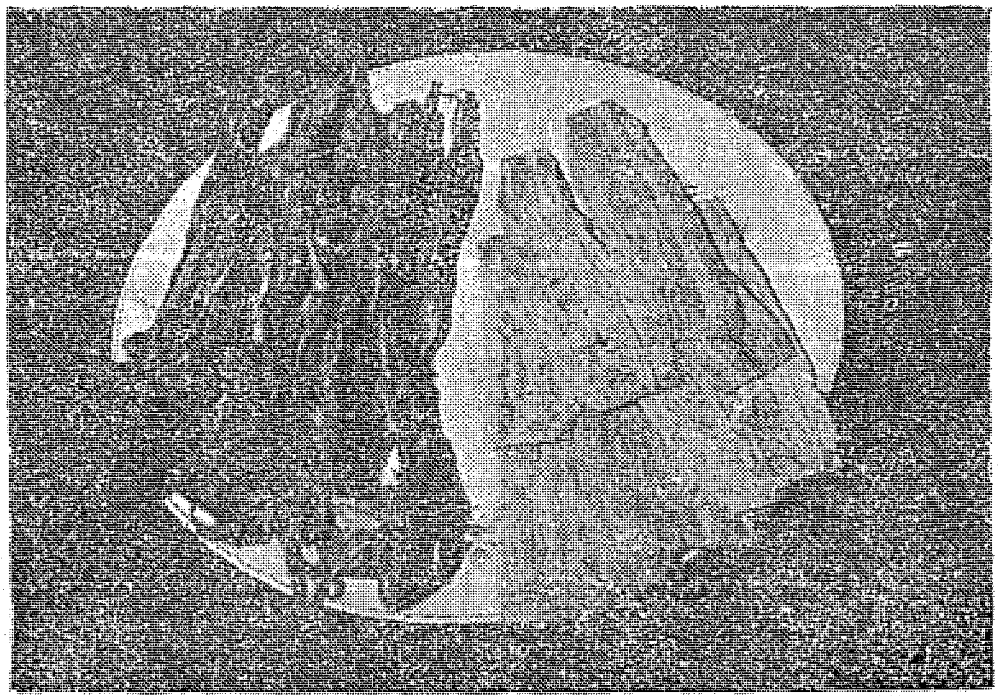


Fig. 5: Irradiated (20 krad) Bombay duck laminates (on right) stay free from insects and molds.

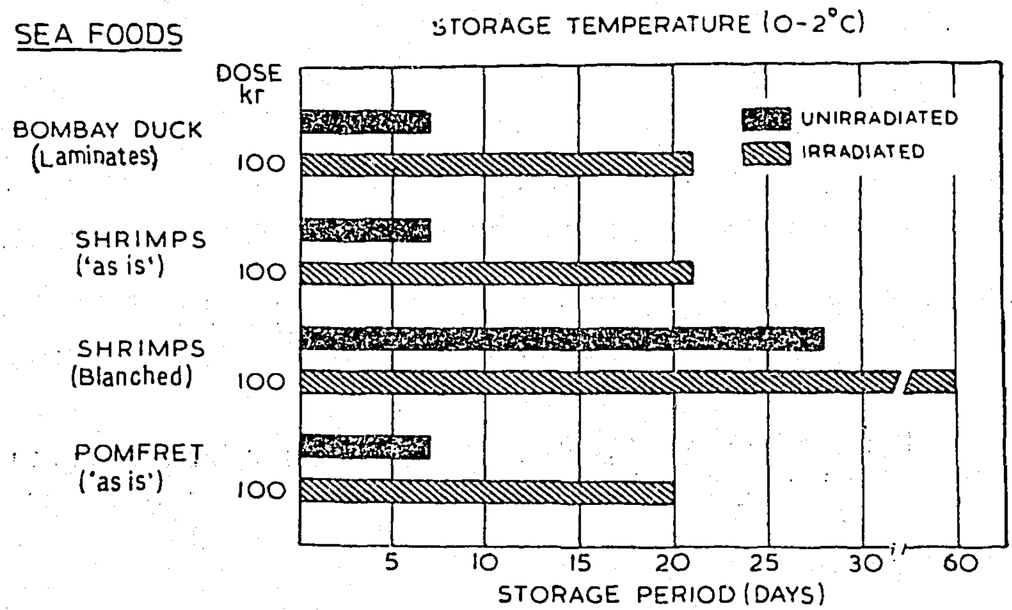


Fig. 6 : Prolonged storage time of irradiated sea foods

formation of off flavours, fresh fruits with high water content are prone to textural loss following irradiation. Also, the food could be organoleptically unacceptable if it was irradiated to eliminate bacterial toxins or mycotoxins. Because of their small molecules, mycotoxins require very high doses for their inactivation. It must be emphasised that food irradiation is not a miracle process which can convert spoiled food into high quality food.

