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Preservation of Food by Ionizing Radiations

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Editorial

Thanks to the 'Green revolution', India is today self sufficient in food production. It is by no means a small achievement that our country is able to feed the nearly one billion population with practically no dependence on external supply. In addition, India also exports a large quantity of food products to other countries.

In spite of the achievements in food production, a large portion of the produce gets spoiled due to poor storage facilities resulting in major erosion in the Indian economy. Hence, food preservation is one area which has drawn considerable attention of our food technologists. Food processing by ionising radiation, both gamma and electron, is an economically viable and environmental friendly alternative to the conventional methods.

Since the Sixties, the Bhabha Atomic Research Centre has been carrying out research on food preservation by irradiation and the technology is now ready to be taken on a commercial basis. Pilot scale food irradiators are being set up for processing of spices in Navi Mumbai and for potato and onion in Nashik. The commissioning of these facilities will usher an era of the commercial use of food preservation by ionising radiation in India.

The public acceptability of irradiated food in India has been poor due to ignorance and misinformation. The present issue of the IANCAS bulletin is focused on Food Irradiation by ionising radiation- its methodology, efficacy, safety and economic benefits. Dr. A.K. Sharma, Guest Editor of the issue has taken great pains in bringing together the experts in the field to give a comprehensive picture of the science of food processing by irradiation. I would like to thank him and all the authors who contributed articles in this issue.

I have great pleasure in reprinting the text of the lecture on 'Changing Scenarios in Isotope Production and Utilisation' delivered by Dr. D.D. Sood in the Annual Conference of the Indian Nuclear Society. The article lucidly covers the applications of radioisotopes in various fields and the readers will find the information useful.

M.R.A. Pillai

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Changing Scenarios in Isotope Production and Utilisation

Dr. D.D. Sood after graduating from the Punjab University in 1958 joined the Training School of the Bhabha Atomic Research Centre (BARC), Mumbai in 1959. He joined the Radiochemistry Division in 1960 and has been actively engaged in the studies pertaining to nuclear fuels, which include thermodynamic studies, development of the sol-gel process and quality control. He has published more than 150 papers and 25 technical reports. He has been awarded Netzch-ITAS award for his contribution to the science of thermal analysis. He is a member of the Editorial Board of the Journal of Chemical Thermodynamics. Currently he is Director, Radiochemistry and Isotope Group at the Bhabha Atomic Research Centre. Dr. Sood is scheduled to take over as Director, Division of Chemical and Physical Sciences, International Atomic Energy Agency, Vienna from August 1998.

Summary

Radioisotopes find a variety of applications in diverse fields such as medicine, industry, agriculture, food preservation and water resource management. Though a majority of the radioisotopes used for the above applications are produced in nuclear reactors, cyclotron produced short lived radioisotopes are also used for medical applications. The isotope production capabilities of the Department of Atomic Energy and some of the important applications of radioisotopes are discussed in this article.

Introduction

Little over a century ago Henri Becquerel discovered radioactivity which was followed by the discovery of the radioactive elements ^{210}Po and ^{226}Ra by Pierre and Marie Curie. Jean Federic Joliet-Curie and Irene Joliet-Curie in 1934 demonstrated the production of the first artificial radionuclide, ^{30}P by bombardment of ^{27}Al with alpha particles emitted from a polonium source. Invention of the Cyclotron at Berkeley by E.O. Lawrence increased the range of artificially produced radioactive isotopes (^{131}I, ^{60}Co and ^{99}Tc etc.). The discovery of nuclear fission by Hahn and Strassmann and the setting up of the reactor at Chicago by Fermi and co-workers in 1942 opened the flood gate for the production of radioisotopes. As of today there are over 2000 radioisotopes which are produced artificially and several of them are beneficially used for improving the quality of life. Thanks to the early work started at the Bhabha Atomic Research Centre, India is today recognised as one of the world leaders in radiation and radioisotope technology.

Production of Radioisotopes

Nuclear reactors is the preferred source of radioisotopes as they could be prepared as by-products by utilising the excess neutrons available for activation of stable elements. In addition, a number of useful fission products (^{90}Sr, ^{137}Cs, ^{99}Tc etc.) could also be separated during or after reprocessing the spent fuel. In India, the production of radioisotopes started in the late fifties with the commissioning of the Apsara reactor in 1956. The production capability was augmented in 1963 when the CIRUS reactor attained its full rated capacity of 40 $MW_{(t)}$. There was a major increase in the production capacity when the 100 $MW_{(t)}$ Dhruva reactor attained criticality in 1985. Dhruva is one of the large research reactors in the world and it caters to the production of a wide spectrum of radioisotopes for use in medicine, industry, agriculture and research. A major part of ^{60}Co, an isotope which is used for several applications including radiation processing, is prepared in the power reactors of the Nuclear Power Corporation. By 1997, the production

Text of the lecture delivered in the Annual Conference of the Indian Nuclear Society, 1997

will be about 2 million Ci of medium specific activity (80-100 Ci/g) ^{60}Co and by 1999 an additional one million Ci of high specific activity (160 Ci/g) ^{60}Co suitable for teletherapy is expected to be available from the power reactors.

The multidisciplinary Cyclotron facility at Calcutta has also been contributing to the production of radioisotopes. ^{67}Ga needed for diagnostic applications is now prepared in limited quantities at VECC, Calcutta and made available to nuclear medicine centres by the Board of Radiation and Isotope Technology (BRIT). One area where additional input is needed is in the production of some of the short lived positron emitting radioisotopes (^{11}C, ^{13}N, ^{15}O, ^{18}F) for positron emission tomography (PET) studies in nuclear medicine.

Radiochemical Processing Facilities

A major challenge in the production of radioisotopes is to prepare them with the appropriate specific activity, radiochemical purity and radionuclidic purity conforming to the specifications for different applications for which they are used. For example, the ^{60}Co needed for radiation processing applications could be of low specific activity (~ 60 Ci/g), whereas very high specific activity (>150 Ci/g) preparation is needed for teletherapy applications. Appropriate irradiation conditions at high flux irradiation position in suitable reactors will be essential to get high specific activity radionuclides. Well equipped processing facilities with hot cells are needed for handling the large quantities of activity involved. The hot cell facilities at the Radiological laboratories and at the High Intensity Radiation Utility Plant (HIRUP) at Trombay; and at the Cobalt handling facility at Rajasthan (RAPCOF) is used for processing the irradiated ^{60}Co and for fabrication of the radiation sources as per the approved designs of regulatory agencies.

Standardisation of appropriate radiochemical separation techniques for preparation of the isotopes in adequate radiochemical and radionuclidic purity is of paramount importance in the production of radioisotopes for several applications especially for medical use. Radiochemical processing facilities set up at the Radiological Laboratories, Trombay is used for the radiochemical separation of several isotopes (^{99}Mo, ^{131}I, ^{32}P, ^{35}S etc.).

Presently, studies are being carried out for the preparation of high specific activity ^{99}Mo, ^{105}Rh, ^{153}Sm, ^{188}Re etc. for medical applications. In order to get the desired radioactive concentration in the final preparation, very high specific activity ^{99}Mo is needed for the preparation of column chromatographic generators for ^{99m}Tc. Fission produced ^{99}Mo offers the required specific activity and hence it is preferred for this application. A major constraint in the preparation of fission produced ^{99}Mo is the necessity of isolating it from a large number of fission products and actinides which are present in the irradiated uranium target. Elaborate radiochemical processing facilities including hot cells are needed for carrying out this work. Because of the large investments involved, the entire supply of ^{99}Mo needed by the nuclear medicine community in the entire world is presently coming from a few manufactures such as the Nordion, in Belgium; AECL, Canada and from the South African reactor.

Accelerator Driven Operated New Irradiation System (ADONIS) for Isotope Production

An innovative idea for the large scale production of radioisotopes is a hybrid technology developed by the Nuclear Research Centre of Belgium in collaboration with the Ion Beam Applications, a Belgian company specialising in the design of cyclotrons for medical applications (1). As per the experimental set up, a high energy proton beam (150 MeV, 1.5 mA) emanating from the cyclotron will be allowed to fall on a molten lead target to produce spallation neutrons. The spallation neutrons after moderation will be used for irradiation of targets made of enriched ^{235}U. The arrangement will result in a sub-critical assembly which will give a thermal neutron flux of $2x10^{14}$ n/cm^2 and a thermal fission power of 600-720 kW. The targets can be loaded and unloaded with the facility on-line. As per calculations, a properly designed ^{235}U target would reach a saturation activity of 335 Ci of ^{99}Mo per gram of ^{235}U. Running of an ADONIS will result in meeting half the world requirement of ^{99}Mo. Though in a very preliminary stage, the proposers of this scheme (M/s SCK-CEN) are optimistic that this sort of assembly can replace the necessity of having reactors for isotope production in future.

Applications of Radioisotopes

Parallel to the research leading to the production of radioisotopes was the quest for exploring their use for the benefit of mankind. Thanks to the pioneering work of a large number of scientists, radioisotopes are used today for a variety of applications. Irrespective of the areas of applications, three fundamental properties of the radioisotopes are taken advantage of in their use. These are:

(i) Ability of the radioisotope to act as a tracer for its inactive counterpart

(ii) Attenuation of the radioactivity when it passes through an object and

(iii) Utilisation of radiation energy.

Based on the above principles a wide spectrum of applications have been developed using radioisotopes in fields such as medicine, industry, agriculture, food preservation etc. Some of these applications are discussed below.

Radioisotopes in Medicine

The use of radioisotopes in medicine is as old as the discovery of radioactivity itself. In the early part of this century, the internal administration of some of the naturally occurring alpha particle emitting isotopes were explored for therapy of certain common diseases such as arthritis. The experiments were unsuccessful mainly due to the non-specific uptake of the radioisotopes and the associated risk due to exposure to high radiation doses. The failure of the early experiments led to a temporary set back in the use of radioisotopes in medicine.

Iodine Radiopharmaceuticals

At the end of World war II, US Atomic Energy Commission allowed the use of fission by-products for medical purpose and the first dose of ^{131}I for a diagnostic investigation was given to a patient at Massechevessets Institute of Technology (MIT) in 1946. This and subsequent experiments clearly demonstrated that the administration of a small quantity of ^{131}I could be effectively used for studying the function and morphology of the thyroid gland.

Parallel to the research for new and efficacious radiopharmaceuticals was the development of the necessary instrumentation. The simple radioactive probe which was used for the measurement of radioactive iodine uptake in the thyroid gland was replaced with a 'Rectilinear Scanner' thanks to the innovative efforts of Benedict Cassen and his colleagues (2). The rectilinear scanner used a NaI(Tl) crystal which moved in the XY direction and the isotopic concentration at different parts of the thyroid gland is measured and simultaneously recorded on a plotter paper, thereby giving a thyroid scan. The uptake pattern of the activity as seen in the thyroid scan was of immense help to the physicians for deciding the course of treatment.

The therapeutic applications of ^{131}I started soon for the treatment of hyperthyroidism and thyroid cancer, the two most prevalent thyroid disorders. Even today, the administration of ^{131}I is the most effective and widely practised method for the treatment of these diseases.

Thanks to the versatile chemistry of iodine, a number of iodine labelled radioactive compounds could be synthesised which have selective uptake in various organs including the liver, kidneys and brain. A short lived isotope of iodine, ^{123}I ($T_{1/2}$ 13 h) produced in cyclotron is preferred in many of these applications as it gives less radiation dose to the patient.

A recent estimate shows that over half million patients are administered with an isotope of radioiodine annually (3). Table 1 lists some of the iodine radiopharmaceuticals which are currently in use. The use of iodine isotopes in medicine is in the decline mainly due to the unfavourable radionuclidic characteristics of ^{131}I (long half life, particulate emission and high energy gammas); and the high cost of the cyclotron produced ^{123}I. Hence the preference of the nuclear medicine community was for a more suitable short lived radioisotope which is abundantly available at low cost. This desire led to the work leading to the development of Tc radiopharmaceuticals for medical applications.

Table 1. Radiopharmaceuticals based on iodine isotopes

Radiopharmaceutical	Application
^{131}I-Sodium iodide	Thyroid imaging, hyperthyrodism and thyroid cancer
^{131}I-Metaiodobenzylguanidine (MIBG)	Neuroendocrine tumors (diagnosis and therapy)
^{123}I-Iodoamphatamine (IMP)	Regional cerebral blood flow
^{123}I-(p-Iodophenyl)3-R,S-methylpentadecanoic acid (BIPP)	Myocardial viability and fatty acid metabolism
^{123}I-L-α aminomethyltyrosine (AMT)	Regional cerebral blood flow

Technetium Radiopharmaceuticals

Technetium was discovered in 1937 by Perrier and Segre in Mo reflector plates which were irradiated with deuterons in the Berkeley cyclotron, thus filling one of the vacancies in the Periodic table (4). An important development which led to the widespread use of Tc in nuclear medicine was the invention of a highly useful instrument called 'Gamma Camera' by Hal Anger (5). The gamma camera could simultaneously measure the activity distribution of a large area and thereby give the image of whole organs. Gamma camera was also suitable for the measurement of rapid changes in the activity distribution due to biochemical changes within the body thereby giving it the capability to be used for functional studies. The detector in this instrument is a large, thin crystal of NaI(Tl) (~ 18 inch dia and upto 15 mm thickness) which is connected to an array of photomultiplier tubes to pick up the signals emanating from the different parts of the crystal. A suitable collimator is kept prior to the crystal and the photomultiplier tubes to give the necessary resolution. The instrument is ideally suitable for the measurement of gamma energies of 100-200 keV. The development of the gamma camera was like the proverbial cart before the horse. Neither the isotope suitable for the gamma camera nor good radiopharmaceuticals capable of giving rapid uptake and clearance pattern were available at that time. The thin crystal of the gamma camera made it unsuitable for use with ^{131}I, the most commonly used isotope in those days.

In the early sixties, Powell Richards and his colleagues at the Brookhaven National laboratory developed a 'Tc cow' or a generator system which could be used for the elution of copious amounts of the short lived isotope of technetium, ^{99m}Tc ($T_{1/2}$ 6 h) (6). The innovative idea behind this development was that long lived ^{99}Mo ($T_{1/2}$ 67 h) could be absorbed on a chromatographic column, and the short lived daughter product ^{99m}Tc could be eluted from it. ^{99}Mo and ^{99m}Tc being in what is known as the 'transient equilibrium', ^{99m}Tc decays with an effective half life of the parent ^{99}Mo ($T_{1/2}$ 67 h) and ^{99m}Tc could be eluted daily from the generator system.

The development of the radioisotope generator discussed above opened up the possibility of the use of short lived radioisotopes at places far away from the site of production. The short half life, decay by isomeric transition (IT), convenient gamma energy of 140 keV in high abundance (88%), absence of particulate emission and above all the ready availability from a generator system contributed to making ^{99m}Tc the isotope of choice in nuclear medicine. The next twenty years saw the proliferation of nuclear medicine centres using ^{99m}Tc. Its decay energy (140 keV) matched well with the already developed gamma camera. All the above factors together with the rapid progress in the Tc radiopharmaceuticals chemistry contributed in making ^{99m}Tc the *work horse* of nuclear medicine.

Along with the developments in the Tc radiopharmaceuticals chemistry, nuclear medicine instrumentation also underwent rapid changes. The single head gamma camera underwent modifications into multi-heads and capability for rotation around the body to give tomographic or spatial resolutions of the images obtained with the instrument, thus giving birth to the modern instrument of nuclear medicine, the single photon emission computed tomography (SPECT) camera. The SPECT machine is capable of giving 3D images and can precisely quantitate the distribution of the activity in various organs within the body at relatively short time intervals. Hence the SPECT cameras together with the new generation Tc radiopharmaceuticals could be used for dynamic studies of the organs such as the heart and brain.

Since its first use in 1961 as TcO_4^- for thyroid scan, the Tc radiopharmaceutical chemistry underwent rapid progress. Tc being a second row transition element, it can be manipulated to form a large number of co-ordination complexes with induced selectivity for uptake in the different organs of interest. A large number of ^{99m}Tc based radiopharmaceuticals are currently available for the diagnosis of a wide spectrum of diseases and disorders. Table 2 lists some of the Tc radiopharmaceuticals and their applications. As of today, over ten million diagnostic investigations are done annually in the USA alone using ^{99m}Tc (7). Research leading to the discovery of new Tc complexes which are capable of giving higher selective uptake in specific organs such as the heart and brain is the challenge for the radiopharmaceuticals chemists today. The Isotope Division has been contributing in a significant way in this area by developing new chelate molecules for complexation of Tc and by studying the *in-vivo* uptake of these Tc complexes in laboratory animals.

Table 2. ^{99m}Tc-Radiopharmaceuticals and their applications

Radiopharmaceutical	Function studied
^{99m}Tc-Hexamethyl propylene amine-oxime (HMPAO)	Brain imaging
^{99m}Tc- Ethyl cysteinate dimer (ECD)	Brain imaging
^{99m}Tc-Hexakis methoxy isobutyl isonitrile (MIBI)	Cardiac function
^{99m}Tc-Phytate	Liver imaging
^{99m}Tc-Mercapto-acetyltriglycine (MAG_3)	Renal tubular function
^{99m}Tc-Glucoheptonate	Renal imaging
^{99m}Tc-methylene diphosphonate (MDP)	Bone imaging
^{99m}Tc-labelled antibodies	Tumor imaging

Medical Cyclotrons and Radiopharmaceuticals for PET Studies

Exclusive Cyclotron Centres for the production of radioisotopes for medical applications started coming into existence in the late sixties and as of now there are about 200 working cyclotrons in the world (as per a survey conducted by IAEA). A dedicated cyclotron (capable of giving up to 30 MeV protons or equivalent energy charged particles) together with a radiochemical laboratory for the chemical synthesis of the radiopharmaceutical and a nuclear medicine Centre with one or two Positron Emission Tomography (PET) cameras constitute a Medical Cyclotron Centre. Typically the machines are operated for the production of short lived positron emitters (^{11}C, ^{13}N, ^{15}O, ^{18}F etc.) during the day shift followed by the production of medium half life radioisotopes such as ^{67}Ga, ^{111}In, ^{123}I, ^{201}Tl for SPECT studies during the night operation. PET radiopharmaceuticals are developed based on biochemical concepts taking advantage of the specific uptake of the biomolecules in the organs of interest. For this purpose, naturally occurring and bio-compatible substances such as biomolecules or drugs are labelled with positron emitting isotopes. The images obtained from PET cameras are superior than those using gamma cameras and Tc radiopharmaceuticals. The major reasons for such superiority in the quality of the image are due to the higher uptake of the radiotracers with C, N, O isotopes and the possibility of injecting much higher quantities of the short lived isotopes without increasing the radiation dose. However, the medical cyclotrons have not become as popular as expected. This is mainly due to the exorbitant cost per investigation. The high cost of installation and maintenance of the Cyclotron Centre, necessity to have large staff component for operation of the cyclotron and the radiopharmaceutical laboratory; and the low turn over of patients (about 5-6 per shift

Table 3. Cyclotron based radiopharmaceuticals

Radiopharmaceutical	Application
^{11}C-Palmitate/acetate	Myocardial metabolism
^{13}N-Ammonia	Blood flow
^{18}F-Fluoro-2-deoxyglucose	Glucose metabolism in brain and heart
^{67}Ga-Citrate	Tumor and infection imaging
^{111}In-Octreotide	Neuoroendocrine tumors
^{111}In-Leucocytes	Inflection and inflammation
^{123}I-Metaiodobenzylguanidine (MIBG)	Neuroendocrine tumors
^{201}Tl chloride	Myocardial perfusion imaging

per PET machine) all make PET investigation affordable only to the privileged few. Table 3 lists some of the radiopharmaceuticals based on cyclotron produced isotopes.

