# UNIT 8 FOOD IRRADIATION

**Structure**



## 8.0 OBJECTIVES

After studying this unit, you should be able to:

- describe different kinds of ionizing radiations;
- define mechanism of irradiation;
- explain applications of gamma irradiation;
- illustrate the effect of radiation on nutrients;
- describe the effect of radiation on micro organisms; and
- assess the beneficial aspects of food irradiation.

## 8.1 INTRODUCTION

Food irradiation is a physical process like drying, freezing, canning and pasteurization. Food can be irradiated wet, dry, thawed or frozen. It is a cold process and does not cause change in texture and freshness of food unlike heat. In fact you will not be able to differentiate between irradiated and non-irradiated food on the basis of colour, flavour, taste, aroma or appearance.

This radiation technique is very effective and due to its highly penetrating nature, it can be used on packed food commodities. It means a food commodity, which is packed, can be radiated for sterilization, disinfestation or disinfection purposes and shipped directly.

As you may be aware that many chemical fumigants / preservatives are used to preserve food commodities. Which sometimes leave toxic residues in foods that may be carcinogenic in nature. Contrary to these chemical fumigants, irradiation does not leave any toxic residue in treated foods. So, it is considered very safe. Besides, radiation-processing facilities are environment friendly and safe to workers and public around.

In spite of all its benefits, the radiation processing technique is not a magic wand. It cannot be used to make spoiled or bad food look good. It cannot eliminate already present toxins and pesticides in food. It is a need based technique and can't be applied to all foods. Amenability of a particular food commodity to irradiation needs to be scientifically established and the food commodities that are duly permitted under PFA Act should only be radiation processed.

## 8.2 IONIZING RADIATIONS

### 8.2.1 Kinds of Ionizing Radiations

Gamma rays, X-rays and electron beam are the part of invisible light waves of electromagnetic spectrum (U.V. rays are also part of this invisible range but wavelength is not as short as that of X-rays or gamma rays). These high-energy radiations can change atoms into electrically charged ions by knocking out an electron from the outer orbit and thus, are called ionizing radiations. But, at dose levels approved for food irradiation, these radiations cannot penetrate nuclei and thus, food can never become radioactive.

Other types of radiation energy with longer wavelengths are infrared and microwaves. Infrared radiation is used in conventional cooking. Microwaves, due to their relatively longer wavelength, have lower energy levels but are strong enough to move molecules and generate heat through friction.

Three types of ionizing radiations are approved to be used for food irradiation.

i) Electron beams generated from machine sources operate at a maximum energy of 10 MeV.

ii) X-rays generated from machine sources operate at a maximum energy of 5 MeV.

iii) Gamma rays are emitted from Co-60 or Ce-137 with respective energies of 1.33 and 0.67 million electron volts (MeV).

**i) Electron beams**

Electron beams are streams of very fast moving electrons produced in electron accelerators. For your better understanding, an electron beam generator is comparable to the device at the back of TV tube that propels electrons into the TV screen at the front of the tube. For irradiation using electron beams, only approved electron accelerators can be used. Electron beams have a selective application in food irradiation due to their poor penetration. They can penetrate only one and one half inches deep into the food commodity. As a result, shipping cartons (pre-packed bulk food commodities) are generally too thick to be processed with electron beams. Since electron beams are generated through machine sources, so they can be switched on or off at will and require shielding.

**ii) X-rays**

X-rays are also generated through machine sources. X-rays are photons and have much better penetration and are able to penetrate through whole cartons of food products. To produce useful quantities of X-rays, a tungsten or tantalum metal plate is attached to the end of accelerator scan horn. The electrons strike the plate and X-rays are generated which pass through the metal plate and penetrate the food product conveyed underneath. But, remember that this X-ray machine is a much powerful version to the machine used in many hospitals and dental clinics. Since X-rays are generated through machine sources, so they can be switched on or off at will and require shielding.

