Gamma Irradiation for Preservation of Food and Allied Products

T. Saravanan, Atul Kumar Tyagi and Ranjeet Singh*
Radiation Processing plant, Vashi
Board of Radiation and Isotope Technology
BRIT/BARC Vashi Complex, Sector-20, Vashi,
Navi Mumbai-400703, India

*Email: ranjitsingh@britatom.gov.in

Abstract

Gamma irradiation is a proven technology for food preservation. Considerable amount of post harvest losses can be prevented by applying gamma irradiation combined with suitable post irradiation storage. It has several advantages over other conventional methods such as fumigation and steam sterilization. Various functions such as sprout inhibition in onions, garlic, ginger potato etc., delay in ripening and senescence of various fruits and vegetables, disinfestations of agricultural commodities from insect pests, deactivation of food spoilage microbes and elimination of food pathogens can be achieved by a single process i.e. irradiation. Radiation processing is a cold process in which there is no increase in temperature and it can be done in bulk without introducing any residues in the product. Radiation processed products are very safe and this process has been endorsed by various national and international statutory bodies. In India, Department of Atomic Energy has set up 3 commercial scale gamma irradiators for low, medium and high dose applications and there are 20 gamma irradiators in the government and private sectors. Gamma irradiation technology is widely accepted worldwide and this industry is expected to grow at faster pace in the coming years.

Keywords: *Gamma irradiation, Food preservation, Shelf life extension, Radiation dose, Food-borne diseases, Quarantine treatment*

1. Introduction

With growing population and improvement in living standards, requirement of food items have increased considerably. Resources of production of food items are limited and cannot be stretched beyond a limit. Consumption of food contaminated by pathogens results in food-borne diseases and causes huge economic as well as manpower losses worldwide. In this situation, preservation of food items or prevention of food losses is very important for ensuring food safety and security.

Preservation of agricultural produce is a major problem in the country. Food losses occur at various stages in the food supply chain such as production, post-harvest and processing stages. In developing countries where the supply chain is less mechanized, larger losses are incurred during drying, storage, processing and in transportation stages.

According to Food Corporation of India estimates, 10-15% of grain production is lost due to inadequate storage facilities. Data from Ministry of Food processing Industries shows that 230 lakh tons of grains, 120 lakh tons of fruits and 210 lakh tons of vegetables are spoiled annually. According to data from Ministry of Food and Civil Supplies, Government of India, approximately 22% of total production of wheat is lost annually due to rotting. As per FAO, approximately 40% of India's fresh fruit and vegetable produce perishes before reaching to consumers. Capacity of cold storage facilities are only about ten percent of country's total perishable produce and that is also used mainly for storage of potato. About 40% loss of the agricultural produce occurs at the post-harvest and processing stages in the developing countries.[1].

In this context, Gamma Irradiation technology can play a vital role in the area of food safety and food security. It is a promising food safety technology for elimination E. coli O157:H7, Campylobacter, and Salmonella from foods which are main disease-causing microorganisms. Irradiation also eliminates spoilage bacteria, insects and parasites, and in certain fruits and vegetables, it delays ripening and inhibits sprouting.

Extensive study has been done by various international agencies like USFDA, FAO and WHO for more than 50 years to find out the effects of irradiation on the food and also on animals and people eating irradiated food[2, 3]. The results of the studies indicate clearly that when irradiation is used on foods within approved dose limits:

- Reduction or elimination of disease-causing microorganisms takes place
- The nutritional value does not change
- Radioactivity is not induced in the food

Irradiation can prevent many food borne diseases and it is a safe and effective technology.

Radiation processing of food products for local consumption and export was approved by the Government of India in March 1996. Department of Atomic Energy has setup one gamma irradiation facility at Lasalgoan, Nashik for food products requiring low dose applications and one more facility for medium dose applications at Vashi, Navi Mumbai to showcase the efficacy and techno-commercial feasibility of such irradiators.

2. Process

Radiation processing involves exposure of food products to ionizing radiation. Gamma rays, X-rays and electrons are ionizing radiation. Sources for gamma rays are Cobalt-60 and Caesium-137 radioisotopes. Electron beams and X-rays are machine sources. Maximum energy limits for Electron beam and X-rays is 10 MeV and 7.5 MeV respectively. Due to highly penetrating nature, γ radiation can penetrate deep into the finally packed food materials causing the desired effects [4].