Radioisotopes for Therapy

As discussed in the initial part of this article, radioisotopes were first unsuccessfully explored for therapeutic applications and nuclear medicine has turned a full circle since then. The major thrust in radiopharmaceuticals chemistry research as of now is in the development of therapeutic radiopharmaceuticals (8). The main constraint in the use of radioisotopes for therapy was the inadequate means to selectively send the radioisotope to the specific organ/tissues of interest. This problem is to an extent circumvented by the continued research leading to the development of more specific carrier molecules which are capable of transporting the radioisotopes to the site of interest. Carrier molecules which are used for this purpose are antibodies, peptides, and receptor affinity molecules.

Focused research is now undertaken at several centres for the production of short-lived, reactor produced, beta particle emitting radionuclides and their radiochemical processing to get the desired radiochemical and radionuclidic purity. The isotopes which are most promising for therapy are ^{32}P, ^{90}Y, ^{105}Rh, ^{109}Pd, ^{153}Sm, $^{186/188}$Re etc. (9). Table 4 lists some of the isotopes and radiopharmaceuticals used for therapy. The radioactivity given to the patient

Table 4. Therapeutic radiopharamceuticals

Radiopharmaceutical	Application
^{32}P-Orthophosphate	Bone metastasis
^{89}Sr-Strontium chloride	Bone metastasis
^{131}I- Sodium iodide	Thyroid cancer
^{153}Sm-EDTMP	Pain relief
$^{186/188}$Re-HEDP	Pain relief

varies from a few mCi to a few hundred mCi depending upon the type of applications and the isotope used.

Radiation Therapy

Early research in radiation biology conclusively proved that radiation can destroy the DNA molecule in the cells thereby making them incapable of further division. A beneficial use of this harmful effect of radiation was the development of teletherapy for the treatment of cancer. A teletherapy unit consists of a remotely operated high intensity (~10,000 Ci) of ^{60}Co point source housed inside a shielded container. After placing the patient in position, the source is brought out and the highly collimated radiations coming out of it is allowed to fall on the tumour tissues to selectively destroy them. For therapy, a radiation dose of up to

5000-6000 Rads (50-60 Gy) could be delivered over several sittings. There are about 130 teletherapy units in India which are located in the major cancer hospitals in the country. A substantial increase in the number of teletherapy units is essential to cater to the large number of cancer patients in our country.

Gamma Knife

A recent advance in external radiation therapy is the development of 'Gamma Knife' for stereotactic radiosurgery of tumours and arteriovenous malformations in the brain (10). Stereotaxy essentially uses the concept that a point can be precisely located if its relationship to three different co-ordinates is known. Radiosurgery refers to the precise delivery of a high dose of radiation exactly to a reconstructed 3D target volume of the tumour. A stereotactic frame or a head-ring serves as a reference platform for reconstructing the patients head and the target lesion within. A precise, one time dose of radiation is then delivered to the lesion simultaneously from different locations in the gamma knife. The radiation can be X-rays or gamma rays from ^{60}Co sources.

Brachytherapy

In brachytherapy, a low intensity radiation source is implanted near the tumour to irradiate the cancerous tissues in its proximity. This method which uses tiny sources of ^{137}Cs, ^{192}Ir, ^{60}Co, ^{125}I, ^{198}Au, ^{182}Ta etc. is very effectively used for treatment of primary tumours affecting the uterus, breast, throat etc. ^{137}Cs sources for brachytherapy applications are routinely manufactured by the Isotope Division and distributed by BRIT to the users in India. Very recently, the Isotope Division has developed ^{125}I sources for brachytherapy for certain intraoccular tumours affecting the eyes.

An exotic but very useful application of radioisotopes in medicine is in the implantation of radioactive stents to prevent restenosis after angioplasty (11). The stent is made radioactive by incorporating a very small amount (~ 1 μCi) of ^{32}P and implantation of these stents during operation significantly reduces the risk of restenosis. Radioactive stents have been developed in the Isotope Division and pilot studies are planned to be carried out at medical centres for its use.

Radioanalytical Techniques

Using radioisotopes as tracers several radioanalytical techniques are developed of which the radioimmunoassay and related techniques find wide application in medicine. Neutron activation and charged particle activation analyses are also used for estimation of trace elements of medical interest in biological specimens.

Radioimmunoassay

Radioimmunoassay (RIA) is the most widely used radioanalytical technique and has become an inevitable tool in modern clinical pathology. Based on the principle of a competitive reaction, RIA uses a reagent called antibody and a radiotracer for the specific measurement of the substance to be analysed. RIA technique has very high sensitivity and specificity and hence can be used for the measurement of extremely low concentrations of biologically important substances such as hormones, drugs, vitamins, viruses etc. in un-extracted blood samples. A related technique called immunoradiometric assay (IRMA) is also used extensively for the above applications. The above methods are carried out *in vitro* and hence there is no administration of radioactivity to the patient.

Sterilisation of Medical Products

Sterilisation of medical products by ionising radiation is an economically viable alternative for the conventional sterilisation methods such as dry/wet heat or treatment with ethylene oxide (EtO). EtO is a surface sterilant and is not effective for killing entrapped or deep seated micro-organisms. Products sterilised by this method will also contain residual EtO and its reactive products. The major advantage of radiation sterilisation is that heat resistant and bulky materials can be effectively sterilised by the penetrating radiation.

Radiation sterilisation is a highly efficient and cold process in which a radiation dose of 2.5 MRad or 25 kGy is delivered to the products to be sterilised. Gamma radiations emanating from high intensity (~ Million Ci) ^{60}Co sources are preferred, though electron beam accelerators are also employed in several countries for sterilisation of medical products. Gamma radiation has the advantage that it could be used for sterilising bulky packages in final packed form. A variety of medical products and devices such as surgical sutures, medical devices, ophthalmic devices, drugs in solid state, plastic, rubber and metal products used in manufacturing of pharmaceuticals etc. are sterilised by radiation processing.

There are about 200 radiation sterilisation plants operating in the world of which four are in our country (12). These are at Mumbai (ISOMED), Bangalore (RASHMI), Delhi (SARC) and Jodhpur (RAVI).

Applications of Radiation in Industry

Industrial applications of radioisotopes and radiation constitute a wide spectrum which include radiation processing, non-destructive testing, nucleonic control systems, inventory control, study of process parameters, trouble shooting in industrial systems etc. (13,14).

Radiation Processing in Industry

High energy ionising radiation has the unique ability to produce very reactive, short lived ionic or free radical species in a variety of substrates without addition of any initiator or cross linking agent and this could be beneficially used for the development of industrial processes. The Isotope Division has been engaged in the development of a number of applications that are of importance to the Indian industry and are economically viable. Some of these activities have already resulted in the development of industrial processes and a few of them are discussed below.

Radiation cross linking of polyethylene 'O' rings : Radiation cross linking of polymers is used for imparting shape stability to the polymers when subjected to elevated temperatures thereby extending the operating temperature range or to realise the effect of shape memory. Using the ILU accelerator available at the Isotope Division, radiation cross linking of polyethylene 'O' rings which are used as inner gaskets for oil drums have been studied to impart them dimensional stability. Commercial production of 100,000 rings per day is expected to begin in the immediate future.

Poly tetrafluoroethylene (PTFE) degradation : PTFE is a unique engineering plastic with excellent high temperature stability, strength and resistance to corrosive chemicals. Its outstanding anti-friction and non-stick properties coupled with its non-toxic nature have resulted in its use as a dry lubricant, additive to lubricants and non-stick coating material. However, the polymer is extremely resistant to pulverisation and when pulverised, the high molecular weight powder slowly agglomerates. By irradiation with gamma rays or electron beam it is possible to impart chain scission in PTFE and prepare useful degraded products which can be used for specialised applications. A single stage irradiation process has been developed which utilises virgin PTFE-grade rejects as the raw material to produce low molecular weight PTFE. The particle size of this PTFE can be brought down up to $<10\ \mu m$. The PTFE degradation can also be achieved by EB irradiation.

Radiation vulcanisation of natural rubber latex (RVNRL) : India is the third largest producer of rubber latex in the world. It is now well established that the conventional sulphur vulcanisation of rubber latex results in the formation of carcinogenic nitrosamines in rubber and many countries where such products are exported have put severe restrictions on their concentration in rubber products. Hence an alternate environment friendly and clean procedure is the vulcanisation of natural rubber latex by irradiation. A pilot scale plant has been commissioned at the Kottayam District in Kerala for radiation vulcanisation of natural rubber latex (RVNRL). The plant is designed to load up to 100,000 Ci of ^{60}Co and has a capacity to process one ton of natural rubber latex per day. This plant is operating since 1992 and the entire RVNRL is sold to the manufacturers of dipped goods.

Heat shrinkable tubings : Cross linking of polyethylene heat shrinkable tubes, which are used as wire joints has been successfully carried out on a pilot plant scale using the EB accelerator at the Isotope Division. Post irradiation tests show that 150 kGy of radiation dose is suitable for tubings made from polyethylene containing an appropriate sensitizer. The process is being scaled up and commercial applications of this product are expected soon.

Radiation cross linked wire and cable : Polymers used for insulation and jacketing of electric wire and cable undergo cross-linking when exposed to radiation and thereby improving some of their properties (15). Improvements are observed in mechanical and thermal properties, deformation characteristics, abrasion resistance, resistance to solvents and swelling behaviours. Though gamma radiation from radioactive isotopes such as ^{60}Co can be used for this purpose, the preference is for the EB accelerator. Preliminary studies conducted at the Isotope Division with the ILU EB accelerator has shown satisfactory test results.

Radioisotopes in Non-Destructive testing (NDT)

The difference in the intensity of the radiation after passing through a test material is useful to get information such as thickness, density, defects etc. of the material under study. Based on this principle, a variety of techniques are developed which are routinely used in non-destructive testing in industry. Sealed sources of radioisotopes are used for non-destructive testing. The major techniques are radiography, gamma scanning, computer aided tomography and nucleonic control systems.

Gamma radiography: Gamma radiography is one of the relatively simple but widely used routine test for finding out defects in welds, castings etc. The isotopes used for gamma radiography are ^{60}Co, ^{192}Ir, ^{137}Cs, ^{241}Am etc. At present, there are about 500 industries using about 1000 radiography cameras for quality control of industrial products.

Computed tomography : Taking cue from medical tomography, a similar technique has been developed for the non-destructive testing of engineering and industrial specimens. A prototype computer tomographic system (CITIS) has been developed at the Isotope Division using a 7 Ci source of ^{137}Cs (16). This system provides a unique cross sectional image of the internal structure of test objects. The method involves collection of transmission data of the penetrating radiation through an object at different planes and subsequent reconstruction using the two dimensional planar profiles of the effective linear attenuation coefficients at designated points to a 3D image. The computed tomography imaging system consists of a gamma ray source, a collimated detector assembly, a precisely controlled mechanical manipulator and a data acquisition system along with a PC. This computer aided tomography system is expected to be useful for the non-destructive testing of a number of precision components used in specialised applications such as in Space, Defence and Atomic Energy.

Gamma scanning : The non-performance of an industrial column in the desired way can result in production losses. In conventional tests it will be essential to shut down the plant before any inspection and trouble shooting operation can be undertaken resulting into further production losses. Gamma scanning can be advantageously used for on-line trouble shooting of industrial columns without disturbing the ongoing production activity.

The Isotope Division in collaboration with the Engineers India Limited (EIL) has developed a gamma scanning technique for trouble shooting of industrial columns (17). In practice, a collimated source and detector are positioned in the horizontal plane either across the diameter (in tray type columns) or across the different equi-length chords (in packed bed columns). Both the source and detector are then moved synchronously along the length of the column and radiation intensity is recorded at desired elevations. The analysis of the data with reference to the internal loading and hardware configuration of the column gives invaluable information about the column. 'Signature scans' obtained at normal working or at pre-commissioning trials could be used for comparison and to derive useful information of the internal configuration of the column. Gamma scanning techniques have wide applications in trouble shooting, debottle-necking, preventive maintenance and for optimisation of the design of industrial columns. This technology along with specialised services is offered by BARC and Engineers India Limited and is now widely availed by the Indian industry.

Radiotracer Applications in Industry

Radioisotope tracers offer several advantages such as high detection sensitivity, capability of *in-situ* detection, limited memory effects and physico-chemical compatibility with the materials under study. Radiotracers are routinely used in industry for a variety of applications such as for leak detection, blockage detection, flow rate measurement, residence time distribution measurements, material inventory etc. Some of these applications for which services are offered by the Isotope Division are discussed below.

Leak detection in buried pipeline : Radiotracer techniques could be used for detecting leaks in pipelines which carries liquids as well as compressed gases. An appropriate chemical form of the short lived ^{82}Br ($T_{1/2}$ 36 h) is preferred for this application. In non-piggable pipelines, 'tracer patch migration technique' is used for detecting the leak (18). The pipeline which needs to be tested is divided into different sections and radiation detectors are kept in trenches at different intervals of the pipeline. The radiotracer in a suitable chemical form is injected into the pipeline. The movement of the radiotracer is monitored by using the radiation detectors located at different trenches. The leaking section of the pipeline will lie beyond the last detector which recorded the flow of the activity and the next detector which failed to record the activity. A radiation survey along the pipeline between the two detectors will lead to the leakage spot. Based on this technique, a 11 kM section of a 74 kM pipeline carrying ethylene gas for Polyolyfiens India Limited (PIL) was investigated and the leaking section of the pipeline was identified.

In piggable pipelines, a slight variation of the technique is adapted. The activity is first injected along with a liquid which is followed by flushing the pipeline with clean liquid. Part of the radioactivity injected would have found its way to the soil near the leaking spot. A radiation detector together with a tape recorder is send through the pipeline using a pig (pipe inspection gauge) to locate the radiation at the leaked portion of the pipeline. The audio signal produced by the radiation detector when passing near the leaked activity is picked up by the tape recorder. Keeping standard sources at different distances in the pipeline will help in identifying the exact location of the leak while replaying the recorder. This method has been successfully used for detecting leaks in pipelines carrying petrochemicals of some of the oil industries in India.

Residence time distribution studies : Continuously operating industrial systems are designed to have certain fixed pattern of flow parameters. Deviation from the optimum flow parameters affect the quality and efficiency of the process. The deviation may be either due to malfunction or due to poor design of the system. Hence estimation of the residence time distribution (RTD) is useful for identification of a number of malfunctions including leak, presence of dead or foul volume, by-passing, channelling or parallel flow paths etc. For the estimation of residence time distribution, a short-lived radiotracer (^{82}Br) in a suitable chemical form is injected to the reactor and the radiotracer is detected at the inlet and outlet of the system using two NaI(Tl) scintillation detectors connected to a data acquisition system. The mean residence time (MRT) of the reactor could be estimated from the time lag between the two measurements. From the MRT and by knowing other parameters of the reactor, the effective volume of the reactor can be found out. Difference in effective volume and standard geometric volume will give useful information about the functioning of the reactor. The Isotope Division has successfully carried out residence time distribution studies in a number of chemical reactors (19).

Radioisotopes in Hydrology

Radiotracers are used in hydrological studies such as sediment transport in harbours (^{46}Sc), flow rate measurement in rivers (^{82}Br), leakage in dams and reservoirs (^{82}Br) etc. Estimation of stable isotopic composition (^{2}H, ^{18}O, ^{13}C, ^{15}N, ^{34}S) is used for the study of the origin of ground water salinity in coastal areas, ground water recharge studies in arid and semi-arid regions, interconnection studies between various water bodies and for ground water pollution studies (20).

Radioisotopes in Agriculture

Agriculture was one of the early beneficiaries of radioisotope techniques. Radioisotopes are used in agriculture for studying the uptake of fertilisers, persistence of pesticides, radiation mutation, irradication of harmful insects etc. Fertilisers labelled with ^{32}P or ^{35}S are used for studying their efficacy, correct time of application, mode of application, depth of application etc. Radiotracers are also used for the study of the role of micro-nutrients in agriculture. Although the role of micro-nutrients is proven, their toxic effects on the environment and crops due to excess application are the concern of agricultural scientists. Radiotracers aid in estimation of optimal amounts of micro-nutrients to be added. The isotopes used for the above studies are ^{54}Mn, ^{57}Co, ^{59}Fe, ^{65}Zn etc. ^{32}P labelled nucleotides are used for DNA fingerprinting studies in molecular agricultural biology.

Radiation Mutation

It is known for long time that exposure to ionising radiation can induce mutation. Mutation being a random phenomenon, some of the mutation can lead to better quality products. Since the early forties, important radiation induced mutants for barley, oats, wheat, mustard etc. were produced by irradiating the seeds with gamma radiation. The better understanding of the genetic functions of the plants, the role of DNA molecules and the evolution of special techniques in molecular biology have all contributed to a systematic research leading to better and high yielding varieties of grains and plants for mass cultivation. Various kinds of radiation is used for mutation among which gamma rays from ^{60}Co is still the most popular. Typically 10-50 Gy of radiation dose is used for inducing mutation. Extensive experiments carried out at the Bhabha Atomic Research Centre has led to the development of a number of high yielding varieties of agricultural plants such as tur (Vishaka-1, TAT-10), green gram (TAP-7), black gram (TAU-1), groundnut (TG-17, TG-3, Somnath TGS-1), jute (TJ-40) and rice (Hari) which are released for mass cultivation in India.