**iii) Gamma rays**

The third type of ionizing radiations approved for food processing are gamma rays that are produced from radioisotopes either Co-60 or Ce-137. Contrary to electron beams and X-rays, radioisotopes cannot be switched off or on at will and they keep on emitting gamma rays. Radioisotopes require shielding. Co-60 source is kept immersed under water when it is not in use and Ce-137 is shielded in lead. Due to their continuous operation, radioisotopes need to be replenished from time to time. Gamma rays are photons and have deep penetration ability.

### 8.2.2 Mechanism of Irradiation

The preservative action of ionizing radiations is due to both primary and secondary effects resulting from interaction of radiations with molecules and microorganisms present in food.

**i) Primary effect**

The incident radiation interacts with the atoms and molecules present in food and cause ejection of electrons. This leads to ionization and dissociation. The ejected electrons cause further excitation of molecules present in food. These are represented in the equation below:

$RH \text{------------------}\rightarrow RH^+ + e^-$ Ionization

$RH \text{------------------}\rightarrow R + H$ Dissociation

$RH \text{------------------}\rightarrow RH^+$ Excitation

**ii) Secondary effect (Radiolysis of water)**

Since water is present in almost all the foods, either in free or bound form, an understanding of chemical changes which water undergoes is important. Gamma rays excite and ionize water and other molecules along their track, giving rise to excitation, ionization and free radicals. These events contribute a great deal to the secondary effects of gamma radiation.

The summary of happenings can be represented by the equation

$$H_2O \text{----}\rightarrow \underset{\text{Free radicals}}{OH^+} + \underset{\text{Hydrated electron}}{e^-\ aq.} + \underset{\text{free radicals (FR)}}{H^+_{FR} + H_2} + H_2O_2 + \underset{\text{Hydronium ion}}{H_3O^+}$$

### 8.2.3 Process of Gamma Irradiation

In a typical gamma irradiation facility, irradiation is carried out inside an irradiation chamber. The later is shielded by 1.5-1.8 meter thick wall. Radiation source Co-60 is contained in slender pencil like stainless steel casings, which in turn are contained in lead shield. Food products, pre-packed or in bulk are placed in suitable containers and carried into the irradiation chamber with the help of automatic conveyor. The conveyor goes through a concrete wall labyrinth. This concrete wall serves as a shield and prevents radiation from reaching the surrounding area.

For irradiation of food products, the radiation source is raised above the water shield, after activating all safety devices. The food containers or boxes move around the source in the cell and get exposed for a specific length of time that allows them to absorb a defined radiation dose.

Gamma irradiation can be compared to switching on a light, illuminating a room and turning it off. Gamma rays pass into the food, affect the food or target organisms present in food and leave the food. Outcome of irradiation depends on type of food products, radiation dose and organisms present in food.

After radiation, proper handling and processing of food should be ensured, because irradiation cannot prevent further contamination from improper handling or processing. Irradiation cannot be used to make spoiled food good or to clean up 'dirty' food. If food already looks, tastes or smells bad, it cannot be saved by any treatment including irradiation. The bad appearance, taste or smell will remain.

Food processes such as heating, freezing, chemical treatment and irradiation are not intended to serve as substitutes to good hygienic practices. Both at national and international levels, good manufacturing practices govern the handling of specific foods and their products. They must be followed in the preparation of food, whether the food is intended for further processing by irradiation or any other means.

Irradiators are designed with several layers of overlapping protection systems / safety devices to detect any malfunctioning of the equipments and to protect working personnel from accidental exposure to the radiations. Potentially hazardous areas are regularly and meticulously monitored. A system of inter locks / checks prevents unauthorized entry into the radiation chamber when the source is out of shield.

All irradiation facilities are under strict control of regulatory agencies. In India, irradiation facilities operate under direct control of AERB (Atomic Energy Regulatory Board), Bhabha Atomic Research Centre, Mumbai. These facilities are thoroughly evaluated for their efficacy and safety before a license is issued. Further monitoring is through periodic checks and regular inspections of the facility and in case of any non-compliance, severe penalties and delicensing of facility results.