Irradiation disrupts the biological processes of the products which are responsible for decay. Radiation energy is delivered to constituents of food and living organisms such as water and other biomolecules. The interactions of radiation and radiolytic products of water with DNA results in impairment of reproduction of microorganism and insects. It helps in achieving the desired objectives pertaining to food safety and security. The radiation sensitivity of the microorganisms depends on their structural properties and their ability to recover from the radiation damage; therefore, it differs among the microorganisms. Radiation resistance is influenced by several other factors also which include the temperature during irradiation, the moisture content, composition of the medium, presence or absence of oxygen, the fresh or frozen state and number of organisms present. The response to the radiation in microbes is expressed in terms of D_{10} -value. It is the dose required to kill 90% of the total number of that microorganism. The process of radiation helps to improve the hygienic quality of food. The dose limits are prescribed considering the balance between what is required to achieve the intended purpose and what can be tolerated by the product without affecting the nutritional properties. Codex Alimentarius Commission Standards and the principles of the Hazard analysis and critical control point (HACCP) provide guidance for food irradiation. Additionally national regulations and standards are followed for radiation processing of food and allied products.

3. Alternate methods of food processing

Fumigation: Product is exposed to gases such as ethylene oxide to carry out fumigation. There is a possibility of chemical residues on the product in this process. Processing efficiency depends on the gas concentration and the exposure time.

Drying: This technique is being used traditionally to preserve food products. One such procedure is to expose food products to sunlight to dry them. This will evaporate the moisture content from food, thus preventing invasion of food from microorganisms. Hot air can also be used to remove moisture from food.

Freezing: This process has been regularly used domestically and commercially for preservation of a wide range of foods. Texture of food might be adversely affected due to rapid freezing.

Heating: Heating of food items by applying sufficient heat can destroy majority of microorganisms and spores. Boiling of milk is one such example.

Vacuum packing: In the absence of oxygen, bacteria cannot survive. In this process, vacuum is created in the packing to remove the oxygen and packings are made air tight. This is usually employed for dry fruits.

Salting & Pickling: In this process, the food is preserved in an edible and antimicrobial liquid. Fermentation and thermal pickling are two types of preservation methods. In fermentation process, organic agents are produced by the bacteria present in the liquid, which would act as preservation agents. In thermal pickling, edible liquid destroys microorganisms and bacteria and acts as preservative.

Cooling: It is a technique of preserving food by slowing down the growth of microorganisms and action of an enzyme that is responsible for the rotting of food. Some of the food products such as meat, dairy products, and fish could be stored in a refrigerator thus increasing the shelf-life of the products.

Canning and bottling: It means sealing cooked food in sterile bottles and cans. The container is boiled and this kills or weakens bacteria. Foods are cooked for various lengths of time. Once the can or bottle is opened the food is again at risk of spoilage.

Modified atmosphere: Some food items are preserved by changing atmosphere during packing and storage. Such crops which are difficult to preserve like salad, are packed in sealed bags with a modified atmosphere to reduce the concentration of oxygen and increase the concentration of carbon dioxide.

Advantages of radiation processing

- It is a physical non-additive one time process.
- Being a cold process, irradiation can be used for inactivation of microorganisms in foods products without causing any changes in quality unlike heat.
- Control is very easy because only one parameter i.e. time of exposure is to be controlled. Irradiation does not leave any harmful toxic residues in food as in the case of chemical fumigants and is more effective.
- It is a reliable process and very useful for processing bulk pre-packed commodities.
- It is a non-polluting and an eco-friendly process.

The purpose of radiation processing (Fig.1)

- Shelf life extension by inactivating/reducing spoilage microbes.
- Elimination of pathogens and parasites.
- Disinfestation of dried stored products from insects.
- Inhibition of sprouting in vegetables such as onion, garlic, ginger and potato etc.
- Delay in ripening and senescence of fruits.
- Phytosanitation to overcome quarantine barriers in fruits and vegetables.