6. Safety and nutritional adequacy of irradiated food

From its inception food irradiation process has generated controversies and faced resistance from some sectors in several countries. The scepticism regarding radiation processing has sprung from an incomplete knowledge and consequent fear since many people mistakenly associate food irradiation with the atom bomb and the lethal effects of ionizing radiation on living organisms. Some countries including USA have legally classed irradiation as a food additive rather than a process and therefore require evidence of safety or wholesomeness of irradiated foods. Wholesomeness means adequate nutritional quality and toxicological and microbiological safety for consumers. When a process is defined as an additive, it becomes necessary to provide proof of safety based on established protocols of food additives. Because of these reasons, research on food irradiation including its efficacy and safety has become so extensive, that currently radiation preservation is one of the most studied processes for foods. Some of the major concerns regarding the safety of irradiated food relate to presence of i) radiolytic products ii) induced radioactivity iii) bacterial or fungal toxins and iv) acquisition of radiation resistance and production of mutants by food bacteria.

It could be argued that some radiolytic products emanating from food constituents following irradiation could be toxic, carcinogenic or mutagenic. However, it should be borne in mind that cooking, frying, drying and other practices also generate breakdown products of food constituents and conventionally processed foods were found to possess more than 90% of these products.

Reports indicate that irradiation fails to destroy some bacterial or fungal toxins easily, because of small size of the molecules and the protection provided by food constituents. However, heat destroys these toxins effectively. For example, botutinal toxin which can resist a dose of 4 Mrad gets destroyed when exposed to heat at 80°C for 10 min.

Mutant strains of microorganisms may result from rradiation. Extensive work carried out to determine if any mutants of non-pathogens are pathogenic or if viruses not normally host specific to man get so transformed has shown no evidence for the occurrence of such phenomena.

Food, following exposure to gamma radiation does not become radioactive because the energy level of radiation employed for the process is restricted (5 MeV for gamma rays and 10 MeV for electron) in such a way that no nuclear change occurs in the food elements.

An enormous research effort has been directed towards biological testing of irradiated foods for the evaluation of their safety and wholesomeness. The exercise involved multigeneration animal feeding trials followed by reproduction, biochemical, clinical and histopathological studies to test for abnormalities arising from toxic, carcinogenic or mutagenic compounds. Experimental protocol was designed in a manner permitting extrapolation of data from animal studies to man with a high degree of certainty. No toxicological hazard specific to irradiated food has been identified.

The possible effects of radiation on carbohydrates include hydrolysis and oxidative degradation. Conversion of complex chains of carbohydrates into simpler compounds by depolymerisation, rendering cellulose more susceptible to enzymatic hydrolysis are some of the examples of radiation effects. However, doses employed for high carbohydrate foods such as grains and vegetables have not been shown to cause any reduction in the nutritive value.

Radiation induced changes in food lipids largely depend on the composition of fatty acids although the main reactions comprise of oxidation, polymerisation, decarboxylation and dehydration. Unsaturated fatty acids are more readily oxidized than are the saturated acids. The chemical changes are minimized when the products are irradiated in frozen condition and by packaging them prior to irradiation so as to exclude light and oxygen. Below doses of 5 Mrad there are only very slight changes in the usual indicators of fat quality, the radiation effect being similar to autooxidation, which manifests in the formation of peroxides followed by the appearance of substances such as aldehydes and ketones. Animal feeding experiments have indicated that, though the rate of digestion and absorption of fats irradiated at 5 Mrad was slightly reduced, this was not found to be nutritionally significant.

Although very high levels of irradiation have marked effects on proteins and amino acids, at the doses employed for food irradiation amino acids are virtually unchanged and consequently proteins do not suffer detectable nutritional losses. Studies of US Army Medical Department have shown that in beef, heated to inactivate autolytic enzymes and then radiation processed with a dose range of 4.7-7.1 Mrad at temperatures between -40 and -9°C there was no significant destruction of cysteine, metionine and tryptophan, the three amino acids considered most sensitive to ionizing radiation. Nutritive value as assessed by availability of lysine and protein efficiency ratio of a variety of proteinaceous foods has been shown to remain unaltered following radiation exposure. Table 3 presents data on amino acid composition of the protein employed in rat diet.