Food Preservation

Irradiation of food and agricultural produces is an important application of radioisotopes which can replace or supplement some of the conventional food processing technologies for safeguarding harvests and for hygienization of food articles. It is a cold process, consumes less energy and is environment friendly. Irradiation does not make the food items radioactive and unlike chemical treatment does not leave any residues in the food. Irradiation using ionising radiation has several applications some of which are discussed below.

Low dose (< 1 kGy) irradiation

(a) Inhibition of sprouting in potatoes, onions, garlic, ginger etc. for long term storage without chemical sprout inhibitors

(b) Prevention of losses caused by insects in stored grains, pulses, spices, dry fruits, nuts, dry fish etc. without the use of fumigants

(c) Destruction of parasites in meat and meat products

Medium dose (1-10 kGy) irradiation

(a) Elimination of spoilage micro-organisms present in berry fruits, meat, poultry and seafood to improve shelf life under refrigeration.

(b) Prevention of food poisoning caused by Salmonella Vibrio and other non-spore forming pathogens present in fresh as well as frozen meat, poultry and sea foods

(c) Hygienization of whole spices, spice powders and spice mixes by reducing microbial load.

High dose (10-45 kGy) irradiation

(a) destruction of spoilage organisms including bacterial spores to obtain shelf-stable sterile products without refrigeration.

As in other radiation processing applications ^{60}Co is the isotope of choice for food irradiation also. Due to the higher penetration power of the high energy gamma rays of ^{60}Co, pallet load of foods up to 1 metre thick can be processed using ^{60}Co sources. A prototype commercial demonstration irradiator for treatment of spices with an initial through put of 20 tons/day is under construction at Navi Mumbai. The first prototype commercial demonstration irradiator for onions is planned to be set up in Nashik District of Maharashtra (21). It is envisaged that the above facilities will pave the way for the establishment of commercial plants in the private sector for treatment of food.

Human Resource Development

Development of trained man power for the realization and proliferation of the isotope technology was one area which was given due attention right from the inception of the isotope program. The Isotope Division has been conducting several organised training courses and on-the-job training activities in medical and industrial applications of radioisotopes. A four week training course on 'Radioimmunoassay and its clinical applications' started in 1981 has trained over 800 technologists and doctors. The Industrial radiography course started in 1978 was reoriented in 1994 as per ISO 9712 specifications. Over 5000 people have been trained at operational and supervisory levels in gamma radiography. On-the-job training for tracer applications is also given to various users at the Isotope Division. Isotope Division is one of the IAEA recognised and highly preferred centres for training scientists from developing countries in isotope technology.

Conclusion

Development of appropriate techniques and technologies for the production and various applications of radioisotopes is an ongoing process. Unlike many other technologies, isotope applications have a very low gestation period. A technology developed in the laboratory is often successfully applied in the field, industry or hospital within a very short time span. This makes the isotope technology one of the highly visible peaceful uses of nuclear energy and a major reason cited for continuing with the nuclear research. Concerted efforts at the laboratories of the Bhabha Atomic Research Centre and the Board of Radiation and Isotope technology are helping in spreading the useful applications of the radioisotopes for the improvement of the quality of life in our vast nation.

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Food Irradiation for Improving Food Security and Hygiene

Dr. Paul Thomas is the Head of Food Technology Division, BARC, where he has been working since 1967. His special area of interest is radiation preservation of foods with particular reference to fresh fruits and vegetables. As Senior Fellow of the Alexander von Humboldt Foundation, he worked at the Institute for Radiation Technology, Karlsruhe, Germany from 1976-78. Dr. Thomas has published over 80 research papers. Dr. Thomas has undertaken several assignments for the International Atomic Energy Agency, Vienna as an expert in food irradiation to countires in Asia, Africa and Middle East. He has represented Government of India in many International meetings and conferences on food irradiation. He is a Fellow of the National Academy of Agricultural Sciences.

Providing safe and nutritious food in adequate amounts to the rapidly expanding population is a challenging task for many countries of the world, particularly the less developed ones. The limitations of arable land coupled with increasing conversion of such land for industrial and urban dwelling activities have contributed further to widen the gap between food requirement and food production. One way of bridging this gap is by conserving what is produced by preventing or reducing post-harvest food spoilage.

Although there are no exact data on how much of the worlds food supply is spoiled annually, the losses are reckoned to be enormous especially in developing countries where, often, the prevailing warm and humid climate favour the growth of insect pests and microorganisms causing deterioration of stored products. It is estimated by the Food and Agriculture Organization (FAO) of the United Nations that 25 to 35 percent of world food production is lost due to damage caused by bacteria, mold, insects and other pests. In developing countries, storage losses of cereal grains and legumes are estimated to be at least 10% whereas the losses in fresh vegetables and fruits are believed to be as high as 50% in certain specific situations. The seasonality of production and the perishable nature of food has thus lead to the search for newer and safer methods of food preservation. Sun-drying, fermenting, salting and smoking have been in practice for several centuries and along with the later inventions of energy intensive processes such as dehydration, canning and freezing and the use of chemical preservatives and fumigants have contributed to the increased food supply and food security in the modern times.

Food-borne illness is a problem recognized by many as one of the leading health concerns facing consumers worldwide. In 1983, a Joint FAO/WHO Expert Committee on Food Safety concluded that foodborne disease was one of the most widespread threats to human health and an important cause of reduced economic productivity. The World Health Organization has estimated that 70% of all deaths associated with diarrhea have been due to consumption of contaminated food. In 1996 the WHO also stated that in developing countries, foodborne parasitic diseases are a major problem, with trematodes affecting 40 million people. Food borne illnesses are also on the increase in developed countries, where, in spite of the tremendous advances in food handling, processing, marketing, adherence to good manufacturing practices (GMP) and Hazard Analysis at Critical Control Points (HACCP), several outbreaks of food poisoning have been reported in the recent years. The enterohemorrhagic (bloody diarrhea) *Escherichia coli* 0157:H7 outbreaks in United States, Scotland and Japan through minced beef, basil and radish sprouts; and cyclosporiasis outbreaks in USA through strawberries and imported raspberries point to the gravity of the problem and the different sources of food through which such outbreaks can occur.

Irradiation is an effective and safe method of preserving food by exposing it, under controlled conditions, to ionizing energy. Irradiation can supplement or replace some of the traditional food processing technologies for safeguarding our harvests and for hygienization of foods. It is a physical process, consumes less energy and is environmentally clean. Food processed by this technology is not in any way made radioactive regardless of dose absorbed or the length of time that the food is exposed. Unlike chemicals irradiation leaves no residue in the food.

Three types of ionizing radiation are permitted for the treatment of foods. (1) gamma rays from Cobalt-60 of 1.33 million electron volts (MeV) and Cesium-137 (0.67 MeV), (2) X-rays generated from machine sources operated at a maximum energy of 5 MeV, and (3) electrons generated from machine sources operated at a maximum energy of 10 MeV.

Gamma rays, X-rays and accelerated electrons have more energy allowing them to dislodge electrons from the molecules in the food to form electrically charged particles, called ions and for this purpose they are referred to as ionizing radiation. In living tissues, the ions caused by such radiation can affect the normal biological processes. Radiation destroys microbes and insects contaminating food by the partial or total inactivation of the genetic material of the living cells in food, either by its direct effects on DNA or through production of radicals and ions that attack DNA. Gamma rays and X-rays can penetrate deeply and therefore even pallet loads of foods can be treated. Because of the relatively poor penetration power of electrons their practical application in food preservation is limited to products not more than 10 cm thick when treated from either sides.

History of food irradiation

The idea of using irradiation for preserving food immediately followed the discovery of radioactivity in 1895 by Henry Bequerel. In the same year the suggestion to use ionizing radiation to destroy microorganisms in food was published in a German medical journal and patents for the use of irradiation to destroy bacteria in food were issued in both the United States and Britain during the next few years. However, the technology could not be commercially considered, because radium, the irradiation source used at that time was not easily available.

The use of X-rays to kill insects, eggs and larvae in tobacco leaves to improve the quality of cigars was described in 1916 by G.A. Runner and in 1921 B. Schwartz employed X-rays to eliminate the parasite *Trichinella* found in pork.

Research into the safety and applications of food irradiation was commenced by the U.S. Atomic Energy Commission and the U.S. Army Laboratories in Natick in the early 1950s using spent fuel rods from nuclear reactors as their first radiation sources. These were eventually replaced with ^{60}Co and ^{137}Cs radioisotopic sources. In the ensuing years, with the ready availability of isotopic sources, research of unprecedented magnitude on food irradiation has been conducted in many countries with respect to both the technology of the process and the suitability of irradiated food for human consumption. Commercially feasible gamma and electron accelerator sources have been developed and tested to prove the technological feasibility of application to a variety of food stuffs.

Food Irradiation research in India

Research and development work on radiation processing of foods in India had its beginning in the late 1950's at the Bhabha Atomic Research Centre, Trombay, Mumbai (Bombay). Realising the immense potential of this technology for reducing the huge post-harvest losses occurring in agricultural, animal and fishery products, a dedicated Food Irradiation and Processing Laboratory (FIPLY) was established in 1967 to evaluate the feasibility of the process in the Indian context.

The major thrust of research and development work has been on the preservation and hygienisation of foods in their natural form. Process parameters in terms of commodity specifications, optimal radiation dose, packaging, and post irradiation storage and handling have been standardized for a large number of food items of both plant and animal origin, particularly those of economic importance to India. The investigations necessitated answering all possible questions concerning the efficacy of the process, quality of the commodities and safety for human consumption. Exhaustive data have been generated to establish the nutritional adequacy, wholesomeness and safety of irradiated foods by monitoring the changes in food constituents and multi-generation feeding trials on laboratory animals.

Parallel to technology development and application, basic studies have also been undertaken to understand the physiological and biochemical mechanisms underlying the radiation preservation of foods. Studies have also been carried out to develop suitable methodologies for detection of irradiation treatment to foods.

Practical Applications of Commercial Importance

Food irradiation is not a panacea for prevention of spoilage in all types of foods. Many of the vegetables including leafy vegetables, some fruits, milk, butter, and egg are not suitable for processing by this technology. Different doses of ionizing energy can be used for different purposes in food preservation as detailed in Table 1. Some of the well studied applications with proven benefits are discussed in the following sections.

Table 1. Practical applications of food irradiation

*Low-dose applications (Less than 1 kGy)**

- Inhibition of sprouting in potatoes, onions, garlic and ginger for long-term storage without the use of chemical sprout inhibitors.
- Prevention of losses caused by insects in stored grains, pulses, spices, dry fruits, nuts and dry fish without the use of fumigants; also as a quarantine treatment in place of fumigants.
- Destruction of parasites in meat and meat products which are of public health significance, such as Trichinae and tape worm in pork, *Entomoeba histolytica* causing amoebic dysentery, *Toxoplasma gondii* causing toxoplasmosis.

Medium-dose applications (1-10 kGy)

- Elimination of spoilage microorganisms present in berry fruits (strawberry), meat, poultry and seafoods to improve shelf-life under refrigeration.
- Prevention of food poisoning caused by *Salmonella, Vibrio* and other non-spore forming pathogens present in fresh as well as frozen meat, poultry and seafoods.
- Shelf-life extension of mushrooms
- Hygienization of whole spices, spice powders and spice mixes by reducing microbial load.

High-dose applications (10-45 kGy)

- Destruction of spoilage organisms including bacterial spores to obtain shelf-stable sterile products without refrigeration.

- *Gy (gray) is the unit of radiation dose = One joule of energy absorbed per kg of matter being irradiated. kGy (kilogray) = 1000 Gy.*

Insect Disinfestation of Stored Products

Ionizing radiation treatment to an absorbed dose of 0.25 to 1 kGy can be used for control of insect infestations in grains, legumes, and products (soji, flour), dried fruits, nuts, vegetables, spices, and dried fishery products. The use of post-harvest chemical fumigants such as methyl bromide, ethylene dibromide, ethylene oxide and phosphine which are currently used to disinfest some of these products can thus be avoided. Many countries have since banned the use of ethylene dibromide and ethylene oxide on account of their toxic residues in foods and from the point of view of worker safety and adverse impact on the environment. Methyl bromide, the currently used post-harvest fumigant for agricultural and horticultural products is to be phased out by the year 2000 under the Montreal Protocol on Substances that deplete the ozone layer. The United Nations Environment Programme (UNEP) 1994 Report of the Methyl Bromide Technical Options Committee, 1995 Assessment, has considered irradiation as one of the viable alternative to methyl bromide for disinfestation of perishable commodities. There are also reports to the effect that insects develop resistance to phosphine, the other post harvest fumigant currently used for control of insect infestation in agri-food products.

Studies conducted at the Bhabha Atomic Research Centre have shown that spoilage due to insect infestation in wheat stored in metal silos, prepackaged Basmati rice, soji (rawa), wheat flour (atta), whole and ground spices, dried fish (Bombay duck and mackerel), pulses, dried fruits and nuts could be prevented by low dose irradiation treatment. The cooking quality of basmati rice in terms of texture, grain length, and typical aroma were not affected by low dose irradiation treatment. Similarly, storage studies on prepacked whole wheat flour irradiated at 0.25 kGy and stored at room temperature for 6 months did not show significant changes in the functional quality and acceptability of chapatis made from it, thereby extending the shelf-life and marketability of the product. Mung beans (green gram) irradiated at doses of 0.25 to 0.75 kGy and germinated (0-6 days), contained significantly lower levels of flatulance causing oligosaccharides compared to the control, thus enhancing their nutritional quality and acceptability.

Irradiation is effective against all developmental stages of the storage insects and the surviving adults are rendered sterile and incapable of reproducing. It is to be noted, however, that radiation disinfestation is not aimed to kill all the living stages of insect pests instantly. For an outright kill of adult insects much higher doses are required and at such dose levels the functional properties and nutritional quality of some foods may be adversely affected. Therefore, lower dose levels which interfere with the development of insects and result in sterility in adults are employed. Following irradiation, the feeding ability of larval stages is considerably diminished and therefore very little product damage takes place during subsequent storage. Since irradiation has no residual effects like chemicals it is necessary to prevent reinfestation by proper storage management and the use of insect resistant packaging materials for packaged food products.

Quarantine Treatment for Fruits and Vegetables

Spread of insect pests from one country to another where it did not exist previously is a serious problem encountered in the international trade of agricultural and horticultural products. Several countries, therefore, have quarantine regulations restricting entry of horticultural commodities unless they have been adequately treated by approved procedures to eliminate the insect pests present in them. Export of fresh mango fruits from India to U.S.A., Australia and Japan is not permitted due to the presence of fruit flies and seed weevil. Since the weevil develops and completes its life cycle inside the mango seed, conventional chemical or physical treatments are not effective against this insect. Our studies have shown that irradiation at 0.15 kGy is effective against fruit flies (*Dacus dorsalis* and *Dacus cucurbitae*) infesting mango fruits while a dose of 0.3 kGy can prevent the development of grubs and pupae of seed weevil (*Cryptorynchus mangifera*) into adults, and adults if present are rendered sterile. Acceptance of irradiation as a quarantine treatment for international trade can open up market for Indian mangoes in countries where it is prohibited now. As already mentioned, the effect of the Montreal Protocol (1987) and the US Clean Air Act (1990) on the future usage of methyl bromide, which is presently the major fumigant for fruits, cereals, grains, and nuts and the acceptance by regional plant protection organisation and the United States Department of Agriculture - Animal and Plant Health Inspection Service (USDA-APHIS) of irradiation as a technical option to replace methyl bromide for the quarantine treatment of fruits and vegetables are significant developments.

Inhibition of Sprouting in Tuber and Bulb Crops

Chemical sprout inhibitors such as maleic hydrazide (MH) and isopropyl-N(3-chlorophenyl) carbamate (CIPC) used in temperate countries for the control of sprouting in onion and potato are not very effective under the warm subtropical and tropical climates. Irradiation at very low dose levels (0.05 to 0.15 kGy) can inhibit sprouting in onion, garlic, potato and ginger.

Pilot-scale studies under commercial storage conditions in two major onion producing and storage centres in Nashik Dt., Maharashtra and Mahuwa in Bhavnagar Dt., Gujarat have demonstrated that sprouting losses could be prevented by irradiation. Losses during storage due to microbial rottage, desiccation and sprouting is influenced by the temperature and humidity conditions of the storage environment. Storage loss in the traditional storage sheds, known as 'chawls' in Nashik Dt., are quite high due to the poor natural aeration existing in these structures. These losses are found to be relatively less in the improved storage structures with good natural ventilation, built by the National Agricultural Co-operative Marketing Federation of India (NAFED) at Pimpalgaon and Lasalgaon. Irradiation at 0.06 to 0.09 kGy was found to save about 20 percent of the 'Rabi' onions stored in these improved storage structures which otherwise would have become unmarketable due to sprouting. Our studies have also shown that irradiation can prevent sprouting in 'Kharif' onions occurring during rail transportation from Nashik Dt. to North Eastern states (Assam) in the winter months. The quality of onions with respect to pungency and lachrymatory factors were not affected by irradiation.

In potatoes irradiation at 0.1 kGy combined with cool storage at 15°C offers a viable alternative to the commercial practice of cold storage at 2-4°C. Laboratory experiments with several commercial cultivars of potatoes have shown that with proper air circulation irradiated potatoes can be held with less than 10 percent losses for a period of 6 months at 15°C. Although irradiation inhibits sprouting completely, irrespective of the temperature of storage, extended storage for periods over two months under the warm ambient conditions (30 to 40°C) existing in summer months is not feasible due to microbial spoilage. The irradiated potatoes are suitable for processing into chips and French fries while onions can be used for dehydration into flakes, powder etc. Cold storage is not only expensive but also results in the accumulation of reducing sugars which cause the undesirable browning in potato chips and French fries. Cold stored potatoes on removal to ambient conditions sprout profusely and the trade usually resorts to manual desprouting.

Delay of Ripening of Fruits

Tropical fruits such as banana, mango and papaya if treated in the mature but unripe stage, at the same or slightly greater doses of ionizing radiation (0.25 to 0.75 kGy) used for disinfestation purposes as a quarantine treatment can delay their ripening and overripening, thereby improving the shelf-life. Irradiated fresh fruits can be stored for longer durations at nonchilling temperatures thus avoiding ripening and chilling damage during refrigerated transport to overseas market. The market life extension observed in irradiated bananas and mangoes is about 5 to 7 days under ambient conditions. The optimum dose and storage regimes vary with the fruit species and varieties. In these fruits, a combination of warm water dip treatment (50°C, 10 min or 55°C, 5 min) and irradiation effectively reduces fungal rot, thereby avoiding the use of chemical fungicides. Some of these fungicides like Bavistin are either banned or are being phased out in many countries for post-harvest applications.