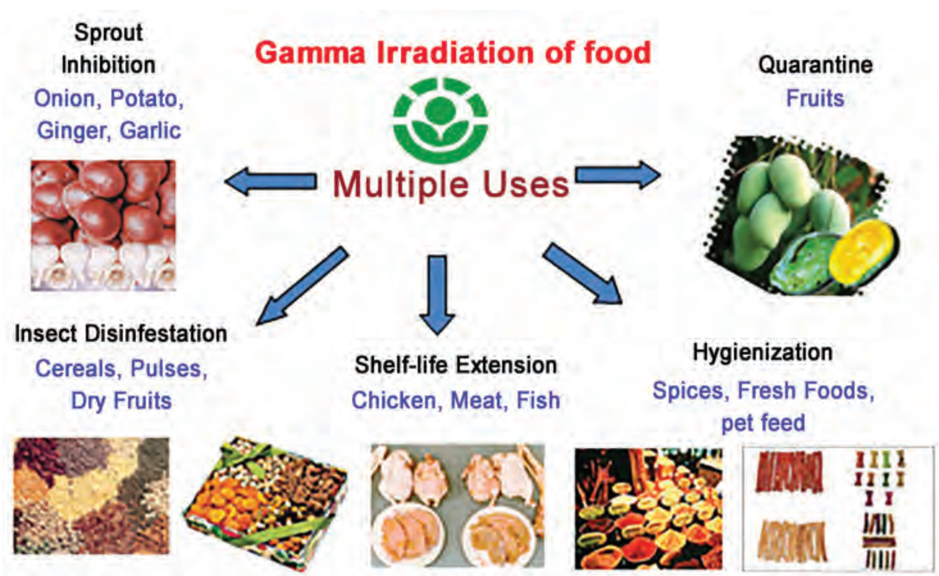


Figure 1: Uses of radiation processing

i) Low dose applications (< 1kGy)

Purpose	Dose(kGy)
Sprout inhibition of tubers, bulbs,	0.02 – 0.2
Delay in ripening of fruits	0.2 – 1.0
Insect disinfestation of cereals, legumes and their products	0.25 – 1.0

(A) (B)

Sprout inhibition in bulbs and tubers. In Fig.2(A) Non-irradiated control (spoiled within 2 months); and Fig.2(B) Irradiated [Minimum absorbed dose ≤0. 2 kGy, 6 months stored at 15±1°C)].

Figure 2: Irradiated & non-irradiated onion and potato

ii) Medium dose applications (1 - 10kGy)

Purpose	Dose(kGy)
Shelf life improvement of meat, fish, fruits and vegetables	1.0 – 3.0
Elimination of pathogens in various foods	1.0 – 7.0
Hygienization of spices (Fig. 3)	6.0 - 14

Figure 3: Various spices that can be radiation processed

Irradiated spices (6 -14 kGy) retain its quality even up to 2 years if the packing is kept intact and unopened.

iii) High dose applications (>10kGy)

Sterilization of packaged food and hospital diets 5.0 – 25.0 kGy

4. Effect of radiation processing on food quality:

- Irradiation does not produce any chemical changes in food. Irradiation does not affect the physical properties of food also.
- No new chemical products have been revealed in the radiation-processed foods despite using highly sensitive scientific tests/techniques for the past 50 years.
- Some radiolytic products and free radicals are produced in the food during irradiation but these are produced during cooking and canning process also.
- International organizations such as IAEA, FAO, WHO and the Codex Alimentarius Commission have already endorsed the safety and wholesomeness of the technology in the early nineties.
- This technology has also been endorsed by FSSAI. The irradiated food product remains radioactivity-free because it never comes in direct contact with the radioactive material.

Limitations to radiation Processing:

- Radiation processing cannot make a bad or spoiled food look good.
- Radiation processing can not be applied to all type of food products and it is a need based technology.
- The pesticides and toxins which are already present in food products, can not be destroyed.
- Amenability of a particular food commodity to radiation processing has to be tested in a laboratory.
- Only those foods which are duly permitted under the Atomic Energy (Radiation Processing of Food and Allied Products) Rules, 2012 can be processed by radiation. The specific benefits are achieved by applying appropriate doses.