### 8.2.4 Units of Irradiation

The units used to measure the effects of radiation are gray and sievert in accordance with recommendations of International Organisation for Standardisation (ISO). Formerly, units used for measuring radiation were the rad and the rem.

The gray (Gy) is the unit used to measure absorbed dose of radiation and is equal to one joule of energy absorbed per kg of matter being irradiated. 1 Gy corresponds to 100 rad.

The unit used to measure the dose equivalent to one given exposure, taking into account the different biological effectiveness of different type of radiation, is the sievert (Sv). 1 Sv corresponds to 100 rem.

The unit used to measure the activity of a given source of radiation is Becquerel (Bq). The former unit was Curie (Ci). 1 Bq is equivalent to 2.7 x $10^{-11}$ Ci.

**Check Your Progress Exercise 1**

**Note:** a) Use the space below for your answer.
b) Compare your answers with those given at the end of the unit.

1. Mark which of the following statements are right (√ ) or wrong ( X ).

   a) 1 Sv is equal to 100 rem ( )

   b) Irradiation can be applied to all types of foods ( )

   c) Irradiation is a cold process ( )

   d) Irradiation can be used to make bad food look good ( )

   e) No radioactivity is induced in the irradiated foods ( )

2. Describe three kinds of ionizing radiations approved for food irradiation.

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3. Explain briefly the primary and secondary effects of irradiation.

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## 8.3 EFFECT OF IONIZING RADIATION ON NUTRIENTS

All processes cause changes in nutritional value of foods, even storage causes fresh foods to loose nutrients. It is well demonstrated that irradiation up to 10 kGy does not cause any significant change in the nutritional value of macronutrients, i.e., lipids, proteins and carbohydrates.

Vitamins are the most essential micronutrients present in foods. Certain vitamins like A, E, C, K and $B_1$ are radiation sensitive. They can be reduced by irradiation but they are similarly reduced when treated by other food processing methods. Irradiation may convert Vitamin C (ascorbic acid) to dehydro ascorbic acid, which is another equally usable form of Vitamin C. Fat soluble vitamins like Vitamin D are radiation resistant and survive irradiation of food products.

Minerals are virtually unchanged. Iron is oxidized but the nutrient value of oxidized iron is same as that of unoxidized iron. Other processes like freezing, thawing, storage have similar effects on iron.

So, the bottom line is that irradiation does not have any adverse impact on the nutritional content of a person's diet.

The FAO / IAEA / WHO Joint Expert Committee has concluded that any food commodity irradiated up to an overall dose of 10 kGy is safe and wholesome for human consumption.

## 8.4 RADIATION SENSITIVITY OF MICROORGANISMS

In case of living organisms, exposure to radiation causes structural and functional changes in macromolecules thereby leading to cell death / injury. DNA or RNA is the most important target for radiation inactivation of living cells. Please note that a low dose that may cause little chemical changes in food can cause sufficient changes in DNA to cause cell death. As you must be aware that DNA carries genetic information and its intactness is important for it's functioning. So, any damage to DNA will result into severe cell injury / death.

Now, radiation acts on DNA in two ways, i.e., i) direct and ii) indirect. In direct action, DNA absorbs radiation and is damaged. The damage to DNA is of various types – single strand breaks, double strand breaks (dsb), alteration of purine or pyrimidine bases or interchain bond formation. In the indirect action, other molecules like water and the free radicals thus produced react with DNA absorb radiation. This primary and secondary effect (direct & indirect effect) we have studied earlier under section 8.2.2.

Both prokaryotic as well as eukaryotic cells possess various DNA repair mechanism, such as direct rejoining of broken ends, excision repair, past replication repair, etc. The double strand breaks are important because most of the microorganisms cannot repair these damages and cells cannot replicate.