Extending Shelf-life of Seafoods, Meat and Meat Products

With a coast line of over 4,500 kilometers, India is one of the major producer and exporter of seafoods. The shelf-life of dressed fresh Bombay duck, white Pomfret, Black Pomfret, Indian Salmon, Mackerel and Shrimp under conventional ice-storage is about 7 to 10 days depending upon the fish variety. Studies at BARC have shown that irradiation at doses of 1 to 2 kGy can increase the shelf-life by 2 to 3 times under melting ice temperature by suppressing the gram-negative spoilage bacteria (*Pseudomonas, Proteus, Aeromonas, Achromobacter*). At these dosages the organoleptic quality characteristics of these fishes remain acceptable. The efficacy of the process has been tested under laboratory conditions as well as during rail transportation in insulated containers to Calcutta and Veraval. Since doses employed are not sufficient for elimination of the spores of *Clostridium botulinum* type E, it is important that storage temperatures should be kept below 3°C.

The shelf-life in the non-frozen state at 0-3°C is about 1 to 2 weeks for lamb and buffalo meat and about 1 week for dressed chicken. The shelf-life of these products could be extended up to 4 weeks by a dose of 2.5 kGy by suppressing the growth of spoilage bacteria (e.g. *Pseudomonas*). Similarly, the shelf-life of cured meat products such as frankfurters and sausages at 0-3°C could be enhanced by irradiation. There is thus the possibility for marketing of these products in chilled conditions instead of frozen storage as practiced by the trade. This could also result in considerable savings in energy during transport and marketing of such products. Our recent studies have shown that irradiation can further enhance shelf-life and improve microbiological quality of intermediate moisture (IM) meat products under ambient storage conditions.

Improving Food Safety

An important benefit of irradiation is that it can enhance the safety of food by eliminating non-spore forming pathogenic microorganisms such as *Salmonella, Campylobacter, Shigella, Listeria, Vibrio and Aeromonas* which are the primary cause of food borne illnesses. Some of these and hepatitis A virus are common pathogenic contaminants of fish and shell fish. There have been several instances of rejection of frozen shrimps and frog legs exported from India to foreign markets due to the presence of *Salmonella*. Most of the gram-negative vegetative pathogens together with *Eschericia coli* and the associated members of the family Enterobacteriaceae have low resistance to radiation. Irradiation at dosages of 3 to 7 kGy is lethal to all the pathogenic vegetative microorganisms. An advantage of this process is that even frozen products in their final shipping packages can be freed of the contaminating pathogens without a rise in the product temperature. For this reason, irradiation is often referred to as a cold process. As mentioned earlier, food borne illnesses due to *Salmonella, Campylobacter, Listeria* and *E.coli* 015H7 are on the increase in several advanced countries in the West. It has been proposed to use irradiation in packaged products as the last step in HACCP to eliminate all these pathogens and prevent food borne infections.

Viruses representing significant health hazards in food include those causing hepatitis and poliomyelitis. They can also be inactivated by irradiation, the rate of inactivation being an exponential function of dose. Viruses tend to be relatively resistant to radiation and a dose of 10 kGy, the maximum permitted for food irradiation applications, may eliminate only 99% of those present.

Several meat and fish borne parasites cause diseases in man through consumption of undercooked or raw meat and fish. Some of the typical examples are cysticercosis caused by the bovine and pork tape worm *Cysticercus* spp.; toxoplasmosis caused by *Toxoplasma gondii* (an intracellular protozoan parasite) in beef, mutton and pork; trichinosis caused by *Trichinella spiralis* (a parasitic nematode) in pork. Irradiation at low doses of 0.3 to 1 kGy can inactivate all of them and other parasitic protozoa and helminths which are of enormous public health significance in tropical countries.

Decontamination of Spices

India has been a major spice growing and exporting country. Due to the prevailing unhygienic practices during growing, drying and processing, most spices get contaminated with a heavy load of microorganisms which can cause spoilage in semi-processed foods into which these spices are incorporated and also in foods in which spices are added after cooking. The presence of pathogenic microbes have also been reported in spices. The initial microbial load in Indian black pepper, red chillies and other spices have been found to range from 10^6 to 10^8 (cfu) per g. Studies at BARC on all the major and minor spices grown in the country have shown that irradiation at a dose of 10 kGy can destroy the contaminating microorganisms to achieve commercial sterility without affecting their natural aromatic constituents. No significant differences in gas chromatographic volatile oil profile as well as non-volatiles were observed between irradiated and nonirradiated samples of the spices. Collaborative studies with a major multinational company and five food testing laboratories including CFTRI, Mysore and UDCT, Mumbai, and RRL, Thiruvananthapuram, have corroborated the microbial safety and quality of irradiated spices. Traditionally the spice export industry has been practicing ethylene oxide fumigation for decontaminating spices in order to meet the stringent quality standards of the importing countries. With the ban on the use of ethylene oxide by several importing countries because of its toxicological and carcinogenic implications, irradiation is being used by more and more countries for ensuring microbial safety of prepackaged whole spices and spice powders.

Sterilization of Foods

High quality shelf-stable (sterile) meat products have been produced in U.S.A. by subjecting enzyme inactivated (by heating to 70°C) chicken and beef vacuum packaged in metal cans or flexible laminated pouches to dosages of 45 kGy in frozen state at -20°C to -40°C. The product can then be stored indefinitely without refrigeration with highly acceptable quality attributes. Irradiation is also employed for sterilization of hospital diets for patients whose immune resistance has been suppressed following bone marrow and organ transplants. Studies have been initiated at BARC on these lines to produce shelf-stable and sterile ethnic foods and meal components.

The foregoing overview on the practical applications of radiation processing of food points to the tremendous potential of the technology in supplementing the traditional food processing and conservation methods for safeguarding our harvests and ensuring foods of good hygienic quality to the consumers.

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Wholesomeness and Safety Evaluation of Irradiated foods

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Safety and Wholesomeness

Since the Food Additives Amendment to the U.S. Federal Food, Drug and Cosmetic Act in 1958 included irradiation under the term food additive, the safety of irradiated foods was required to be tested accordingly in order to satisfy the regulatory agency. It has made the wholesomeness testing of irradiated foods one of the most researched topic on food safety.

According to the United States Food and Drug Administration (Federal Register, 1986) "Safe" or "safety" means that there is a reasonable certainty in the minds of competent scientists that the "substance" (in this case substance or substances produced in food as a result of irradiation) is not harmful under the intended conditions of use. The safety may be determined by scientific procedures. In determining safety, the following factors shall be considered:

1. The probable consumption of the substance and of any substance formed in or on food because of its use.
2. The cumulative effect of the substance in the diet, taking into account any chemically or pharmacologically related substances in such diet.
3. Safety factors which in the opinion of experts qualified by scientific training and experience to evaluate the safety of food and food

ingredients generally recognized as appropriate.

Thus the concept of safety involves reducing the element of uncertainty to a point where regulatory agencies can reasonably conclude that no harm will result from the proposed use of a substance. "Wholesomeness" on the other hand is a more general term and includes other attributes of food such as nutritional adequacy and organoleptic quality besides radiological, microbiological, and toxicological safety.

Wholesomeness of Irradiated Foods

Wholesomeness of irradiated foods involves evaluation of the following aspects.

i. Possibility of induced radioactivity
ii. Microbiological safety
iii. Safety of chemical changes
iv. Nutritional adequacy
v. Animal feeding
vi. Human trials

Baring the case of irradiated foods such an extensive protocol for wholesomeness and safety testing has never been undertaken for any other food product or process. Therefore, the literature available on the subject is voluminous and the pronouncement of the safety of irradiated foods is based on the best available scientific evidence.

Induced Radioactivity

Radiation and radioactivity are not alien to the nature and man. In fact, the primordial molecules of life and early organic evolution were nurtured under intense showers of cosmic radiation. Even today natural radiation exposure of man from cosmic radiation, terrestrial radiation and radioactivity in body is around 0.5, 0.5 and 0.2 mSv/year, respectively. Compared to this the average dose received by the population from diagnostic radiology may be as high as 0.7 mSv/year. On the other hand average dose to population from nuclear power plants and industrial irradiators may be as low as 0.01 mSv/year. All these exposures are several fold lower than the recommended ICRP limit of 5 mSv/year. However, food irradiation has nothing to do with the direct exposure of man to radiation. The process has also nothing to do with the contamination of food with radioactive material, which is quite often confused with food irradiation, more so after Chernobyl and Irish butter hit the news headlines. Food irradiation is all about the exposure of food to fixed energy and doses of ionizing radiation and consumption of food so irradiated by man. Irradiation of food is either carried out with radionuclide sources such as cobalt-60 having an energy of 1.33 MeV associated with its gamma ray photons or with machines generating accelerated electrons and X-rays possessing maximum permissible energies of 10 and 5 MeV, respectively. At these energies no induced radioactivity has ever been detected in food.

Microbiological Safety

Microbiological aspects of any food processing technology are of paramount importance from the stand point of its efficacy, safety and feasibility. With irradiation aimed at achieving commercial sterility in food, no public health problem of microbiological origin could be foreseen, provided integrity of the container remains intact. For nonsterilizing doses, however, the various aspects of microbiological safety have been studied. These include:

i. Selective changes in microflora
ii. Induction and selection of mutants
iii. Development of radioresistance microbes
iv. Toxin producing potential of microbes and substrate
v. Changes in diagnostic characters of microbes

The question of microbiological safety of irradiated foods has been the subject of a number of reviews (ICMSF,1980; CAST,1986; Diehl, 1995). Each of the above aspects can however be only briefly discussed here.

Selective changes in microflora

There is an apprehension that irradiation will selectively eliminate radiation sensitive microbes and leave the resistant ones to proliferate in food. Though it is true that vegetative cells of bacteria are more sensitive to radiation than the spores. The predominance of spores of spoilage and pathogenic microbes among the microflora of nonsterilized irradiated foods can not be ruled out. To avoid the possible detrimental effects of residual microflora the guidelines for post irradiation storage have to be followed, which are no different from those required by other processes such as heat. For example, toxin formation by *Clostridium botulinum* type E can only be prevented by storing foods below 3°C. Spoilage of such foods may be less putrefactive and more of acidic nature. Selective changes in microflora are not unique to radiation alone. Heat treatment also selectively destroys vegetative cells of bacteria and selects thermoduric and thermophilic microbes which are spore formers and food so treated also requires proper storage regimes. Similarly, psychrophilic microbes would predominate in foods preserved by low temperatures and xerophilic microbes may predominate foods preserved by dehydration.

Induction and selection of mutants

The concern that radiation will mutate microbes and bring out the worst in them has also been considered by the microbiologists. Though it has been used to increase the rate of mutation in living organisms for the past almost seven decades, radiation is not the best of the known mutagens. During irradiation of food, however, a theoretical possibility exists that mutations may transform a nonpathogenic microbe into a pathogenic one and a nonvirulent or less virulent one to a highly virulent one. Many studies have been directed to address this question. Mutants produced or selected by irradiation have been found to be less competitive and fit compared to the wild types. On the contrary it has been shown that irradiation can lead to the loss of virulence and infectivity of pathogens (Farkas, 1989).

Development of radioresistant microbes

Extending the above logic, in the absence of a conscious effort for selection, the event of a mutant forming and proliferating is highly unlikely. Despite the best efforts of the researchers, very few radiation resistant mutants have been obtained in laboratory after repeated exposure of microbes to gamma rays and selection. The mutated organism requires appropriate conditions and time for adaptation and expression of acquired traits. The conditions in preserved food are not conducive for this.

Toxin producing potential of irradiated microbes and substrate

A number of earlier reports in literature indicated the possibility of increased aflatoxin formation by irradiated spores of aflatoxin producing fungi *Aspergillus flavus* and *Aspergillus parasiticus* in nonirradiated substrates (Applegate and Chipley, 1976). Around the same time National Institute of Nutrition, Hyderabad, reported increased toxin formation in foods exposed to gamma radiation, autoclaved and inoculated with the spores of *A.flavus* (Priyadarshini and Tulpule, 1976). Several subsequent studies in our laboratory and abroad later proved that the results and inferences drawn in the above studies either could not be directly attributed to radiation or were not relevant to the actual practice of food irradiation (Sharma et al., 1978, 1979, 1980, 1981, 1990; Behere et al., 1978; Odamtten et al, 1987; Rahman and Idziak, 1977).

Most studies around the world that simulated conditions employed in the actual practice of food irradiation do not indicate any increased risk of toxin formation in irradiated foods.

Changes in diagnostic characters of microbes

From the foregoing discussions it is clear that at the doses employed in food irradiation there is no likelihood of any drastic change in the constitution of a microbe and the present day diagnostic tools and techniques will remain competent enough to detect it.

At the request of FAO and WHO, Board of the International Committee on Food Microbiology and Hygiene of the International Union of Microbiological Societies met in Copenhagen in 1982 and came to conclusion that irradiation of food up to an overall average dose of 10 kGy introduces no special microbiological problems.

Safety of Chemical Changes

Ionizing radiations bring about their effects by transferring their energy to molecules of the medium they traverse. In the process they cause molecular ionizations, excitations and dissociations resulting in the formation of free radicals. The probability of these changes is proportional to the relative abundance of the molecular species, and size.

Therefore, water and macromolecules, especially DNA, become the major targets of ionizing radiations in a living system. Though the generation and subsequent reactions of free radicals in the above reactions comprise the major route by which radiolytic products are formed, these are transitory species with a small half life. In dry foods free radicals may last a little longer but disappear immediately upon contact with water. Free radical formation is not unique to irradiation. Formation of free radicals is common to many life processes. Free radicals are also formed during processing by other methods such as cooking and frying.

Radiolytic products are the newly formed chemical species in a system following irradiation. The concentration of radiolytic products formed in food is extremely small as approximately only one molecule is changed per 100 eV of absorbed energy in a system. Energy of radiation is distributed in proportion to weight fraction of the components of food. All known radiolytic products are found in unprocessed foods or foods treated by other methods of food processing. There are hardly any unique radiolytic products and also the formation of radiolytic products can be predicted. In fact, the chemical differences between irradiated foods and non-irradiated foods are too small to be detected easily, and therefore, sophisticated instrumentation is needed to detect irradiated foods.

Nutritional Adequacy

Assessment of the nutritional adequacy of irradiated foods involves, proximate analysis of major food components, checking for loss of vitamins, amino acids, biological value of proteins, net protein utilization, protein efficiency ratio and *in vitro* digestibility. Though rough composition of food remains unchanged, in some foods vitamin losses are encountered. Losses in foods are much less compared to those observed in pure systems. This is because of the protection offered by the food constituents to vitamins. Amongst the water soluble vitamins, thiamine (B_1) is the most sensitive followed by pyridoxin (B_6). Riboflavin, niacin, pantothenic acid and vitamin B_{12} are relatively resistant to radiation. Ascorbic acid (vitamin C), though sensitive to radiation is converted to dehydroascorbate, which is as effective in human system as ascorbate. However, thiamine is equally, if not more, sensitive to heat. In the case of fat soluble vitamins, vitamin E is the most sensitive followed by vitamin A, D and K. Though it is reasonable to believe that irradiation followed by cooking will result in compounding the loss of vitamins in food, available data show that the compounding of loss is not that alarming and in certain cases irradiated and cooked commodity even showed better retention of vitamins (WHO, 1994). Moreover, certain losses should be accepted as the trade-offs for the technological benefits of food irradiation. Vitamin losses could, however be minimized by irradiation at low temperatures and with the exclusion of oxygen. No major losses in amino acids and utilization of proteins have been observed in irradiated foods.

Animal Feeding Studies

Animal feeding studies have been the hallmark of food irradiation safety evaluation program and excellent reviews are available on the subject (WHO, 1994; Diehl, 1995). Both short term and long term multigeneration studies have been carried out. The various parameters investigated during these studies include, growth, food intake, hematological indices, reproduction and lactation, histopathology, enzymological studies, mutagenicity, chromosomal abnormalities, teratogenicity, and dominant lethal mutations. In 1986 USFDA undertook a review of the animal studies carried out on irradiated foods. A total of 400 studies were categorized on the basis of scientific quality as "A" for accepted, "B" for accepted with reservation and "R" for rejected. It rejected 150 studies and grounds for rejection included, radiation dose not specified, Dose too low or too high, number of animals too small, nutritionally inadequate diet, improper controls, and GLP not followed. The remaining studies falling in category "A" or "B" were reviewed in detail by the USFDA. None of the short term and long term toxicity studies in animals fed irradiated foods, such as fish, pork, chicken, mango, onion, potato, wheat, shrimp, strawberries, milk powder showed any adverse effects. The same was found to be true for the mutagenicity studies but for the publications from National Institute of Nutrition, Hyderabad, reporting increased polyploidy in children fed irradiated wheat and increased polyploidy and dominant lethal mutations in rats fed irradiated wheat (Bhaskram and Sadasivan 1975, Vijaylaxmi, 1975, 1976). The results of a number of many "A" class studies from other laboratories of the world including those from BARC (Chauhan et.al., 1975, George et.al., 1976; Chaubey et.al., 1978; Arvindakshan et.al., 1978) did not corroborate the NIN data. A two member scientific committee appointed by the Government of India critically examined the techniques, the appropriateness of the experimental design, the data collected and the interpretations made in the NIN studies and compared those with BARC study. After a careful scrutiny this committee concluded that the bulk of the data in these studies were not only mutually contradictory but also at variance with the well established facts of biology (Kesavan and Sukhatme, 1978; Kesavan, 1978). The committee was satisfied that once the data in NIN studies are corrected for biases which had given rise to these contradictions, no evidence of polyploidy could be associated with ingestion of irradiated wheat. USFDA later endorsed the conclusions of Kesavan and Sukhatme committee while permitting radiation processing of food (Federal Register, 1986).

Studies on Human Volunteers

There are three major feeding studies carried out on human volunteers. One in USA and two in Peoples Republic of China. The largest study involved more than 400 volunteers in China. 60% of their daily ration consisted of food items irradiated at 1-8 kGy dose. These studies were conducted for 30-120 days and no adverse effects were observed (WHO, 1994).