Table 3: Effect of irradiation (7.0 Mrad) on the amino acid composition of the protein in rat diet

Amino acid	unirradiated diet	Irradiated diet
Aspargine	8.85	8.38
Threonine	3.80	3.73
Serine	4.17	4.10
Glutamic acid	15.70	15.10
Glycine	5.82	5.80
Alanine	5.61	5.54
Valine	4.80	4.70
soleucine	4.00	4.00
Leucine	7.44	7.47
Tyrosine	3.28	3.38
Phenylalanine	4.10	4.30
Lysine	5.72	5.82
Histidine	2.30	2.37
Arginine	6.04	6.04
Methionine	2.33	2.11
Cystine	1.34	1.44
Tryptophan	1.16	1.32

Source: Ley, F.J.; Bleby, J; Coates, M.E and Patterson, J.S (1969) Lab. Animals 3, 221.

The amount of vitamin destruction that results from irradiation upto 6 Mrad is not very different from the destruction resulting from cooking. Most vitamins respond differently towards heat and radiation. Nevertheless, vitamins with low radiostability are usually also susceptible to attack by some other agent such as oxygen shown in Table 4. Vitamin E

Table 4: Sensitivity of vitamins towards different agents

Vitamin	Heat	Oxygen	Light	Ionizing radiation
Water soluble				
Ascorbic acid	0	++	+	++
Thiamin	++	0 or +	0 or +	++
Riboflavin	0	0	++	0
Nicotinic acid	0	0	0	0
Pantothenic acid	+	0	0	0
Pyridoxinc	0	0 or +	+	+
Biotin	+	0	0	0
Folic acid	+	+	+	0
Vitamin B_{12}	0	+	+	++
Choline	0	+	0	0
Fat soluble				
Vitamin A	0 or +	+	+	++
Vitamin D	0	0 or +	0	0
Vitamin E	0	++	0	++
Vitamin K	0	0	+	+

O. Stable; + Fairly Sensitive and ++ Very Sensitive

Source: Elias P. S and Cohen. A. J. Eds. (1977) "Radiation Chemistry of Major Food Components" p. 187 Elsevier, Amsterdam.

and thiamin are the most radiolabile fat soluble and water soluble vitamins respectively. If the food is cooked following irradiation there will be additional vitamin loss. Potentially some foods could suffer total thiamin loss. Care should therefore be taken to supplement vitamins in the diet when the entire regimen is made up of irradiated diet.

7. International acceptability

International acceptance of the safety of irradiated foods is considered a prerequisite for the wide commercialization of radiation processing. International project in the Field of Food Irradiation (IFIP) was therefore established with 25 countries funding the project. Independent groups carried out research on feeding trials to assess toxicological safety and wholesomeness of irradiated food and the data acquired were examined in 1976 by a joint FAO/IAEA/WHO expert committee on the wholesomeness of irradiated food (JECFI). This international body after careful scrutiny, concluded that it was perfectly safe to consume irradiated potatoes, wheat and flour, strawberries, pawpaws and chicken. It gave provisional approval for the irradiation of onions, fish and rice. Codex Alimentarious Commission (the executive body of the WHO which is responsible for setting standards for international trade in food) then declared that irradiation is a process similar to canning and freezing and not a food additive. The much needed fillip came to food irradiation in 1930, when the joint FAO/IAEA/WHO expert committee declared that irradiation of any food commodity upto a overall dose of 10 kGy (1.0 Mrad) causes no toxicological hazard and therefore no further toxicological testing should be necessary. This unconditional international clearance of irradiated foods stimulated greater interest on radiation technology and at present more than 30 countries have recognized the advantages of the process and have given clearance for the use of irradiation in processing some 40 food commodities. The American FDA which initially resisted food irradiation has now approved irradiation upto 0.1 kGy for any food product and for spices, has set the limit upto 30 kGy. The UK government's Advisory Committee on Irradiated and Novel Foods (ACINF) after nearly four years' debate has concurred with the conclusions of JECFI for clearing foods irradiated upto 10 kGy. Table 5 provides information on the commercial scale food irradiation facilities operating around the world currently. In January 1986, India also approved irradiation of potatoes and onions, as well as spices and frozen seafoods intended for export. As a prelude to commercialisation, the government has constituted a regulatory body, the National Monitoring Agency (NMA) to evolve guidelines for practical application of food irradiation and to set stringent regulations for the protection of health and safety of consumers and to prevent unethical practices in the trade. Fabrication of a transportable moving bed onion irradiator for demonstrating the efficacy of irradiation in extending the shelf life of the vegetable is in progress. This irradiator could be set up at the site of major onion crop production. Likewise, an irradiator intended for radiation processing of spices is proposed to be located at an appropriate site.

8. Cost of radiation processing

The cost of food irradiation stems from the following :

1. capital costs of radiation plant, building, conveyor systems, source and its replenishment costs;

2. recurring cost arising from operation and maintenance requirements;

3. product specific cost relating to specific process requirements, handling, storage etc.

Table 6 provides estimated values of radiation processing costs. It is seen that radiation processing increases the cost of the product only marginally in comparison with other food processing techniques.