When a population of microorganisms is irradiated with a low dose, only a few of the cells are damaged or killed. With increasing dose, the number of survivors decreases exponentially. Different species and different strains of same species require different doses to reach the same degree of inactivation. In order to characterize organisms by their radiation sensitivity, the decimal reduction dose ($D_{10}$) is used. $D_{10}$ is the dose required to kill 90 per cent of a population.

**i) Bacteria**

Bacteria are prokaryotic organisms. The cytoplasm is highly hydrated (70-80% water) and is surrounded by cytoplasmic membrane and a cell wall. Chromosomal DNA is not surrounded by a nuclear membrane. Because of high water content and large amount of DNA, bacteria are very sensitive to radiation.

In general, gram –ve bacteria are more sensitive while some gram +ve cocci are extremely resistant due to their highly efficient DNA repair system. Spores are 10-20 times more resistant than vegetative cells because they have little or no free water and are surrounded by thick impermeable wall. Each bacterium is characterized by a particular $D_{10}$ value reflecting its inherent sensitivity to radiation. Certain extrinsic factors like temperature, $O_2$ content, water activity, nature of medium and presence or absence of sensitizers or protectors also determine the $D_{10}$ value of a particular microorganism.

**ii) Virus**

Viruses are simplest biological entities. They are metabolically dormant and do not contain cytoplasm or metabolic enzymes needed for growth. They are the obligate intracellular parasites. The simplest virus particle consists, basically, of a nucleic acid genome (DNA or RNA) and a protein coat. The genome size is 100 to 1000 times smaller than that of bacteria. Therefore, viruses are considerably more resistant to radiation than bacteria or fungi. Further, estimation of dose requirements, to ensure safety from viral infections solely through irradiation, ranged from 20 to 100 kGy, which makes irradiation an unlikely choice for virus treatment in foods.

**iii) Yeasts and Moulds**

Yeats and moulds are eukaryotic cells, i.e., they have a true nucleus. Generally, they are as sensitive to radiation as vegetative cells of bacteria. However, filamentous fungi contain more than one nucleus (may be 100 nucleus per cell) and are highly resistant to radiation.

**iv) Prion**

The prion particles associated with BSE (Bovine spongiform encephalopathy), commonly known as mad cow disease, do not have nuclei at all. They are not inactivated by irradiation except at extremely high doses. This means irradiation will work very well to eliminate parasites and bacteria from food but will not work to eliminate viruses and prions.

## 8.5 EFFECT OF IRRADIATION ON INSECTS (QUARANTINE TREATMENT)

Of all the contaminating organisms to which food irradiation is directed, insects are the most complex. The number of insect species probably exceeds a million and around 500 are considered pests of major importance. Pests and their life stages vary in their sensitivity to radiation. The insects that are not immediately killed by radiation are rendered sterile and unable to reproduce. So, irradiation is most accurately called a Pest Control measure. Lethality is not always quarantine application; requirement can be met by using doses that effectively stop reproduction in insects.

Irradiation has marked advantages over chemical fumigants as:

- Irradiation does not leave harmful toxic residues unlike chemical fumigants/pesticides.
- Even at very low dose levels, radiation affects pests at all life stages. Even eggs can be eliminated by radiation unlike chemical fumigants.
- To control pests in stored grains, insecticides / pesticides may need to be applied repeatedly and thus, leading to higher levels of toxic residues. On the contrary, irradiation is one-time effective process.
- As quarantine treatment, irradiation brings two kinds of useful effects:
- Prevention of transfer of insects from one locality to another, as might occur in the shipment of infested foods. Such a transfer could lead to the establishment of the insects in a new area.
- Prevention of insect damage to foods.

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**Check Your Progress Exercise 2**

**Note:** a) Use the space below for your answer.
b) Compare your answers with those given at the end of the unit.

1. Why viruses and prions are more radiation resistant than bacteria?

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2. What happens when living organisms are exposed to radiation?

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3. i) Name two vitamins which are radiation sensitive.

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ii) Name two vitamins which are radiation resistant.

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iii) What is $D_{10}$?