Current Safety Status

The Office of the Surgeon General of the U.S.Army which sponsored extensive studies between 1948-1965 concluded in 1965 that foods irradiated with doses up to the sterilizing dose of 56 kGy with a cobalt-60 source of gamma radiation or with electrons of energies up to 10 MeV have been found to be wholesome, that is, safe and nutritionally adequate (Brynjolfson, 1985). At the international level, joint expert committees sponsored by the United Nations' Food and Agricultural Organization (FAO), International Atomic Energy Agency (IAEA) and World Health organization (WHO) were convened in 1964, 1969, 1976 and 1980 to consider the question of wholesomeness of irradiated foods. At the last meeting in 1980 the Joint FAO/IAEA/WHO Expert Committee on Irradiated Food (JECFI), reviewed the extensive data collected up to that time and concluded that irradiation of any commodity up to an over all dose of 10 kGy presents no toxicological hazards and introduces no special nutritional or microbiological problems. In 1983 JECFI recommendations were adopted by the Codex Alimentarius Commission, a Joint FAO/WHO body that sets world standards for food health and safety. The commission issued a Recommended International Code of Practice for the Operation of Facilities Used For the Treatment of Food. In 1986 U.S. Food and Drug Agency legalized irradiation of a wide range of food products and the Scientific Committee of the Commission of the European Communities endorsed the findings and the conclusions of JECFI in 1980. In 1992 at the request of a member state, Australia, WHO constituted an expert group to review the wholesomeness data available up to that period. The conclusions of the expert group published in the form of a monograph (WHO, 1994) were no different from the earlier JECFI findings.

Endorsement of the technology by scientific professional bodies serves to boost the confidence of the consumer as well as the industry in the technology. Several reputed professional bodies in the USA such as American Medical Association, Institute of Food Technologists, The American Council of Science and Health, The National Association of State Department of Agriculture, Council for Agricultural Science and Technology, American Frozen Food Institute, American Meat Institute, American Dietetics Association and American Gastroentrological Association have endorsed the utility and safety of irradiated foods. Today some 40 countries worldwide including India have approved the use of food irradiation for over 100 food items and about 30 of these are applying the technology on a limited commercial scale. South Africa alone has cleared more than 40 items of food.

In 1994 Government of India by the amendment of Prevention of Food Adulteration rules (1954) approved irradiation of onion, potato and spices for internal marketing and consumption. Additional items including wheat and wheat products, rice, legumes and products, meat and meat products including poultry have been recently included in the list of irradiated foods under PFA Act (see Annexure). At present a small pilot scale food irradiation facility in the Food Technology Division, BARC, has the license for commercial operation. Licensing of a commercial medical product irradiator (ISOMED) in Mumbai, for food processing has also been sought. A dedicated irradiator for spices will be commissioned soon by the Board of Radiation and Isotope Technology (BRIT) in Vashi, New Mumbai. BARC is also proposing to establish an irradiation facility in Lasalgaon, Nashik District, Maharashtra, for treatment of onion.

Conclusion

No human activity is free of all risks and there is no thing as absolute safety. Decisions and judgments regarding the safety of a technology are based on the best information available. Food irradiation technology provides the maximum assurance to consumers regarding its safety through a database which is unparalleled in the history of food processing technology.

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Food Irradiators - Infrastructure and Economics

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The technical requirement (infrastructure) and economics of the food irradiation technology are important aspects that need to be studied and finalised before commercialisation. Thus the details of a food irradiation facility including infrastructure requirement, design and process control of the process are reviewed in this article.

Food Irradiation Features

Food irradiation facilities can be classified as Research, Pilot and Commercial.

Research facilities are designed with a view to have high versatility in their use, application of range of doses, dose rates and varying conditions of temperature during irradiation and handling of different kind of products of various packing densities. They offer very low efficiency of irradiation use and hence economics of processing do not apply.

Pilot scale facilities are generally designed with limited versatility and higher product throughput. They may be required to satisfy a few experimentally proven processes for taking up processing in different quantities for process evaluation and market acceptance studies. Here also economics of processing play a secondary role.

Commercial scale facilities on the other hand are a class by themselves. Economics of processing dominate other conditions of facility design which should also necessarily satisfy the stringent demands of the irradiation process requirements of a proposed treatment. It is difficult to evolve an economic and optimum design for a general purpose food irradiation facility applicable to treatments ranging from sprout inhibition to sterilisation without compromising the factors like source utilisation efficiency and uniform dose distribution. A number of factors such as product density, range of doses and dose rates, volume of products to be handled and radiation source to be used are to be considered before finalisation of the design.

Normally the sources of ionising radiation used in food irradiation facilities are (1) Radionuclide sources, mainly Cobalt-60, (2) Machine sources including electron accelerators providing electron beams of energies upto 10 MeV and X-rays of energies up to 5 MeV may be used.

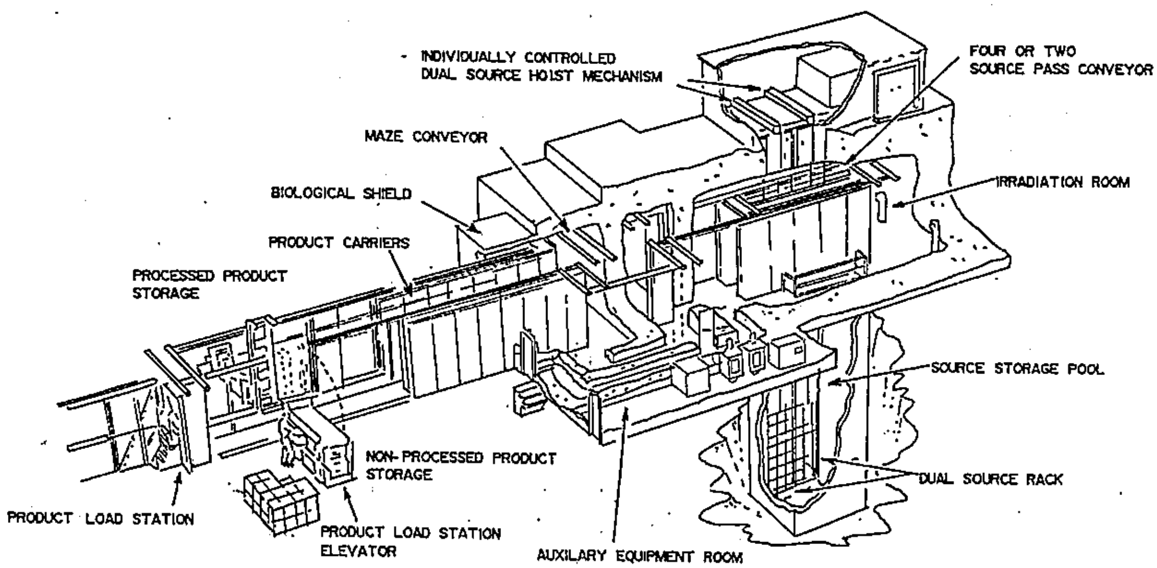

Fig. 1 Multi-purpose Commercial Food Irradiator

Because of their high penetrating capacities, gamma rays and X- rays may be used for relatively thick products. For Cobalt-60 (gamma radiation average photon energy of 1.25 MeV) about 50% of the incident radiation energy is absorbed in a 0.1 m depth of unit density material. For situations in which only a shallow penetration is needed and in which rapid conveyor speeds can be used (as with grains or spices) electron beams can provide a more uniform dose distribution at lower cost per unit mass of product when large amounts of product are involved. Throughput of processing of food products in a radiation facility using Cobalt- 60 source or other power sources may be related to dose requirements of a process as follows

Throughput

$$(\text{kg/h}) = \frac{\text{Power in kW of source} \times 3600}{\text{Dose in kGy}}$$

(1 MCi or 37 PBq of Cobalt-60 = 15.0 kW), where, E is the efficiency of the radiation energy utilisation in the process expressed in fraction (Fig. 1).

The food irradiation facility generally consists of 4 major parts

1. A source of gamma radiation (Cobalt-60)
2. A shielded room to expose and store the source safely (a concrete cell and water pool)
3. Mechanism to convey products in and out of the cell and to deliver the required dose effectively to the products (Product conveyor and control mechanism) and
4. Systems to ensure safety and reliability of the operation of the facility (Safety devices and interlocks).

Based on these requirements in 1990 International Atomic Energy Agency classified the irradiators in 4 categories.

Category 1 type irradiators : Self shielded Gamma cells and Gamma chambers. At present about 15 different types are in use world over. The loaded activity varies from few 100 Ci upto 20 kCi of Cobalt-60.

Category 2 type irradiators : Shielded irradiation room with dry source storage Panoramic research, Pilot and Industrial scale irradiators units are in use. The size of the irradiation room varies from some few sq. meters floor space to large 50 sq. meters. The loaded activity ranges from 1 kCi to 0.5 MCi.

Category 3 type irradiators : Source fixed to the storage pool, under water low efficiency special irradiators are of this type and are the cheapest units. The activity is upto 200 kCi.

Category 4 type irradiators : Shielded room wet storage, pilot, multipurpose, low, medium, high efficiency, high capacity irradiators are designed for commercial irradiation. Minimum 10 countries are involved in its production. The maximum load could be upto 10 MCi Cobalt-60.

Siting of Irradiators

Geological features that could adversely affect the integrity of radiation shields should be evaluated, taking into account the physical properties of materials underlying the irradiator sites or its environs. Areas of potential or actual surface or subsurface subsidence, uplift or collapse should be taken into consideration while assessing the suitability of site. Other factors that are not necessarily due to natural features (e.g. underground mining) but that could result in instability should also be considered.

In areas with significant potential for seismic disturbance, gamma irradiators may be equipped with seismic detectors which on being activated by any disturbance would trigger appropriate control mechanisms to shield the source automatically. In locating the irradiator a minimum screening distance as mentioned below shall be maintained :

(a) Ammunition, explosive dumps civil and military air fields : 2 kms

(b) For all other sites : 50 to 100 m

The minimum levels of subsoil ground water shall not cause flooding of the irradiator, or influence the pool water level or cause damage to the structure.

Safety Requirements for the Design of Irradiator

Safety design should be in accordance with the requirement of the Atomic Energy Regulatory Board. These include

(a) safety philosophy

(b) safety analysis

(c) internal design

(d) sealed source

(e) source frame

(f) source storage

(g) irradiation cell

(h) operating systems

(i) control console

(j) safety interlocks

(k) power failure

(l) quality assurance

(m) overall safety of installation.

Operating systems

General Requirements

Irradiation may be achieved by either moving the source close to the product or by positioning the product close to the fixed source. In the 1st case the source movement may be either vertical or horizontal. Motive power to the source movement system and the product positioning system may be either electrical, pneumatic, or hydraulic and this power shall be cut off during any servicing or maintenance operation.

Specific Requirements

Maintenance of source frame: (For category 2 & 3 irradiators)

The source frame shall be capable of being moved from its shielded position to the irradiation position by at least two wire ropes of identical specifications described in Indian Standards.

The source frame shall automatically return to its fully shielded position in the event of any one of the following:

(1) Power failure

(2) Smoke/fire alarm

(3) Snapping or loosening of wire ropes

(4) Ground motion in excess of present threshold of seismic detector

(5) Emergency stop from the control panel

(6) Disengagement of the door latch bar

(7) Actuation of entry control device at product entry/exit ports

(8) Failure of cell ventilation

(9) Product carriers jammed.

Product Movement

The product movement system shall be such that any malfunction of the system shall cause termination of irradiation. All components of this system shall be designed for fail safe operation. Means shall be provided at product entry/exit ports to prevent inadvertent entry of any person in the irradiation cell during operation. Means shall be provided to terminate irradiator operation from inside the cell. The device shall be conspicuously labeled and marked. Actuation of this device shall cause visual or audible warning in control room.

Control Console

All operations of the irradiator shall be performed from the control console by qualified operators. The selection and status of critical equipments shall be displayed on the control console. An on demand display of other parameters may be provided . Control and display for routine operations shall be physically separated and distinctly marked from the control and display for emergency operations. There shall be clear and permanent display of following processes.

Parameters on the control panel

•	Radiation level	:	Normal/Abnormal
•	Cell Ventilation	:	on/off
•	Product carrier	:	Clear/Jammed
•	Personnel Access Door:		Open/Closed
•	Water level	:	High/Normal/Low (in category 3 & 4 irradiators)

Apart from normal parameters, emergency situations and abnormal conditions shall also be displayed on the panel by means of audio or visual indications. The control console should have a programmable logic circuit with provisions for auto diagnosis and indication of an abnormal situation. Permanent display of source position shall also be provided on the personnel entry door in a prominent manner.

Safety Interlocks: The following shall be electrically mechanically or hydraulically interlocked with source position so as to interrupt/ terminate the irradiation process when any of these are actuated.

- Personnel access door and cell radiation level
- Personnel access door and water level
- Personnel access door and ventilation system
- Product Movement system
- Smoke/Fire alarms & power supply to the cell
- Tensions in wire ropes
- Roof plug
- Alarm from Seismic Detector, if any

The above interlocks shall be of fail safe design.

Power failure

Means shall be provided to ensure that the irradiation process is automatically terminated in the event of loss of power supply exceeding ten seconds. Diesel generators shall be provided to resume power operation in the event of persistent loss of on-line power.

Quality Assurance

Adequate quality assurance programme including appropriate quality control measures shall be established for the design and manufacturer of irradiators. The Quality Assurance program shall meet the requirements of IS 9000 or IS 14999 services. Records of all quality assurance procedures shall be maintained for the entire life of the irradiator.

Loading and Unloading of Sources

Transport of Sources : Packaging and transport of radioactive sources shall be in accordance with the provision of the AERB safety code SC/TR/01 (1986).

Installation of Sources in the Source Frame

The source loading and unloading operations may be carried out either from inside the irradiation cell or from outside the cell through a loading port. The source transport container may be brought to the cell either through an opening on the cell roof or through product entry/personnel entry route.

When an opening is provided on the cell roof, the opening shall be kept closed by a shielded plug during operation of the irradiator. Operation of the irradiator shall be automatically prevented if the roof plug is not properly fixed in its place. Loading of sources from outside the cell shall be through individual source channels clearly marked and identified from the loading port.

Every source Position on the loading port and transport shall have a shutter action which is interlocked with the selection and alignment of relative channels. Actual source transfer (either from the loading or the transport flask) shall be possible only after ensuring selection and correct alignment of the relative channel positions and which is verified by trial operations.

Responsibilities of Designers and Manufacturers

The following information shall be provided to the operating organization by the manufacturers:

1. Detailed description of design and operation of irradiator, safety systems, and control circuit
2. List of components identified as per the following classification:
   Group A : Replaceable by manufacturer or with his explicit consent
   Group B : Replaceable to exact specifications
   Group C : Replaceable without restriction
3. Site specific data as given in site selection criteria.
4. Operating and maintenance procedures including type and frequency of checks for various systems.
5. Safety analysis report on the facility.
6. Test procedures and reports establishing conformance of each component, subsystem, system and its operation in accordance with its design and relevant standard specifications.
7. Schedule of tests and checks on various components, subsystems, systems and procedures to accomplish these.
8. Instructions and procedures to be followed in emergency situations.
9. Reports on the precommissioning tests and their results.

The following information regarding sources shall be maintained by source manufacturer and operating organizations:

(a) Identification and model number of each source, source activity as on date of installation, and its location in the source frame,
(b) Source classification designation certificate issued by the competent authority
(c) Bend test certificate
(d) Leak test certificate by the manufacturer
(e) Contamination test certificate issued by manufacturer
(f) Special form radioactive certificate issued by the competent authority
(g) Any other information as specified by the competent authority.

Requirements for Packaging/Storage

Where packaging is essential to prevent post treatment recontamination the food should be packaged before treatment.

Package size especially with bulk packs should be such that they can be handled efficiently thereby avoiding excessive delays and temperature abuse.

The choice of the packaging material and the nature of the container for specific food is usually determined by the purpose they are to serve and storage conditions, such as prevention of moisture loss or moisture uptake, to provide an atmosphere devoid of air, or to avoid mechanical damage to food.

Sterilized food must have containers which prevent access to bacteria or other microorganisms.

Training of Manpower for Operation and Inspection

The operating organization shall ensure that those of their employees who are engaged in work with ionizing radiation receive such information, instructions and training as will enable them to conduct that work in accordance with the requirements of their written instructions;

Dosimetry and Process Control

Control of the food irradiation process in all type of facilities involves the use of accepted methods of measuring the absorbed radiation dose and the distribution of that dose in the product package, and of monitoring of the physical parameters of the process (2).

Dosimetry for food irradiation is analogous to heat penetration in thermal processing, with dosimeters being the analogs of thermocouples in that they are employed to provide an accurate measure of the rate and total energy delivered or absorbed. There are several types of dosimeters, the most common ones being based on a chemical change that is linear within a practical dose range.

Dosimetry is the keystone of the proper radiation processing. Careful dosimetry is required to ensure that a technologically useful dose has been applied while maintaining the best possible dose uniformity ratio.

In addition acknowledgement of the absorbed dose is needed in order to ensure that it does not exceed the established legal dose limit. Therefore prior to commissioning of the plant, extensive dosimetric calibrations of the irradiator are carried out and are followed during the processing by routine dosimetry.

Because it is not possible to distinguish irradiated from unirradiated products by inspection of their appearance, it is important that appropriate indicator devices which undergo radiation induced colour change be attached to each container/package, and that physical barriers be employed in the radiation plant to keep irradiated and nonirradiated products separate.

Documentation or Record Keeping

Documentation or record keeping is an essential part of food irradiation facility, and must be provided in a complete and reliable manner.

Records are kept to provide information on various aspects of a facility operation viz. (1) Facility characteristics, maintenance etc. (2) Personnel and environmental safety; (3) Food product receipt, treatment and shipment, (4) Government licensing authorization etc. (5) Personnel qualifications, training, performance, safety etc.. (6) customer relation and (7) financial.