5. Regulations

Gamma irradiation of food products is well regulated in India. Radiation Processing Plants are licensed by Atomic Energy Regulatory Board, Department of Atomic Energy, FDA and Food Safety and Standards Authority of India. As per the Atomic Energy (Radiation Processing of Food and Allied Products) Rules, 2012, the list of food products approved for irradiation and dose limits are given in the following Table [5].

Schedule – I [see clause (b) of rule 6]

Classes of Food Products and Dose Limits for Radiation Processing

Class	Food	Purpose	Dose limit (KGy) Min.	Max.
Class 1	Bulbs, stem and root tubers and rhizomes	Inhibit sprouting	0.02	0.2
Class 2	Fresh fruits and vegetables (other than Class 1)	Delay ripening	0.2	1.0
		Insect disinfestation	0.2	1.0
		Shelf-life extension	1.0	2.5
		Quarantine application	0.1	1.0
Class 3	Cereals and their milled products, pulses and their milled products, nuts, oil seeds, dried fruits and their products	Insect disinfestation	0.25	1.0
		Reduction of microbial load	1.5	5.0
Class 4	Fish, aquaculture, seafood and their products (fresh or frozen) and crustaceans	Elimination of pathogenic microorganisms	1.0	7.0
		Shelf-life extension	1.0	3.0
		Control of human parasites	0.3	2.0
Class 5	Meat and meat products including poultry (fresh and frozen) and eggs	Elimination of pathogenic microorganisms	1.0	7.0
		Shelf-life extension	1.0	3.0
		Control of human parasites	0.3	2.0
Class 6	Dry vegetables, seasonings, spices, condiments, dry herbs and their products, tea, coffee, cocoa and plant products	Microbial decontamination	6.0	14.0
		Insect disinfestation	0.3	1.0
Class 7	Dried foods of animal origin and their products	Insect disinfestation	0.3	1.0
		Control of moulds	1.0	3.0
		Elimination of pathogenic microorganisms	2.0	7.0
Class 8	Ethnic foods, military rations, space foods, ready-to-eat, ready-to-cook/minimally processed foods	Quarantine application	0.25	1
		Reduction of microorganisms	2	10
		Sterilization	5	25

The list of approved allied products for irradiation and dose limits are given in the following table.

Schedule – II [see clause (b) of rule 6]

Dose Limits for Radiation Processing of Allied Products

Sr. No.	Allied product	Purpose	Dose limits (KGy) Min	Max
1	Animal food and feed	Insect disinfestation	0.25	1.0
		Microbial decontamination	5.0	10.0
2	Ayurvedic herbs and their products, and medicines	Insect disinfestation	0.25	1.0
		Microbial decontamination	5.0	10.0
		Sterilization	10	25

3	Packaging materials for food/allied products	Microbial decontamination	5.0	10.0
		Sterilization	10	25
4	Food additives	Insect disinfestation	0.25	1.0
		Microbial decontamination	5.0	10.0
		Sterilization	10	25
5	Health foods, Dietary supplements and nutraceuticals	Insect disinfestation	0.25	1.0
		Microbial decontamination	5.0	10.0
		Sterilization	10	25
6	Body-care and cleansing products	Microbial decontamination	5.0	10.0
		Sterilization	10	25
7	Cut flowers	Quarantine application	0.25	1.0
		Shelf-life extension	0.25	1.0

Radiation processed products should be labelled with the following information and Radura symbol for identifying irradiated food items.

PROCESSED BY RADIATION

NAME OF THE PRODUCT :

PURPOSE OF RADIATION PROCESSING :

OPERATING LICENCE NO. :

BATCH IDENTIFICATION NO. :
(BIN) (as provided by facility)

DATE OF PROCESSING :