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4. Write True (T) or False (F) for the following statements:

   i) Gram +ve cocci are more radiation resistant in comparison to gram –ve bacteria.

   ii) Single strand breaks of DNA are more important in radiation exposure.

   iii) Protein get adversely affected when foods are irradiated at a dose of 10 kGy.

   iv) Irradiation can even eliminate eggs of pests present in food.

   v) Viruses and prions are easily killed by irradiation.

## 8.6 PRACTICAL APPLICATIONS OF FOOD IRRADIATION

The recommended doses of ionizing radiation for different purposes in food preservation are different as explained below

a) Low dose, up to 1 kGy

- Sprout inhibition in bulbs and tubers (0.03 – 0.15 kGy).
- Delay in fruit ripening (0.25 – 0.75 kGy).
- Insect dis-infestation and elimination of food-borne parasites (0.25 – 1 kGy).

b) Medium dose, 1 – 10 kGy

- Reduction of spoilage microbes to improve shelf-life of meat, poultry and sea foods under refrigeration (1.5 – 3 kGy).
- Elimination of pathogenic microbes in fresh and frozen meat, poultry & sea foods (3 – 7 kGy).
- Reduction of microbes in spices to improve hygiene (10 kGy).

c) High dose, 25 – 70 kGy

- Elimination of viruses.
- Sterilization of packaged meat, poultry and their products which are shelf stable without refrigeration (25 – 70 kGy).
- Sterilization of hospital diets for immuno compromised patients.
- Food for astronauts in space.

## 8.7 BENEFICIAL ASPECTS OF FOOD IRRADIATION

### 8.7.1 Decontamination of Spices

Spices, herbs and vegetable seasonings are valued for their distinctive flavours, colours and aromas. Unfortunately, they are often contaminated with high levels of bacteria, moulds and yeasts. If untreated, the spices will result in rapid spoilage of foods they are supposed to enhance. Since spices are often contaminated with pathogenic bacteria, they can result in serious food-borne illnesses.

Spices are generally decontaminated by irradiation or fumigation with ethylene oxide gas (ETO). To understand the advantages of irradiation over ETO, the various points are given below:

**i) Effectiveness**

Irradiation is considered the most effective way to sanitize spices and the most countries have allowed it worldwide. Irradiation at a dose between 7.5 – 15 kGy (average dose 10 kGy) has been established to effectively control the microbiological contamination. Storage further enhances the sanitation effect because injured cells are unable to repair and die out over the time.

In comparison, ETO is far less effective. Although, it is a known fact that ETO is highly toxic to microbial contaminants but, it cannot be used alone. To stabilize ETO, it is mixed with 80% $CO_2$ and steam is used to deliver the gases, which in turn, reduces its microbiological efficacy. Infact, steam increases the moisture level of treated spices and may result in increased mould growth. Moreover, ETO has low penetration than radiation and hence, bulk ground spices cannot be treated effectively using ETO.

Further, to meet the requirements of international standards, spices are generally treated twice or more with ETO and thus, can easily result into unacceptable high levels of toxic chemical residues in treated spices. On the contrary, irradiation is an effective one time process.

**ii) Toxic residues**

ETO reacts with organic spice components to leave harmful residues, like ethylene chlorohydrin and ethylene bromohydrin, in spices. Ethylene chlorohydrin is a known carcinogen that persists in the spices for many months, even after food processing. For this reason, ETO is banned in many countries. On the contrary, irradiation does not leave any harmful toxic residue and is completely safe.

**iii) Loss of sensory attributes**

The use of steam with ETO is a strong argument against its use as a spice treatment. Steam results in the loss of volatile oils and hence, loss of aroma and flavour. Treatment with ETO can also result in unacceptable colour change. It results into darkening of onion and garlic powder. Chilies, paprika and turmeric may loose their bright colour. It may cause development of off-flavours in mustard and mustard flour.

On the other hand, radiation treatment preserves all sensory attributes in spices. Chili, paprika and turmeric colours are stable to radiation treatment.