Economics of Food Irradiation

In recent years, a few large scale irradiation processing plants have been set up in countries, such as France, Thailand, Italy, Japan, The Netherlands, South Africa, USA, USSR, China, etc., with a view to developing market potentials and consumer appreciation. Food irradiation is of relevance to developing countries, particularly for preventing

Table 1. Japanese Potato Irradiator - Economics[a]

Capacity	10 T/hr
Capacity utilisation (Max.)	10,000 T/month or 20,000 T/year
Source	Cobtalt-60 - 300 kCi
Dose	15/6 kilorads
Insallation cost	US $ 0.2 Million (Rs.117 lakhs) at 1974 price)
Operational cost	US $ 0.2 Million (Rs.18 lakhs) (average cost during the 1974-77 period)
Unit cost of processing	US $ 10.0/Tonne (1974)

[a]Taken from "The first potato irradiator of Japan the success and setback encountered during three years of commercial operations". Joiji Umeda, Food Irradiation Information No. 8, Feb. 1978

Table 2. Hungarian Onion Irradiator[a]

Capacity	6 T/hr
Capacity utilisation (Max.)	20 hr/day, 160 days/year
Source	31 kCi, Cobalt-60
Dose	5 ± 2 kilorads
Insallation cost	US $ 53.4 x 10^3
Operational cost	US $ 23.4 x 10^3
Unit cost of processing	US $ 4.7/T

[a]The potential for commercial onion irradiator in Hungary, Bela, Kalman, Food Irradiation Information No. 8, Feb. 1978, p.11

Table 4. Example Calculation of Radiation Processing Cost (in lakhs)

Project capital heads	Total capital cost of the project	Capital cost considered for depreciation of M&E	Capital cost considered for depreciation of building assuming 60 yrs life
Product handling system	100	100	-
Auxiliary equipment and control system etc.	35	35	-
Building and cell etc.	280	-	280
Electrical and ventilation works	131	131	-
Vehicle	5	5	-
Laboratory equipment and furniture etc.	25	25	-
Consultation charges	5	-	-
Co-60 source 100 kCi	50	-	-
Travelling expenditure	14	-	-
Health physics equipment	5	5	-
Office furniture and equipment	10	10	-
Land cost	10	-	-
	670	311	280
Manpower cost during O&M stage (for 2 yrs)	30	-	-
Total	700	311	280

Operating Costs

Costing Heads	1st case with interest on term loan	2nd case without interest on term loan
Personnel salary (annual)	15.00	15.00
Utilities and services (Electrical power + water + house keeping + vehicle maint. + diesel + stationary etc.	15.00	15.00
Maintenance and repairs (spares, lubricants etc.)	5.00	5.00
Co-60 replenishment charges @ 12% yr	5.00	5.00
Shipping and installation (Co-60)	1.00	1.00
Invest on term loan working capital @ 18% yr. On Rs.670 lacs	120.60	-
Depreciation @ 10% p.a. on M&E (Rs.311 lacs)	31.10	31.10
Depreciation of building cost of Rs. 280 lacs (60 yr. Life)	4.60	4.60
Total	197.30	76.70
Say	198	77.00

1st Case (with interest on term loan)

Quality processed (T/yr)	30,000	40,000	60,000
Capacity utilisation @ 80% (T/yr)	24,000	32.000	48,000
Operating costs (Rs. in lakhs)	198	198	198
Unit processing cost (Rs./T)	825	618	413
Processing cost (Paise/kg)	82.5	61.8	41.5

2nd Case (with interest on term loan)

Quality processed (T/yr)	30,000	40,000	60,000
Capacity utilisation @ 80% (T/yr)	24,000	32.000	48,000
Operating costs (Rs. in lakhs)	77	77	77
Unit processing cost (Rs./T)	320	240	160
Processing cost (Paise/kg)	32.0	24.0	16.0

Feasibility of the process

Irradiator outpur (T/yr)	24,000	32,000	48,000
Considering 20% spoilage (T/yr)	4,800	6,400	9.600
Gain, due to radiation processing (assuming market cost of onion as Rs.3,000/t) Rs. in lakhs)	144	192	288

wastage of agricultural produce. The introduction of such technology would, however, depend on the cost effectiveness of the process. The economic aspect of food irradiation has not so far received adequate attention, though some of the manufacturers of irradiation systems have advanced a number of guidelines.

The estimation of food irradiation cost, would depend on a host of factors that are specific to each item which include pattern of production, storage, distribution, handling, and internal consumption or export. Despite the complexity of this problem, there exists a need to work out approximate cost estimates for food irradiation and the actual processing. This would help to make investment decisions for developing the technology.

Irradiation System

It is necessary to select an appropriate size irradiator for economic operations. Processor 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.

Food irradiator cost estimates may be then easily made from two basic data : (1) the installed Cobalt-60 activity in mega curies (A) and (2) maximum designed capacity of the irradiator (Am) expressed in mega curies.

An extensive analysis of the available information on the cost of shield and conveyor systems used in a variety of irradiators, both for demonstration and commercial radiation processing, and our own experience with the design, installation and operation of irradiation facilities have indicated that a simplified approach could be tailored to provide estimates with an order of magnitude accuracy for food irradiators.

(a) Capital Cost Estimate

Total investment I (Rs. in million = Cost of Source (S) + Cost of building and Plant (B) where,

S (Rs. in million) = AiP

where, Ai is the strength of Cobalt-60 source initially installed in terms of number of curies in million and P, the price of Cobalt-60 per curie inclusive of transport and installation cost at site.

$$B = \text{Building and plant} = 7.5\ Am^{0.3}$$

where, Am is the maximum design capacity of the radiation plant rated in terms of number of curies in million at the highest throughput requirements (applicable in the range of 0.1 to 5 million curies of Cobalt-60).

Total investment cost I = S + B

$$I\ (\text{Rs. in million}) = AiP + 7.5\ Am^{0.3} \qquad (1)$$

(b) Running Costs (R)

Running cost factor comprises of both fixed and variable costs and may be briefly written as

R = Fixed cost (F) + Variable cost (V)

where, F (in million Rs.) = cost of source replacement + depreciation + maintenance + tax etc. and may be approximated by the expression

$$F\ (\text{Rs.in million}) = (0.29\ AiP + 1.08\ Am^{0.3})\ V$$

= labour + overheads which may be again approximated by

$$V = \text{Rs. } 6{,}200\ A.\ Ns.\ Nm \times 10^{-6}\ (\text{million})$$

where, A = AiP, Ns = number of shifts operated every day and Nm = Number of months the plant is operated in a year.

The formula provides (+50% to -30%) valid for the range of activity from 0.1 to 5 mega curies of Co-60 installed. However, the value of $B = 7.5\ Am^{0.3}$ was based on prices prevalent in the country in 1984 - 1985. Annual increases of about 10 - 15% in the case of labour and material may be considered for future estimates. It is seen that the initial cost of Co-60 becomes the prime determining factor in the overall capital cost in large plants and as a result in every large plant the processing cost tends to equal the cost of energy consumed.

In the next few paragraphs we shall briefly discuss the economics of onion/potato irradiation as specific examples.

Examples

Onion Irradiation

Two examples of cost estimates are available from Japan and Hungary on irradiation processing of onion and potatoes, as shown on Tables 1 and 2, respectively. Japanese data are based on the actual operating experience of an irradiator installed in 1973 at Hokkaido. The investment cost appears to be fairly high. Hungarian estimates are perhaps based on conceptual design of the irradiator and appear to be rather low.

Cost Reduction Concept

The irradiation systems are generally capital intensive. Therefore, it becomes necessary to consider the reduction in the overall processing cost. The various factors that influence the processing cost include the enhanced throughputs, an optimal design of the irradiator for specific product, the use of low cost shielding material, the location of the irradiation system with an appropriate link with the food production and processing chain.

The estimations made above are based on a specific set of assumptions and input prices. The irradiation technology correlates economics of scale with unit cost. Transportation costs and disruption to current marketing procedures may need reckoning in the costing. A sample calculation of radiation processing cost for a 10 Ton/hr capacity commercial irradiator for onion and potato have been given in Table 3 which is self explanatory. It may please be noted that when interest on capital or term loan is taken into account for costing purpose profitability in irradiation processing trade will appear only after a period of 2 years of operation or alternately by processing more amount of product or by reducing the entire plant cost.

Conclusion

Thus it can be seen that for the ease in commercialization of food irradiation processing understanding the details of food irradiators, infrastructure, and economics as given in the text will be very useful and handy for implementation of this technology.

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Food Irradiation Facilities: Regulatory Aspects

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Introduction

Government of India has recognized the potential use of ionizing radiation in the preservation of food. It has set up appropriate regulatory frame work, adequately supported by administrative and technical infrastructure to carry out commercial food irradiation in the country.

Industrial gamma irradiators for food preservation started in the late 1950's, initially in the industrialized countries and then in the rest of the world. In the last 15 years, the International Atomic Energy Agency (IAEA) has provided around 40 irradiators of different types to the developing countries. More than 160 gamma irradiation facilities and 600 electron beam facilities have been in use all over the world since 1950. By and large, the industry has a good safety record. During the first years of the industry till 1975 there were fatal accidents. But since 1989, one serious incident has been reported each year. From 1975 to 1994 five fatal incidents have been reported internationally. The contributing causes have been analyzed.

Firstly, there was either a flaw in the initial design of the facility or the equipment was not maintained to meet the initial design intent or new procedures or changes created situations which were not anticipated in the design. Secondly, a complete safety system was unavailable because of the component failure or action by the operating organization or personnel to disable or bypass the system. Thirdly, occasionally workers tend to ignore conflicting sources of information or they act inappropriately.

Review of these incidents reveals many important points. If redundant and diverse systems were available, the accidents would have been readily prevented. If safety is to be assured, design of the facility has to be reviewed carefully to identify conditions critical to safety. The management of the operating organisation can quickly lose control of the level of knowledge and performance of the employees if systematic audits are not conducted and training not provided.

The incidents clearly indicate greater need for training and indoctrination of workers at all levels. Workers may become ignorant if systematic audits and training are not provided regularly. It is inconceivable that in some instances personnel involved in accidents had employed tricks to circumvent safety systems. Total involvement of the operating personnel and their commitment to safety culture is essential to operate the gamma irradiators safely and efficiently.

Since radioactive sources or electron accelerators used in food irradiation facilities are capable of delivering very high radiation doses in a relatively short time, it is absolutely necessary to ensure that they are operated with due care. The need for setting up an appropriate regulatory mechanism is obvious. Government of India has set up appropriate administrative, legal and technical machinery to carry out the food irradiation programme.

Regulatory Provisions

The commercial irradiation of food in India is regulated by the Atomic Energy (Control of Irradiation of Food) Rules 1996 (G.S.R 254 The Gazette of India June 22,1996 Part II Section 3(i)) and Prevention of Food Adulteration(Fifth Amendment) Rules,1994. The former is issued by the Central Government by exercising powers conferred by section 30 read with Sections 14 and 17 of the Atomic Energy Act 1962. Section 14 deals with the control over production and use of atomic energy. Section 17 pertains to special provisions to safety and Section 30 confers the power to make rules on the Central Government.

The rules are enforced by the Licensing Authority and the Competent Authority. The Rules envisage issuance of a licence by the Department of Atomic Energy after the applicant obtains a certificate of approval from the Competent Authority. The Chairman, Atomic Energy Regulatory Board (AERB) is appointed as the Competent Authority under the rules.

Certificate of Approval

A licence is needed to operate a food irradiation facility. According to the Food Irradiation Rules a licence can be obtained from the Licensing Authority only after a certificate of approval has been granted by the Competent Authority. For obtaining the certificate of approval, an application has to be submitted to AERB in Form III of the Food Irradiation Rules. Documents to be submitted along with the application have been specified in Schedule III of the rules and in detail in Form III. These include:

1. Description of radiation source, address of the supplier, operating conditions, source drive system, etc.
2. A site plan (1:500 scale or as appropriate) of the installation indicating the location of buildings including residential complexes. Occupancy within 50 meters radius of the facility.
3. Architectural blue prints (appropriate scale) showing layout of equipment.
4. Details on geology of the location, water table, soil characteristics, seismicity.
5. Complete design drawing of the facility including details of shielding surrounding the source, wall thickness and labyrinth access if applicable; openings, voids, reinforcements, mechanical and electrical safety systems, ventilation, fire protection systems.
6. Source movement system (where applicable).
7. Safety analysis report to demonstrate the adequacy of radiation safety under normal and anticipated accident conditions.
8. Operating and emergency procedures.
9. List of calibrated radiation monitoring equipment in working condition.

10. Description of the organizational structure including delegation of authority and responsibility for operation of the facility.

A certificate of approval can be granted by the Competent Authority, after the applicant satisfies that the facility is in conformity with the general conditions for design, operation and efficiency criteria. These aspects are specifically set out in Schedule IV of the Food Irradiation Rules. The essential requirements are: safety of the design, availability of qualified personnel, availability of monitoring instruments, system for verifying doses to foods and availability of good operating and emergency procedures.

If the applicant does not satisfy the requirements, the Competent Authority may refuse the certificate of approval after giving the applicant a reasonable opportunity of being heard against the proposed refusal. The Competent Authority may suspend the certificate of approval on the basis of inspection reports stating that the facility has ceased to conform to the safety and efficiency criteria detailed in the rules.

Operating Procedures

The safe operating procedures to be followed by a food irradiation facility have been laid down in the Food Irradiation Rules. They aim at ensuring that the operational limits are not exceeded. In particular, they require procedures for access control, the security of the food irradiation facility, radiation surveillance, safe transport of radioactive sources, and provide for maintenance of records. Suitable log books and records of food irradiation are required to be maintained. Suitable certificate of irradiation and irradiation voucher have to be issued by the licensee. The radiation survey instruments required in a food irradiation facility have been prescribed. They cover all the requirements of radiation protection monitoring in such a facility. The radiation symbol is required to be displayed at the facility. The decayed radioactive sources have to be disposed of as directed by the competent authority.

Conditions for the operation of food irradiation facilities for irradiated food have been laid down in detail in the Food Irradiation Rules. These concern the irradiation plants, dosimetry and process control, good radiation processing practice and product and inventory control. Great stress has been laid on dosimetry. Guidance has been provided on the determination of average absorbed dose, effective and limiting dose values, routine dosimetry and process control to demonstrate the dosimetry. Re-irradiation is not allowed except in the case of low-moisture content foods, i. e. spices.

Inspection of the Facilities

According to the rules, the Competent Authority or persons authorised by him shall inspect the irradiation facility at least once in a year; but the maximum gap between the two visits shall not exceed eight months. The inspections help to verify whether the facilities comply with the provisions of the Food Irradiation Rules. The licensee is bound to provide all reasonable facilities to the inspectors. The inspectors have the right of access to the irradiation facilities and to all the documents related to the facility (many of these documents are listed in the rules). They may also check the performance of the unit and carry out dosimetry.

Copies of the order of suspension and the inspection report will be sent to the Licensing Authority by the Competent Authority. The Competent Authority shall enter the particulars of inspection in the certificate of approval. The Competent Authority may revoke the suspension if he/she is satisfied that the defects mentioned in the suspension order have been rectified.

Personnel

The food irradiation facility shall have an Operator, a Quality Control Officer and a Radiological Safety Officer recognized by the Competent Authority. The minimum qualifications required for these posts as laid down in the Rules are shown below.

Radiological Safety Officer

The minimum qualification: He should be a science graduate with physics as one of the subjects.

He should have successfully undergone instructions specified for the training of a Radiological Safety Officer (RSO). He should have also successfully undergone instructions for the Training of a Radiological Safety Officer Level III as specified by the Atomic Energy Regulatory Board and should possess a valid certificate to that effect. The subjects for instructions should include fundamentals of radiation and radiation protection, concept of dose limit, use of instruments, survey techniques in radiation detection and knowledge of personnel monitoring equipments, inspection and maintenance of safety interlocks, operation and emergency procedures.

Operator

The operator should be a science graduate or a diploma holder in mechanical or electrical engineering. The operator has to undergo instruction in subjects prescribed for a Radiological Safety Officer, in addition to the instruction in elements of food technology and food irradiation technology. The topics are detailed in the Rules.

Quality Control Officer

The Quality Control Officer should be either M.Sc/ B.Tech in microbiology, food technology or food chemistry.

Radiological Safety

The Food Irradiation Rules require that the licensee shall provide personnel monitoring devices to every person entering the irradiation facility. The Radiological Safety Officer shall instruct radiation workers in his charge on the hazards of radiation and on suitable safety measures and work practices aimed at minimizing radiation exposures to them. He is expected to investigate and initiate prompt and suitable safety measures in respect of any situation that could result in radiation hazards. The RSO shall make available to his employees reports of hazardous situations alongwith details of remedial measures that may have been initiated by them.

The duties of RSO include carrying out leakage tests specified by the Competent Authority. For this, he must check the resin bed in the water containing system with a radiation survey instrument. In case any radioactivity level is detected the water circulation system shall be stopped and the irradiator withdrawn from service. Besides this, the pool water has to be checked using an on line radiation monitor. The Rules specify leakage tests for dry storage facility as well.

Emergency Procedures

The licensee of a food irradiation facility is bound to prepare brief and clear emergency procedures, describing anticipated emergency situations and the action to be taken to minimize the radiation dose to the persons in the vicinity of the irradiation facility.

Decommissioning and Disposal of Radioactive Sources

The Competent Authority shall specify the manner in which the irradiation facility has to be decommissioned. In order to release a site for other uses, the licensee has to get a certificate of release from the Licensing Authority. The Licensing Authority shall issue it only after getting a report from the Competent Authority.

Some Design Safety Aspects

Radiological safety of food irradiation facilities can be achieved by ensuring that they comply with the provisions of the relevant safety codes and standards prescribed by AERB. Generally, a gamma irradiation facility consists of radioactive sources (Cobalt-60) of very high activity in the form of slugs which are encapsulated in stainless or other appropriate metal claddings. The radioactive source and the source assembly itself has to satisfy several specifications imposed in the AERB Standard Specification "Testing and Classification of Sealed Radioactive Sources (AERB/SS-3)". These tests include tests related to impact, temperature, vibration, pressure etc. In addition the AERB Standard Specification "Radiological Safety for the Design and Installation of Land-Based Stationary Gamma Irradiators" (AERB-SS-6) specifies design safety requirements in respect of irradiators. Stringent site selection criteria have also been laid down in AERB-SS-6. The specific features of the irradiation depend on its type.

The source frame is well designed, well protected and of sufficient strength. There are two wire ropes for moving the source. Each of these is capable of moving the source by itself. The tension in the wire ropes is balanced.

Access Control

Access to the irradiation chamber will be controlled through a door which has appropriate interlocks to ensure that nobody can enter the chamber when the source is in the exposed condition. Irradiation cannot start if either the personnel access door or product access door is open. Also, the source goes into its shielded position if either of these is opened. A prominent emergency stop switch is provided inside the irradiation cell, so that anyone trapped inside when irradiation starts, can terminate it at once. An emergency stop switch is also provided at the control console.

Shielding

In the wet irradiator the source is normally kept in the shielded position under several metres of water. The water used as shield is demineralized and its quality is maintained with an on-line clean-up system.