Table 5 : Status of practical application of food irradiation (as of June 1988)

Country	Company (City)	Food item	Total quantity (Ton/Annum)
Argentina	National Atomic Energy Commission	spices, cocoa powder, spinach	~50
Belgium	IRE (Fleurus)	spices,	8-10,000
Brazil	EMBRARAD (Sao Paulo)	spices	~200
Chile	CCHEN (Santiago)	onions	~500
China	Shanghai Irradiation Centre	potatoes, apples	~500
Cuba	Institute of Food Industrial Res. (Havana)	potatoes onions	~500
France	Conservatome (Lyon)	spices	~2,500
	Caric (Paris)	spices, poultry	~500
	S.P.I. (Vannes)	poultry	~2,000
France	Oris (Nice)	spices	~200
German Dem. Rep.	Central Inst. Isotop. Radiat. Res. (Weideroda)	onions	~600
	Qneis Agric. Coop.	onions	~5,000

(continued)

Country	Company (City)	Food item	Total quantity (Ton/Annum)
Hungary	AGROSTER (Budapest)	spices	~400
Israel	Sorvan (Yavne)	spices	~120
Japan	Shihoro Agricultural Coop. (Hokkaido)	potatoes	15-20,000
Netherlands	GAMMASTER (Ede)	spices, frozen foods, poultry, dehydrated vegetabies, egg powder	~18,000
South Africa	ISO-STER (Johannesberg)	spices, dehydrated vegetables	~1,000
	High Energy Processing (Pelindaba)	fruits, spices, potatoes, onions	~20,000
Thailand	OAEP (Bangkok)	onions, fermented sausages	~600
U.S.A.	ISOMEDIX, Inc. (N. Y.)	spices	~1,000
	Radiation Technol. (N. J.)	spices	~500
	Radiation Sterilizer (Cal.)	spices	~1,800
USSR	Odessa Port Elevator	grain	~400,000
Yugoslavia	Boris Kidic Inst. (Belgrade)	spices	~100

Table 6 : Capital and service costs for radiation processing of foods

Process & Produce	Throughput (Tonnes/hr)	Irradiation Capital Cost (Rs $\times 10^5$)	Unit processing cost (paise/kg)
Sprout inhibition			
Onion (7 Krad)	12	60	5
Potato (10 Krad)	8	50 - 60	8 - 10
Disinfestation			
Dried or fresh fruits	5 - 10	100	10 - 20
Packed Grain (30 Krad)	5 - 10	100	10 - 12
Grain (free flow, 30 Krad)	50	200 - 250	2 - 4
Pasteurization			
Fresh fish (250 Krad)	2	150 - 175	40 - 60
Spices (750 Krad)	1	100 - 120	100 - 120

Source : Krishnamurthy, K and Bongirwar, D.R. (1987) Indian Food Ind. 6, 5.

9. Conclusions

Radiation processing of foods has the potential to provide mankind with such benefits as elimination of toxic fumigants for insect disinfestation, extended shelf life for refrigerated products, elimination of foodborne pathogens and parasites and to provide high quality packaged food with indefinite shelf life at room temperature. It would provide greater diversity in available food stuffs by enabling foods to be shipped and stored for extended periods prior to consumption. It would also open new export markets for many countries.

Some questions and answers on food irradiation

1. Does food irradiation make foods radioactive ?

The irradiation with gamma rays will not induce radioactivity in any product, including foods. Just as medical X-rays do not cause skin, bone or teeth to become radioactive, gamma rays do not induce radioactivity in foods.

2. Will food irradiation lead to hazardous working conditions for workers in the irradiation facilities ?

No. Several years of operation has shown them to be very safe work places.

3. What will be the environmental impact of these irradiation plants? Do they cause an increase in the amount of radiation or radioactive waste in the environment?

An isotope irradiator really has no environmental impact. All radioactive source materials are doubly or triply encapsulated in stainless steel covers to prevent escape of radioactive material. Periodic tests of storage water and irradiation facility work areas are conducted to ensure the absence of contamination. In the case of Cobalt-60 source, when the activity level decreases to an unacceptable level the source is sent back for reactivation so that no waste is generated. The entire process is designed to maintain the highest standards of safety of the operating personnel and public.

About the author

Vyasarao Ninjoor holds a doctorate degree in biochemistry from Bombay University (1976). He has taught for 8 years at graduate and post graduate level in science and medical faculties. He has worked at the University of California and at the University of Georgia for some years. Currently, he heads the Foods Science Section of Food Technology and Enzymes Division of Bhabha Atomic Research Centre, Trombay, Bombay. He has been an active researcher for more than two decades in the fields of protein nutrition, cellular biology, food sciences and radiation technology and has about 80 research papers to his credit. Presently he is engaged in studying enzymological aspects of food spoilage.