**iv) Environment safety issues**

Since ETO is a known carcinogen, worker safety issues are the biggest concern in ETO operations. Irradiation has been established as an environment friendly food processing technique.

**v) Packaging problems**

Most spice packaging materials are compatible with irradiation. Spices packed in bulk packages, retail packages, heat-sealed bags, and gas impervious packs, can be easily and effectively irradiated. Irradiation allows the spice package to remain closed and sealed at all times. On the other hand, in ETO treatment gas impervious packs cannot be used. Further, after treating with ETO, spice packages need to be stored open (for a week or so) gas escape. This causes increased warehousing cost as well as recontamination of spices. In irradiation, there is no waiting period after processing and the material can be shipped directly and thus, no additional storage costs are incurred.

So on the basis of above-mentioned facts, it is concluded that irradiation is the most effective method to sanitize spices, particularly because

- it results in cleaner, better quality spices,
- it does not significantly change the sensory or functional properties of spices,
- it results in much lower levels of microbial contamination and thus, it is an effective treatment to meet international standards of food safety.

A prototype commercial demonstration irradiator with a throughput of 20 tonnes per day for treatment of spices is operational in Vashi, Navi Mumbai. This is under the management of Board of Radiation and Isotope Technology (BRIT), a constituent unit of Deptt. of Atomic Energy (DAE), BARC, Mumbai. A commercial irradiator, Shriram Applied Radiation Centre (SARC), a constituent unit of Shriram Institute for Industrial Research, Delhi is also licensed by AERB to irradiate spices for sanitization.

### 8.7.2 Delayed Ripening in Fruits

Irradiation at low dose levels (0.25 to 0.75 kGy) can delay ripening and over-ripening in mature but unripe tropical fruits like banana, mango and papaya. Climacteric fruits exhibit delay in ripening only if irradiated in the preclimacteric stage. Once the ripening has been initiated, irradiation does not change or alter the course of ripening.

The self-life of irradiated fruits can further be extended by combing other post harvest procedures like waxing, packaging in perforated bags, refrigeration and modified atmosphere.

### 8.7.3 Sprout Inhibition in Tubers and Bulbs

Traditionally, onions are bulk stored under ambient conditions in chawls, medas or sheds, the size and design of which varies from region to region. During prolonged storage, losses occur due to sprouting, desiccation and microbial rottage. The estimated losses are 30–50 per cent. Low ambient temperature and high humidity during rainy season promote sprouting. The losses through microbial spoilage can be reduced but sprouting can’t be checked by improving ventilation. Sprouting alone causes 25–30 per cent of total losses. Sprouted onions shrivel faster due to increased water loss by transpiration. The reserve food substances present in the fleshy scales are also used up for the sprout growth, which ultimately renders the onion bulb unfit for consumption.

Some chemical sprout inhibitors such as maleic hydrazide and isopropyl carbamate are used in temperate countries but these are not very effective in sub-tropical and tropical climates. Cold storage at 0-1°C with low relative humidity (65-70%) is also practiced in many temperate countries but strict temperature and humidity control is must. Moreover, cold storage is energy intensive and expensive technique.

On the other hand, irradiation at very low dose levels (0.06-0.09kGy) inhibits sprouting when properly cured bulbs are irradiated within 2-3 weeks of harvesting.

Potatoes cannot be stored more than 4-6 weeks at ambient temperature. They are stored in cold storage at 2-4°C having relative humidity 85-95 per cent. Since the refrigeration facilities in India are not meeting the requirements of increased crop production, so it is feared that 25-30 per cent of the commodity is lost within 2-3 months of harvesting due to dehydration and microbial spoilage.

Irradiation of potatoes combined with refrigeration at 15°C can extend the storage period up to six months with minimum losses. Irradiation has extra benefit over prevailing refrigeration technique.

In general, irradiation at the dose levels required for sprout inhibition of bulbs and tubers does not change their texture, and external appearance, sensory qualities and processing potential.