Irradiator should be equipped with a radiation zone monitor integrated with the personnel access door interlocks to prevent room access when the source is in 'ON' position. The monitor shall also generate audible and visible alarm if radiation level exceeds that when the same is in the fully shielded part.

The source can be lifted remotely into the irradiation position. Mechanical arrangements to convey the packaged food item near the source to ensure uniform irradiation of the contents is built into the irradiation facility.

Other Features

Special care is taken for the removal of decay heat. Good facilities for fire fighting are provided. Irradiation cell is well ventilated to prevent accumulation of noxious and toxic gases. The irradiator cannot function if power fails and stops if product carriers are jammed. Radiation monitors and warning signals have to be provided. Irradiation cannot start in the following cases:

a. Failure of motive power
b. Emergency stop from the irradiation cell
c. Entry door latch inoperative
d. Unequal tension in wire ropes
e. Low water pool level
f. Failure of cell ventilation
g. Jamming of product carriers and
h. Temperature / smoke alarm

Also, irradiation is terminated automatically at once in the following cases:

a. Failure of motive power
b. Emergency stop from the control console
c. Disengagement of the personnel access door latch bar
d. Actuation of entry control device at product entry / exit ports
e. Snapping or loosening of wire ropes
f. Failure of cell ventilation
g. Jamming of product carriers
h. Temperature / smoke alarm

Interlocks can be bypassed during maintenance with a special service key control. This has to be done by authorised persons only. The design of all safety systems follows the defence-in-depth philosophy. Each safety system should be redundant and diverse to improve its reliability. The major components of each system should be duplicated by supporting systems of different types to reduce the risk of multiple failures. Safety systems are also independent so that a fault in one system should not cause the collapse of the other. All safety systems are designed to be tamper-proof and difficult to override without the use of special tools. Systems are so designed that in case it fails, the device is left in safe condition.

The test requirements in respect of the irradiators are specified in "Radiological Safety for the Design and Installation of Land Based Stationary Gamma Irradiators" (AERB-SS-6).

Review Process

AERB has set up a multi-tier review procedure to issue the certificate of approval. A Design Safety Review Committee set up on September 12, 1996 will review the design of the irradiation facility and the siting requirements pertaining to radiological and conventional safety. Their recommendations will be reviewed by a higher committee-the Safety Review Committee for Applications of Radiation (SARCAR)-with specialists in fields such as engineering, radiation safety, medicine, radiological physics and medical physics. A working group set up by the Board shall examine the aspects of dosimetry and other relevant conditions stipulated in the Atomic Energy (Control of Irradiation of Food) Rules, 1996. The certificate of approval is given by the Board only after it receives the recommendations from the Design Safety Review Committee and the Working group.

AERB insisted that a special training programme for operators should be organized at the Bhabha Atomic Research Centre to satisfy the training requirements specified in the rules. BARC which has developed multi-disciplinary expertise in all topics related to food irradiation has held the course at BARC. AERB ensures that qualified personnel are in place in the irradiation facility before certificate of approval is granted.

Offences and Penalties

Section 24 of the Atomic Energy Act stipulates that whoever contravenes any order made under Section 14 or any condition subject to which a licence is granted under that Section or contravenes any rule made under Section 17 or any requirement, prohibition or restriction imposed under any such rule or obstructs any person authorized by the Central Government under subsection (4) of Section 17 in the exercise of powers under that section shall be punishable with imprisonment for a term which may extend to five years, or with fine or with both. Atomic Energy (Control of Food Irradiation Rules) 1996 have been promulgated by exercising the powers conferred by Section 30 read with Sections 14 and 17 of the Atomic Energy Act 1962.

Conclusions

In view of the potential for high radiation exposures, the irradiator facility should be operated with due care. The regulatory mechanisms to enforce safety in these installations are in place in the country. Total involvement of the operating personnel and their commitment to safety culture is essential to operate the gamma irradiators safely and efficiently. The Radiological Safety Officer with the cooperation of the management should carry out safety audit regularly. Under no circumstances he should allow any practice which may dilute safety requirements. He shall ensure the maintenance and upkeep of the radiation monitoring instruments.

Some Useful References

1. Atomic Energy Act, 1962 (33 of 1962)
2. Atomic Energy (Control Irradiation of Food) Rules, 1996.
3. Prevention of Food Adulteration (Fifth Amendment) Rules 1994 G.S.R. 614(E) Dated August 9, 1994.
4. AERB Standard Specification "Testing and Classification of Sealed Radioactive Sources" (AERB/SS-3).
5. AERB Standard Specification "Radiological Safety for the Design and Installation of Land-Based Stationary Gamma Irradiators" (AERB /SS-6).

Irradiated Foods : Consumer's Response

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The discrepancy between the long list of clearances for irradiated food granted by more than 40 countries and the irradiated commodities actually produced and marketed in these countries is striking. It is obviously clear that food industry and trade are not making much use of this technique even though a number of countries have provided the regulations.

There may be several reasons such as economical use of an irradiation facility year around, or limitation on exports as the foreign trading partners either do not allow irradiated food or clearances may be for other commodities than what is exported. The fear of consumer resistance is certainly the most important reason as it has direct bearing on trade of irradiated food. The rate of survival of new product in the markets of advanced counties like US is less than 25% in the following year, and in long range about 90% new products launched are destined to failure.

Consumer Acceptance of Irradiated Food

The acceptance of irradiated food has been normally treated in three ways : by consumer surveys with questionnaire, interviews etc., by limited market testing and in actual retail selling. Several surveys have been conducted using questionnaire, or interviews of different strata from university staff to housewives especially in USA, some of the European countries and few Asian countries like China, Thailand, etc. After going through all these reports, it is clear that the acceptability of irradiated food has been largely depended upon consumer knowledge and orientation about the process of irradiation and the benefits. For example, the study conducted by Wiese Research Associates Inc. in March 1984 concluded that only about one in four adults had heard of this method of food preservation (1). Among those who were aware of food irradiation 30% had no concern about food irradiation, 30% had minor concern, 37% had major concern and 3% were undecided. Among those who were unaware of the process 16% had no concern, 29% had minor concern, 39% had major concern, and 16% were undecided. The cause of concern most frequently mentioned was the word radiation itself. Other causes were "might be harmful to people", "may have side effects", "may be cancer causing" only 1% of the concerns mentioned were related to cost or cost efficiency. The level of concern for chemical sprays and preservatives was higher than that for irradiation.

When consumers were asked about their interest in buying spices treated with fumigation (ethylene oxide) or irradiation, 58.1% preferred irradiation, 3.5% fumigation, 25.9% were uncertain, and 12.6% answered "neither" (2). Similarly, when a survey was carried out by the University of Georgia's Food Safety and quality Enhancement Laboratory found that consumer awareness of food irradiation went up from 23% in 1984 to 70% in 1993 (3). Asked about the importance of irradiation, three to four times as many consumers considered irradiation of poultry, pork, beef and seafood "very necessary" compared to fruits and vegetable. In this case, the consumers seem to be aware of the problem of food borne disease and of food irradiations' potential role in controlling the pathogens.

Upto 1990 many consumers in the US had not formed an opinion about irradiation. In 1993, following increased science based coverage, 70% had heard of irradiation, although 88% of these said they did not know very much about the process and 30% thought that irradiated food was radioactive (4). Specific concerns about irradiation were :

- Safety
- Nutritional quality
- Potential harm to employees
- Potential danger from living near an irradiator facility

Outbreaks of *E. coli* infection

Following the outbreak of *E. coli* in the West Coast of the USA in early 1993 and the increasing interest in the use of irradiation to ensure hygienic quality of food of animal origin, the American Meat Institute funded a nationwide three part study to measure consumer attitudes to irradiation in relation to food safety. The results indicated that while most consumers were aware of food irradiation, few were knowledgeable of the process. According to the survey, after the benefits of irradiation were explained and endorsements by health organisation were made, 54% of those interviewed said they were more willing to purchase irradiated meat rather than non irradiated meat. Sixty percent of the survey participants said they would be willing to pay a 5% premium for hamburgers with bacterial counts greatly reduced by irradiation. Even in this survey consumers viewed irradiation as more necessary for meat, seafood and poultry products than for fruits and vegetables (4).

Attitude studies have shown that label statements serve as a source of information. Responses of consumers to products bearing statements were :

Table 1. Customer response to irradiated food

Irradiated food		Consumer response
A.	"Irradiated to extend shelf life"	• 2/3rd considered better compared to non-irradiated products • 33% uncertain • 4% thought food would not store well
B.	"Irradiated to control microbes"	• 42% considered better • 28% lower • 14% lower
C.	"Irradiated to quality control"	lowest impact

The greatest interest was generated with label "Irradiated to control micro-organisms". It is important to consider consumer attitude towards irradiated foods in the context of consumer attitudes to food in general and to the food processes. A food does not have to appeal to everyone to be successful.

The conclusion from various consumer attitude surveys, conducted mainly in advanced countries, showed that consumers at large were not knowledgeable about food irradiation. They need accurate information about the safety, benefits and limitations of food irradiation to be able to make an informed decision whether they will accept irradiated food or not.

Market Tests

Market tests provide excellent information about consumer acceptance and can speed the commercialisation of irradiation. A good market test allows informed choice, attempts to measure and understand the group of consumers and the context of the test, provide information, measure sales as well as consumer opinion, and report all the information well.

Boesseau (5) has said the best way to generate and evaluate consumer acceptance is test marketing in which irradiated and non-irradiated food items are sold in the same place at the same time. Further, availability of tests for identification of irradiated food and correct and comprehensive labeling of irradiated foods would help consumer acceptance.

During the past decade, a number of market trials of several irradiated food items with clear labeling indicating the treatment were carried out in both advanced and developing countries.

In Bangladesh, market testing and consumer acceptability have been studied for onions, potatoes and dried fish. The food items were supplied at wholesale prices to a number of shops and departmental stores. Irradiated products were labeled "Preserved by irradiation and approved by the Government" and displayed alongside non irradiated items for comparison.

The test marketing studies indicate acceptance. In the later part of the study, after 3-5 months of storage, consumers were reluctant to buy non-irradiated onions at the same price as that of irradiated. The non-irradiated potato tubers were not acceptable due to heavy sprouting and quality deterioration. Similarly non-irradiated dried fish were spoiled due to treading of inspects and fungal contamination during the later part of storage.

In US, papayas, mangoes and strawberries have been tested for consumer response (Table 2).

In the Chicago trials, even with a "buy one get the other free" promotion, customers preferred irradiated pints. In case of grapefruit and juice 90% of the produce sold was irradiated. In the second year, the irradiated produce outsold the non- irradiated by 20 to 1.

In China, numerous foods have been market tested. Analysis of consumer acceptance forms distributed to and filed by 1000 customers showed that 84% found irradiated apples acceptable and 93% consumer said they would purchase the produce again and the food irradiation should be developed worldwide.

Countrywide experiences of acceptability are summarised in Table 3.

The positive consumer response to irradiated food in the market places motivated retail stores to start marketing of irradiated food. For example South Africa no longer does market testing. It is commercially irradiating 8,370 tonnes of food and ingredients each year (6). Similarly, China has

Table 2. Consumer response to irradiated foods

Area and date	Produce	Response
Florida, 1986	Mangoes	Positive
Southern California, 1987	Papaya	66-80% preferred irradiated fruit and outsold identically priced fruit > 10:1
Florida, 1992	Strawberries	Irradiated fruit (600 pints on day 5) although priced higher Non-irradiated (450 pints)
Chicago, 1992	Strawberries, Grape fruit, juice, oranges	After showing customers via newsletter containing pro- and anti- material 1200 pints of irradiated strawberries sold (about 90-95%)

Table 3. Results of consumer acceptance studies in various countries.

Country	Food item	Results
Thailand, 1986	Nham fermented pork sausage	• 34% purchased the irradiated products out of curiosity. • 66%considered to be less likely to be harmful • 95% incidated they would purchase the irradiated product again
Philippines, 1985	Onions	Sales 29-71% higher than non-irradiated depending on variety
Pakistan, 1991	Potatoes and onions	39% willing to buy, 57% thought food irradiation should be commercialised
Argentina, 1985	Onions and garlic	10 tons of irradiated product sold within 3 days of marketing.
South Africa, 1978-79	Potatoes Papayas Mangoes Strawberries	Sold 13 tons Sold 20 tons Sold 20 tons Sold 7 tons 40% buyers judged the foods acceptable
France, 1991	14,000 tons of various foods irradiated i.e. spices dried fruits, vegetables, deboned poultry meat	

conducted extensive market testing of whole variety of foods, and is now commercially irradiating very large volumes of food products. In many countries, market testing is not allowed unless regulatory approvals are in place. In such areas, consumer attitude research is the only means of assessing consumer response.

Indian Scenario

Irradiation of onions, potatoes and spices is permitted to domestic marketing according to the Amendment of the PFA in August 1994. Additionally, rice, semiolina (sooji and rawa), atta (wheat flour), maida (refined wheat flour), raisins, dried figs, dried dates, mango, ginger, garlic, shallots (small onions), meat (buffalo, lamb and pork) and meat products (salami, sausages etc.) and chicken have been cleared during April 1998 for domestic use by Gazette notification amendment of Prevention of Food Adultration Act (1974). A few studies have been conducted on consumer acceptability. Some studies on acceptability have been conducted at the BARC. The consumer response (%) on food irradiation and acceptance of snack items prepared from irradiated potatoes and onions that were served during the lunch hours of various conferences and seminars held at different places in Mumbai showed very encouraging response from the participants. Results are included in Table 4.

Table 4. Acceptance of snacks

	Total	Male	Female
Like	94.4	89.5	93.9
Do not like	1.6	2.0	1.1
Uncertain	5.5	6.8	4.2
No response	1.5	1.7	0.8
Willingness to buy or eat irradiated foods			
Willing	82.3	83.2	81.9
Unwilling	2.6	3.2	1.7
Uncertain	12.6	10.8	14.7
No response	2.5	2.8	1.7

At the Department of P.G. Studies and Research in Home Science, SNDT Women's University, a consumer evaluation trial was conducted for selected commonly used irradiated and non-irradiated spices and condiments, viz. chilli powder, turmeric (whole and powder), black pepper

Table 5. Consumer response (%) on food irradiated and acceptance of snacks prepared from irradiated potatoes and onions.

	Total	Male	Female
No. of respondents	759	399	360
Heard about food irradiation before (Response %)			
Yes	90.0	89.5	91.9
No	9.2	10.25	8.1
No response	0.8	0.25	0.0

Percentage preferring Aroma / Flavour of non-irradiated to irradiated spices

Aroma of spice		
	Month 0 % participants	Month 12 % participants
Chilli powder	32.1	9.1
Coriander powder	71.4	0
Garam Masala	50.0	18.7
Flavour of spice		
Turmeric powder	56.5	0
Coriander powder	71.4	21.9
Garam Masala	41.5	18.7

(whole and powder), cardamom and ginger (dried) (7).

Housewives were given irradiated and non-irradiated spices at 4 time points during a one year period in coded packets after informed consent. The spices were also used in the cafeteria and tested. Raw spices, overall scores for flavour, aroma and acceptability did not differ significantly between the irradiated and non-irradiated spices.

In quantity cooking trials, the participants were asked to compare the irradiated and non irradiated spices and to state whether the former was similar to, better or poorer than the non-irradiated.

At the beginning of the study, although 25-50% preferred the non irradiated, at the end of the year long study, the percentage preferring the non-irradiated spices dropped. These trends were observed for 3 sensory characteristic : flavour aroma and colour (Table 5).

For all the spices the percent preference for the irradiated spices is shown in Table 6.

Often those who adopt a new technology early are those who have a higher standard/level of living, have more prestigious occupations etc. Bruhn (4) has reported that such people are more favourable

Table 6. Preference test results at 3 time points

	Flavour			Aroma		
I > NI	0	6	12	0	6	12
Turmeric powder	21.8	34.4	38.9	18.8	23.5	27.8
Chilli powder	37.1	45.3	65.2	10.8	30.8	78.8
Cumin seeds	39.0	22.8	48.4	32.7	22.8	41.9
Pepper powder	18.8	32.3	33.4	9.4	36.0	41.4
Garam Masala	41.4	26.9	62.5	27.5	25.0	65.6
Coriander powder	14.3	36.4	24.2	14.3	21.2	100.0
Cardamom	37.5	30.4	54.1	30.8	19.7	25.0

towards change and cope better with uncertainty and have a greater ability to deal with the abstract.

Science literacy probably plays an important role in acceptance of irradiated food. In the USA, those who oppose food irradiation are also highly concerned about the use of chemicals in food, place a high value on an ecologically balanced world, oppose the use of nuclear technology and prefer to eat only "organic" or unprocessed food.

Certain chemographic factor have been related to views towards irradiation. Women are more concerned about issues that may affect food safety, including irradiation. People with formal education at the high school level and about were more likely to purchase irradiated products.

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Regulation and Control of Food Irradiation

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The safety of irradiated food and that of irradiation facilities have undergone intense scrutiny by the scientific establishments as well as the law enforcing agencies around the world. Governments have enacted rules and regulations and provided guidelines and standards to ensure a high degree of product and process safety. In India the safety of an irradiation facility is regulated through Atomic Energy Regulatory Board (AERB), whereas, the safety of the product, that is irradiated food, is regulated through the Prevention of Food Adulteration Act (PFA), 1954 (37 of 1954), Rules, 1955, enforceable by the Food and Drug Administration (FDA). The licensing of irradiated food is covered under a dual licensing system:

- License from the Department of Atomic Energy under Atomic Energy (Control of Irradiation of Food) Rules, 1996, for operation of an irradiation facility.
- License from the Local Licensing Authority under PFA Rules, 1955, for irradiation of a commodity.

This dual system of control ensures that food irradiation does not pose any undue risk to the consumers, workers, and environment. The regulations and controls pertaining to the safety of irradiation facilities has been discussed elsewhere in this issue. The present article is mainly focused on the regulations and controls pertaining to the product safety.

Clearance of Irradiated Food Items

A source of radiation is specifically defined as a food additive under the Federal Food, Drug and Cosmetic Act of USA. The US Secretary of Health may approve a food additive petition from an interested person or may propose the issuance of a food additive regulation upon the Secretary's own initiative (Federal Register, 1986). It is therefore axiomatic that in USA any new food irradiation application should receive approval of the Secretary of Health. The Government of India has adopted more or less similar approach for clearance of irradiated food items.