6. Types of Gamma radiation processing facility

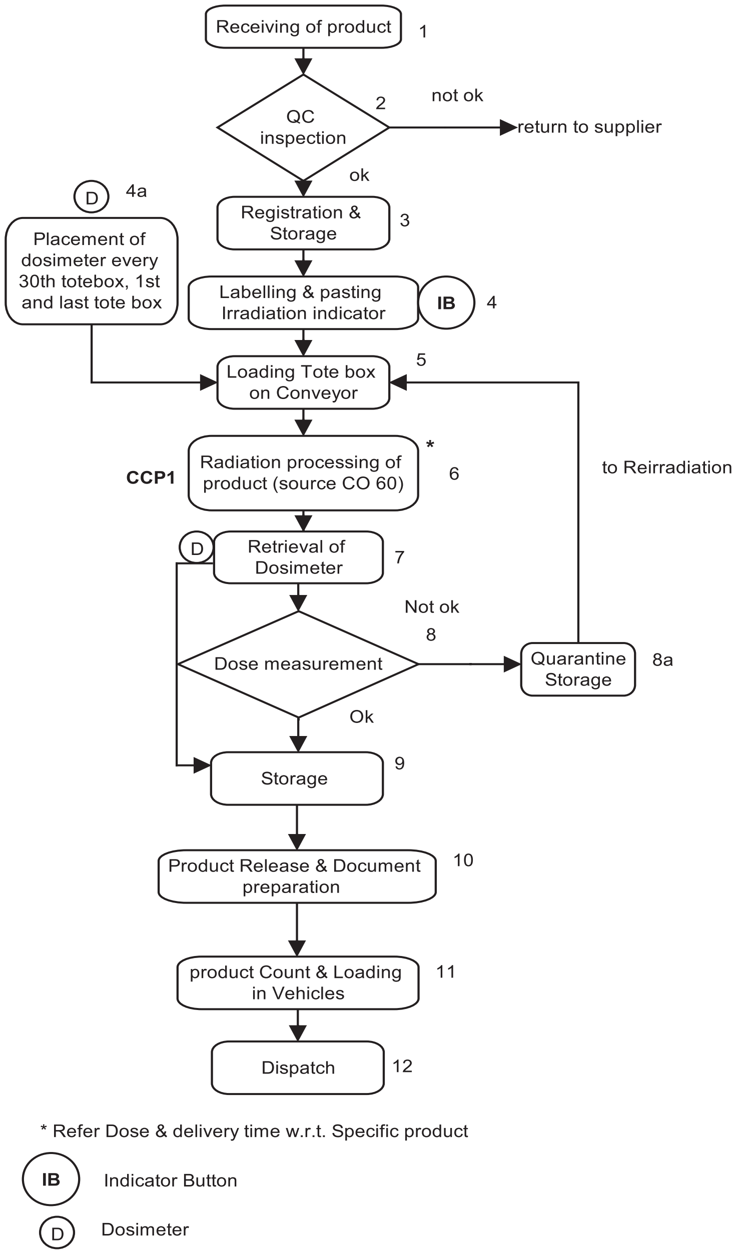
Gamma irradiators are categorized into 4 types depending on the source storage and product conveyor arrangement [6].

(i) **Category-I:** This is self-contained dry storage type irradiator. The sealed source always remains contained in a dry container constructed of solid materials like lead.

(ii) **Category-II:** This is panoramic dry storage type irradiator. Human access to irradiation cell is restricted in this design during operation and the sealed source remains in dry container when not in use.

(iii) **Category-III:** This is self-contained wet storage type irradiator. Sealed source is contained in a storage pool containing DM water. Human access physically restricted to the source.

(iv) **Category-IV:** This is panoramic wet storage type irradiator that allows controlled human access into the cell area. Sealed source remains in storage pool when not in operation.



A typical process flow at Radiation Processing Plant of BRIT, Vashi, Navi Mumbai.

A gamma radiation processing plant essentially consist of i) Source housing with in-built safety systems, ii) biological shield, iii) conveyor system that can take the product in and out of the irradiation cell, iii) physically separated areas for storing unprocessed and radiation processed products and laboratory facilities for dose measurement and to check other quality control parameters. Biological shielding of irradiation chamber is generally constructed of 1.5 to 2 meter thick high density concrete walls. Most widely used gamma radiation source is

Cobalt-60 (γ energy 1.17 MeV and 1.33 MeV) but Caesium-137 (γ energy 0.66 MeV) can also be used for radiation processing. Generally, radiation source is stored under water pool of 6 m depth if plant is shut down. The water shield prevents radiation from escaping into the irradiation chamber. This will permit free access for personnel to carry out maintenance of the plant. While carrying out irradiation of product, the source frame will be raised to the irradiation position after carrying out all safety procedures and restricting human entry.