National Monitoring Agency

In 1987 the Government of India set up a National Monitoring Agency (NMA) to consider various aspects of radiation processing of food. The NMA under the Chairpersonship of the Secretary, Ministry of Health and Family Welfare has 10 members comprising of the Director General of Health Services, Director General, Indian Council of Medical Research (ICMR), Secretary-Department of Atomic Energy (DAE), Secretary, Department of Scientific and Industrial Research (CSIR) & DG CSIR, Secretary, Department of Science and Technology (DST), Secretary, Department of Food, Secretary, Department of Agriculture, Secretary, Department of Commerce, Secretary, Department of Civil Supplies, Secretary, Department of Food Processing and Assistant Director General (PFA) as its Member Secretary (Mukherjee, 1996). The assigned functions of NMA are :

- to examine each commodity with reference to data made available and suggest the maximum dose applicable to it.
- to give clearance to the various kinds of food stuffs for irradiation.
- to evolve guidelines for food irradiation practices in the matter of preservation of food stuffs.
- to recommend licenses to facilities owned by individuals or institutions for irradiation of food stuffs.
- to consider any other matter related to the use of irradiation as a means of preserving food stuffs.

The Ministry of Health and Family Welfare acts as a coordinator in all matters relating to food irradiation. It would ensure compliance with the dose and labelling requirements for a particular commodity under the PFA rules.

In 1990 NMA approved irradiation of spices, potato and onion, thereafter the proposal was notified as a draft in 1992 and the final notification was published in 1994 vide GSR No. 614(E) dated August 9, 1994 (see Annexure 1).

Expert Group Constituted by NMA

In 1993 NMA constituted an Expert Group under the chairpersonship of Director General of Health Services for examining the other food articles for radiation processing and make recommendation for their approval. The core Expert Group besides the Chairperson comprises of representatives of ICMR, National Institute of Nutrition, BARC, Ministry of Civil Supplies, Ministry of Atomic Energy, Ministry of Agriculture, Department of Biotechnology. Depending on the commodity required to be cleared, the Expert Group can coopt members from related Ministries and Institutions.

Central Committee for Food Standards (CCFS)

In order to facilitate decision making by the NMA and the Expert Group, it was proposed that petitions for food irradiation applications be reviewed by a technically competent committee like the CCFS. The committee comprises of Director General, DGHS, as the chairperson, Directors of the Central Food Laboratories, 2 experts of the Government of India, Representatives of the Ministries of Food, Agriculture, Civil Supplies, Commerce, Defence, Railways, State Governments, FDA, Consumer Organisations, Hotel industry, ICMR and Bureau of Indian Standards.

Thus a three tier system for reviewing a petition for clearance of irradiated food has been evolved. Once an application is made to the DGHS, it is forwarded through the NMA to the Expert Group, which in turn forwards it to the CCFS for recommendations. After review the recommendations of the CCFS are passed on to the NMA for approval. Following this the draft rules are placed for public review and comments before issuing a Gazette notification and inclusion in PFA rules.

Thus it should be clear from the foregoing that radiation processing of food can be done only in a facility licensed to do so and that too of those items that are included in PFA rules.

Food Irradiation Facilities

A license is needed for operation of an irradiation facility. The license could be obtained after fulfilling the requirements of Atomic Energy Regulatory Board (see the accompanying article).

Operating Personnel

A food irradiation facility is to be manned by trained personnel. A six week training course for operators of food irradiattion facilities based on syllabus prescribed by the Atomic Energy Regulatory Board is conducted by the Food Technology Division, BARC.

Packaging and Labelling Requirements

Sub-rule (26) of the rule 49 of the PFA requires that all irradiated food shall be sold in prepacked condition only. The type of packaging material used for irradiated food for sale or for stock for sale or for exhibition for sale or for storage for sale shall conform to the requirement of packaging material as per rule 49. Primary rigid containers including metal cans, steel containers, tin plated and lined with appropriate enamel and secondary rigid containers made of wood and fibre board could be used. Flexible packaging material films including, nitrocellulose or vinylidine coated cellophane, wax coated paper board, glassine paper, polystyrine, rubber, vinyl chloride, polyethylene, nylon, vegetable parchment are authorised for packaging of food for radiation processing.

Rule 37-C states that the labelling of irradiated food shall be in accordance with the provisions of rule 32 and rule 42 of the PFA Rules, 1955, and the provisions of the Atomic Energy (Control of Irradiation of Food) Rules, 1996, under the Atomic Energy Act, 1962. According to this rule all packages of irradiated food shall bear the following declaration and logo:

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PROCESSED BY IRRADIATION METHOD

DATE OF IRRADIATION

LICENSE No.

PURPOSE OF IRRADIATION

Good Manufacturing Practices (GMP)

It is important that the food irradiation plants, and the business houses trading in irradiated food follow GMP. The food irradiation plants should take effective steps in checking the incoming product quality and only a standard product in standard packing be allowed to be irradiated. Irradiation facilities should follow the General Principles of food hygiene, prepared by the FAO/WHO Codex Alimentarius Commission as basic recommendation to ensure hygenic food handling and processing.

Additional Food Items Approved

In April 1998 PFA approved irradiation of additional items including rice, wheat products such as atta and semolina (sooji or rawa), raisins, figs, and dried dates for insect disinfestation, mango for delay in ripening and quarantine treatment, ginger, garlic and shallots for sprout inhibition, and meat and meat product including chicken for improvement in shelf-life and elimination of parasites and pathogens (see Annexure 1).

Approvals Requested

In addition to approvals listed in Annexure 1, another application has been forwarded to the Directorate General of Health Services for approval of irradiation for shelf-life enhancement of refrigerated seafood, pathogen control in frozen seafood, insect disinfestation of dry fish, pulses and pulse products.

Conclusions

It is clear that any infringement of the provisions of food irradiation rules provided under the PFA would invite punishments and penalties as per the Act. The regulations and controls on food irradiation may appear little complex at the outset. However, these controls have been evolved over a period of time in accordance with the accepted norms of safety to safeguard the interests of the consumer at large. The compliance with these controls and regulations can provide the best guarantee of quality.

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2. Mukherjee, D. (1996). Irradiation of food - Legal aspects. In National Seminar on Nutritional and Safety Aspects of Food Irradiation, SNDT Women's University, December, 1996

First Commercial Radiation Processing Facility for Spices in India

Shri D.S. Lavale graduated in mechanical engineering from Vikram University, Ujjain in the year 1969. After graduating from the BARC Training School in 1971, he joined the Isotope Division, BARC. He has received training in O & M of commercial radiation plants in European countries. He has actively participated in the construction and commissioning of the ISOMED Plant, Mumbai. He has contributed to the design, construction and commissioning of major radiation plants in India namely, RASHMI, Bangalore; SARC, Delhi and SHRI, Baroda. He has served as a technical expert for IAEA and also assisted the Agency in bringing out a safety series on "Radiation Safety of Gamma and Electron Irradiation Facilities". Currently he is heading the Projects Group of BRIT and is engaged in setting up the Spice Irradiator and two other industrial radiation processing projects

Dr. S. Gangadharan graduated from Madras University in 1959 and has been with DAE since 1960 following graduation from the BARC Training School. He obtained his Ph.D. from University of Pittsburg, USA. He is currently Chief Executive, Board of Radiation and Isotope Technology, DAE and the Project Director, National Centre for Compositional Characterisation of Materials, Hyderabad. He is an expert in nuclear analytical chemistry and ultra-trace elemental analysis for applications to material sciences, environmental and life sciences, forensic sciences and archeology. Dr. Gangadharan has been IAEA technical expert to Thailand and Zaire and has been associated with important assignment of IAEA, Vienna.

Introduction

Food irradiation is now finding acceptance as a process for food preservation and hygienisation. Controlling agencies in many countries are in the process of issuing clearances for irradiation of selected food items on case by case basis. A number of facilities for food irradiation have already come up in many countries. Government of India formulated national regulation by amending Atomic Energy Act 1962 and Prevention of Food Adulteration Act (PFA) 1954 to legally include food irradiation as a commercial food preservation process for selected food items in September 1994.

Department of Atomic Energy being responsible for the application of radiation technology in the country, responded promptly by initiating a project for setting up a demonstration plant for the radiation processing of spices which perhaps is the most immediate application of this technology. Purpose of the project is to generate techno-economic data for the technology in the Indian context while exploiting the plant commercially, as a service contract facility. For the convenience of the customers, the irradiator is ideally located in close proximity to a large spice trading and exporting market of the country in Navi Mumbai.

The expected product mix the plant is likely to handle includes black pepper, chili, turmeric, dehydrated ginger, whole and ground spices, spice mixes and condiments. Some of these were conventionally treated by fumigation with methyl bromide and ethylene oxide. The chemical fumigants are being phased out due to the problems of toxic residues and environmental concerns.

The Plant Systems

To-date civil construction for the plant building and radiation cell is in progress and parallelly the irradiator equipment is being fabricated. Layout of plant building is shown in Fig. 1. Commercial operation of the plant will be carried out by

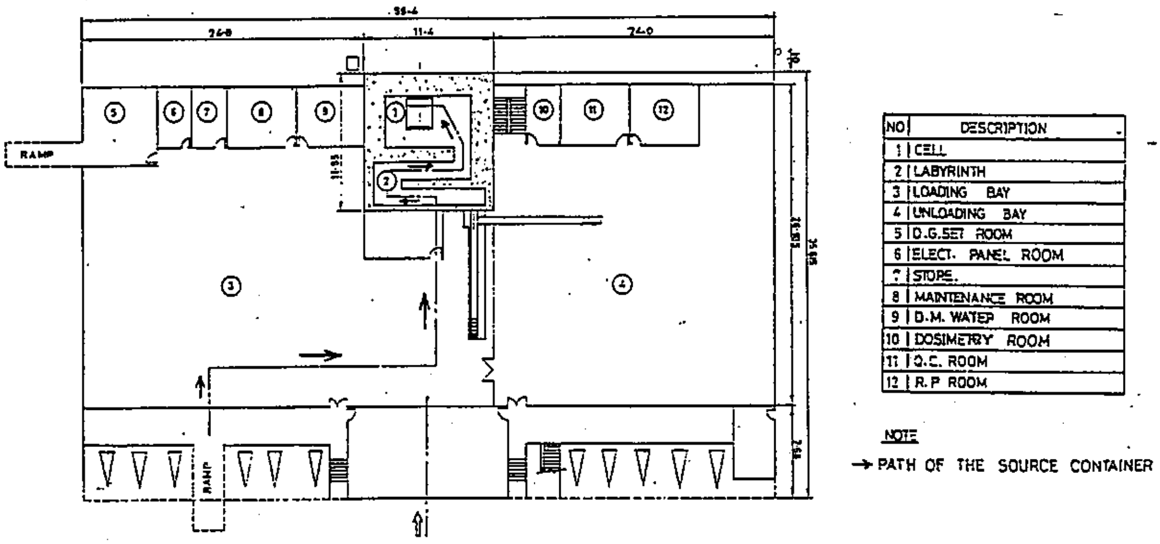

Fig. 1 The facility layout of the spice irradiator

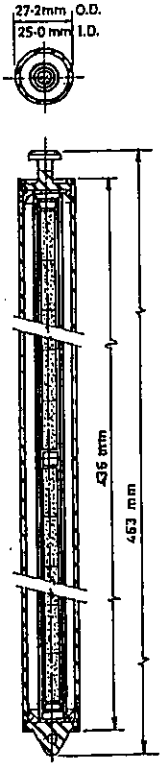

Fig. 2 Cobalt-60 integral sealed source unit for wet storage (W-91)

BRIT/DAE. DAE's commitment to the food irradiation programme is expected to create a better consumer acceptance for the irradiated products.

Source System

The basic Cobalt-60 source to be used in the plant is shown in Fig. 2. The source is manufactured locally and is approved by the Atomic Energy Regulatory Board (AERB), the controlling authority for matters pertaining to radiation safety in the country. Sources of this design are in use in other radiation plants in the country for several years. Maximum designed source capacity of the plant is 37 PBq (1 Mega Curie). For its obvious merits, a wet source storage system has been used in the plant. The source assembly is in a plaque form, with spare source positions to augment the source capacity for compensating the source decay. The 6 M travel of source frame for rest to exposed position is performed by a hydraulic cylinder through a wire rope and a multiple pulley system.

Radiation Shielding

The Radiation shield has been designed for exposures lower than 30 mSv/year outside the radiation cell. This being a stipulated radiation exposure limit in the country by AERB. Ordinary

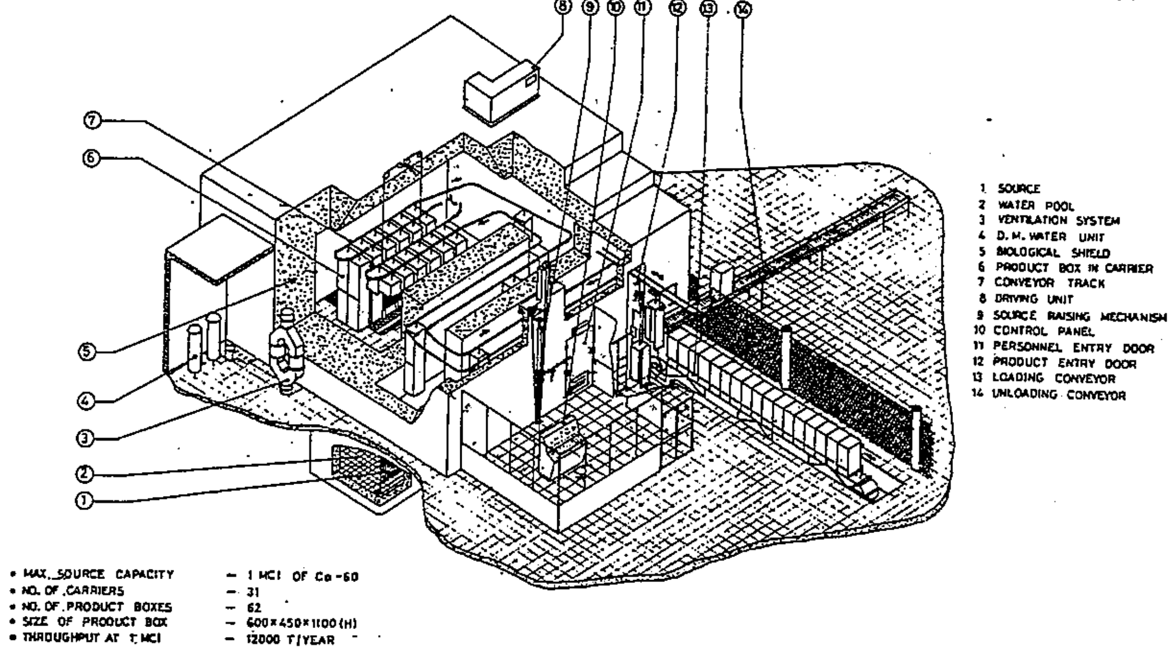

Fig. 3 General arrangements of equipment in the Spice Irradiator Plant

concrete of 1.9 M in thickness, 6 M deep water pool and a multiple bend maze access are some of the features in the design of radiation shield to limit the exposure levels below the stipulated level. Radiation levels are continuously monitored by radiation survey meters installed at suitable locations.

Product Handling System

At 1 MCi source loading about 30 tons of products with average density of 0.4 gm/cc at an average absorbed dose of 10 kGy will be processed per day. The product is expected to arrive in the plant in bulk quantities, sealed in sacks or in cardboard cartons and is to be manually loaded into the aluminium tote boxes. Standard totes riding on hanging carriers are used for product movement in the plant. For realizing better source utilisation, a production overlap geometry is used. Size of the tote 600 mm L x 450 mm W x 1100 mm H has been carefully selected to facilitate loading of varying density products, keeping in mind the conflicting requirements of dose uniformity to the product. Totes are loaded into carriers having two shelves hanging on overhead monorail track in 2+2 pass configuration at the source pass mechanism. The carriers are in continuous motion on the track powered through a series of chains and pusher loops. Mechanisms for changing the sides of totes across the source and shuffling of totes in their levels in carriers are also incorporated in the system. The drive for the conveyor chain is mounted on cell roof, out of radiation zone. To enable radiation at source strengths ranging from 100 kCi to 1 MCi and for dose range from 6 kGy to 25 kGy, a wider, infinitely variable speed range for the conveyor is provided. Adequate safety measures for the protection of the process and product are also incorporated in plant design. General arrangement of equipment in radiation cell is shown in Fig. 3.

Dosimetry Considerations

Average weight of product per tote box is maintained at 50 kg irrespective of the product density through adjustments in product volume. This will facilitate simultaneous irradiation of product with varying density thus eliminating the need for flushing before each product change over. For a lighter product like chili an expected overdose ratio is 1.3, whereas for heavier products like turmeric an expected overdose ratio is of the order of 1.6.

Control System

The safety interlocks provided in the plant are as per the recommendations of IAEA safety series No. 107 for land based, Category IV irradiators.

The control system of the irradiator is designed on fail safe principles. It means that in the event of any fault or emergency situation the radiation source is lowered to the water pool, which acts as shield for radiation. The control system is built around a rugged state of the art programmable logic controller known for its high reliability.

Some of the important parameters interlocked with source raise are :

(i) Cell search procedures and locking of personnel access door

(ii) Trip wire in radiation cell pulled

(iii) Pressure Plate in maze access stepped upon by an intruder

(iv) Low water level in water pool

(v) Airflow switch signaling no air flow

(vi) Service key switches operated during maintenance

(vii) Rope stretch/break

(viii) Product conveyor failing to start during specified time

(ix) Emergency push buttons at various strategic locations actuated

(x) Low oil level in hydraulic reservoir

(xi) Heat detector actuated

(xii) Smoke detector actuated

(xiii) AC/DC under/over voltages

The front end of the control system is served by an IBM/PC compatible computer which logs in the status of the sensors and the output devices of the plant, online, as reported to by the programmable logic controller providing status display on the monitor as well as print outs for records.

Utilities

Utilities like demineralized water plant, provision for heat exchanger for pool water cooling, ozone extraction system, fire fighting system are incorporated in the plant. A large area for the storage of fresh products and processed products, physically separated from each other is provided in the plant layout. The handling of product at loading and unloading conveyors is manual, aided by simple material handling equipment e.g. pallet trucks, stackers etc. for palletizing the product for its onward handling.

Conclusion

With the commissioning of the irradiator towards the end of 1997, India would reach another milestone in radiation technology. It would be worthwhile recalling the establishment of ISOMED at Mumbai in 1974 which introduced the technology of radiation sterilization in the country. Over two decades this technology was transformed from an emerging to an established technology. It is expected to achieve similar results in the field of food irradiation technology with the commissioning of spice irradiator.

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