7. Status of radiation processing plants

Worldwide more than 50 countries are carrying out industrial scale irradiation of food and allied products. In many countries like USA, China, France and South Africa, irradiated food items are sold on regular basis. Apart from DAE's three Gamma Radiation Processing Plants, there are 20 gamma radiation processing plants in State Government/Private Sector in the country. There are 10 plants under construction stage and expected to become operational within next two years. As a part of Atma Nirbhar Bharat Yojna, Honourable Finance Minister has announced the participation of entrepreneurs to use radiation technology on PPP mode. Ministry of Food Processing Industries, Govt. of India provides financial assistance to eligible entrepreneurs for setting up gamma radiation processing plants under Pradhan Mantri Kisan SAMPADA Yojana (PMKSY). Department of Atomic Energy has established Technology development cum incubation centres in five different parts of the country through which tech-entrepreneurs in India shall explore the possibility of setting up of various types of irradiators to process all categories of approved list of food and allied products. This will help the radiation processing industry to grow at faster pace.

8. Gamma Irradiators of BRIT, DAE

A. Radiation Processing Plant, Vashi: Radiation Processing Plant, Vashi (RPP) is the first commercial scale gamma irradiator for food processing in India. The facility was commissioned on 1st January 2000. The mandate of the facility was to showcase the commercial viability of Gamma Irradiators for food processing. The facility is providing radiation processing services to approximately 425 customers from all over the country for irradiation of spices, Ayurvedic raw materials, pet feed, animal feed and packaging material etc.

The facility has obtained certification of ISO 9001:2015, ISO 22000:2018 and ISO 13485:2016. It is also in the list of approved plants by European Union.

Figure 4A: Radiation Processing Plant, Vashi

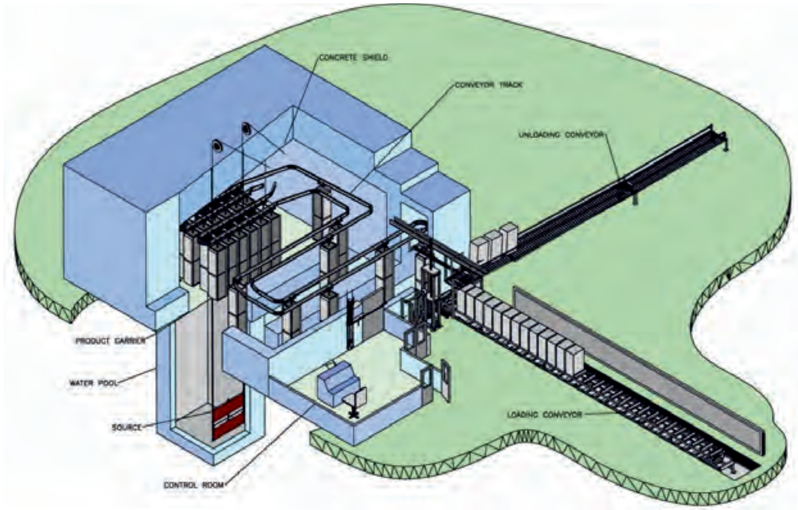


Figure 4B: 3D view of Radiation Processing Plant, Vashi

The plant is a Category IV, continuous type panoramic Gamma Irradiator. In this category, source is stored in a water pool when not in operation and source handling operations are carried out under water with special tools to prevent any radiation exposure to working personnel.

The product in carriers or tote boxes are mechanically transported inside the irradiation cell through conveyors and moved around the source rack. Movement of the product carrier is maintained in such a way that both the sides of the product box face the source frame equally to ensure better dose uniformity. The dose uniformity depends on density and thickness of product, energy of radiation and type. According to the requirement of dose, conveyor speed or dwell time will be adjusted. Irradiators are designed to impart absorbed dose within the prescribed minimum (Dmin) and maximum (Dmax) dose limits in accordance with the government regulatory requirements. The ratio Dmax/Dmin is known as dose uniformity ratio, it should be as possible as close to 1.

The plant is irradiating approximately 5000 Tons of food and Allied products annually and proved commercial viability of the technology. Based on the commercial success of this plant, many entrepreneurs have come forward to set up Gamma Irradiation Plants in various parts of the country.

B. KRUSHAK Irradiator, Lasalgaon: The plant is also a Category IV, continuous type panoramic Gamma Irradiator. KRUSHAK irradiator was commissioned in 2003 and is operational since then. Initially this facility was meant for gamma irradiation of low dose products such as onion, potato, garlic, ginger etc. for the purpose of sprout inhibition. In April 2007, USDA approved the facility for radiation processing of mangoes for quarantine purpose and export to USA. Since then this facility is also being used for irradiation of mangoes for export to US and approx. 600 tons of mangoes are irradiated annually and exported to USA. In 2010, modification of KRUSHAK irradiator for multitasking was completed to deliver the dose to various products in the range of 40 to 4000 Gy. The facility is now being used to process all the food products approved under PFA Act which includes sprout inhibition (onion, potato, garlic, ginger etc), disinfestations of cereals and pulses and microbial decontamination of spices and allied products. The facility has obtained certification of ISO 9001:2015, ISO 22000:2018.

Presently around 3000 tons of various products such as spices, herbal raw material, food supplements, onions, garlic and mangoes are irradiated annually.

Figure 5: KRUSHAK Irradiator, Lasalgoan

Figure 6: Product conveyor system in KRUSHAK Irradiator, Lasalgaon

Based on the success of mango irradiation at KRUSHAK, two more gamma irradiation plants have obtained USDA approval for mango irradiation in the country.

C. ISOMED, BARC South Gate, Mumbai: ISOMED is a Gamma Radiation Processing Facility for Terminal Sterilisation of Healthcare products. It is located on Chembur, Mahul Road, next to Tata Thermal Power Station, near the South Gate of BARC. The plant is a Category II, continuous type panoramic Gamma Irradiator. In this category, source is stored in a dry shielded pit when not in operation. It was set up under UNDP project by the Department of Atomic Energy in the year 1974. Over 46 years of impeccable functioning of IOSMED facility, in the radiation sterilisation domain, has propelled several entrepreneurs to set up radiation processing facilities across the nation. ISOMED facility possesses Quality Management System certifications viz. ISO 9001, ISO 22000, ISO 18001, ISO 14001, ISO 13485, ISO 11137 Part I together with WHO GMP certification. ISOMED has recently introduced offering a 4 days custom built professional training course on ISO 11137 for the radiation processing industry. Presently this facility is under renovation and scheduled to be operational in near future.

9. Conclusion

The technology and commercial viability of radiation processing is now well established and it is contributing to the growth of food processing industries. Considering the volume of products produced, consumed and exported, there is much hope for gamma radiation processing technology in the coming years. Many private entrepreneurs who have set up their gamma irradiation facilities 8 to 10 years ago, have started setting up their second facilities. This indicates the success of this technology and it is expected that the number of such facilities will increase rather rapidly in future.

Department of Atomic Energy is regularly carrying out seminars, conferences to disseminate knowledge of this technology to the entrepreneurs, exporters and customers but there is a need that other ministries/department such as Ministry of Food Processing Industries, Food Corporation of India and APEDA etc. come together and take active interest for preservation of stored grains, cereals, pulses, fruits and vegetables by applying gamma irradiation technology. This will immensely help in improving food safety and food security in the country.

References

1. S. N. Jha, R. K. Vishwakarma, Tauqueer Ahmed, Anil Rai and Anil K Dixit (ICAR-All India Coordinated Research Project, sponsored by MoFPI) Chapter I, II, VI & VII.
2. Satyendra Gautam, Jyoti Tripathi, Journal of Experimental Biology: Vol. 54, pp. 700-707, (2016).
3. Codex General Standard for Irradiated Foods (CAC 2003) Page-1
4. Technical document on radiation processing of food and medical products, BRIT, 2014. Page-27
5. Atomic Energy (Radiation Processing of Food and Allied Products) Rules, 2012, Government of India. Page 9-14
6. IAEA Specific Safety Guide (SSG-8), Page 4-8