The first prototype commercial demonstration irradiator for potatoes and onions (POTON) with a throughput of 10 tonnes/hour is being set up in Lasalgaon, Nashik, Maharashtra. This unit is under the management of Board of Radiation & Isotope Technology (BRIT), a constituent unit of Department of Atomic Energy (DAE), BARC, Mumbai. Besides, two pilot plant irradiation facilities, namely the Food Package Irradiator in Food Technology Division, BARC, Mumbai and another at the Defense Laboratory, Jodhpur have been licensed for irradiating food items that have been cleared for domestic trade and consumption.

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**Check Your Progress Exercise 3**

**Note:** a) Use the space below for your answer.
b) Compare your answers with those given at the end of the unit.

1. Describe two important beneficial applications of food irradiation.

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2. Write True (T) or False (F) for the following statements:

   i) To inhibit sprouting in tubers, a medium dose application is desired.

   ii) Medium dose irradiation can eliminate bacterial pathogens present in food products.

   iii) There is no commercial irradiator in India to process onions and potatoes.

3. Write two advantages of irradiation over ETO in decontamination of spices.

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## 8.8 LET US SUM UP

- Three types of ionizing radiations are approved for food irradiation.
- Any food commodity irradiated up to 10 kGy is wholesome and safe for human consumption.
- Bacteria, viruses and fungi differ in their sensitivities towards radiation.
- Foods are irradiated at different dose (low, medium and high) levels for different applications.
- Irradiation has benefits over chemical fumigants and other food preservation techniques.
- Irradiation is one time, safe, environment friendly and efficient technique.
- Irradiation can effectively address many issues like food safety, food losses and quarantine treatments. This is a very promising technique in the field of food preservation.
- All irradiated products are labelled with an international logo called 'Radura'. It is also marked with statement "Processed by ionizing radiation" and purpose of Irradiation.

## 8.9 KEY WORDS

**Irradiation** : It is the process of preserving the food by ionizing gamma-rays, X-rays and electrons. It destroys the microorganisms and inhibits the biochemical changes.

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| **Gamma-rays** | : | Radioisotopes Co-60 or Ce-137 produce gamma ($\gamma$) rays. These rays are photons and have a deep penetration ability. |
| **X-rays** | : | These rays are photons, generated by X-rays machines, operate at an energy level of 5 MeV. They have less penetrative effect them r-rays. |
| **Electron beams** | : | They are fast moving electrons, produced in electron accelerators, operate at a maximum energy level of 10 MeV. They have selective application due to their poor penetration ability. |
| **Mechanism of irradiation** | : | The ionizing radiation preserve the food material by acting in two ways. The primary effect is through ejection of electrically charged or neutral radicals which destroy microorganisms. The secondary effect is ionization of water present in food by radiation. It helps in destruction of microorganism and inhibition of biochemical changes. |

## 8.10 ANSWERS TO CHECK YOUR PROGRESS EXERCISES

### Check Your Progress Exercise 1

Your answer should include the following points:

1. a) √ b) X c) √ d) X e) √

2. The three kinds of ionizing radiations are:

   Gamma rays, X-rays, and Electron beams.

   i) *Gamma rays* – These rays are produced from radio isotopes Co.60 or Ce-137. The gamma rays are photons and have a deep penetration ability. The energies emitted by Co-60 and Ce-137 are 1.33 and 0.67 million electron volts (MeV), respectively.

   ii) *X-rays* – These rays are generated from machine source and operate at an energy level of 5 MeV. These rays are photons and can penetrate through even whole cartons of food.

   iii) *Electron beams* – These are streams of very fast moving electrons produced in electron accelerators and operate at a maximum energy level of 10 MeV. Electron beams have a selective application in food irradiation due to their poor penetration, i.e., only one to one and a half inch deep into the food.

3. The preservative effect of ionizing radiation is due to primary and secondary effects resulting from interaction of radiations with molecules and microorganisms present in food.

The primary effect is due to the ejection of electrons with atoms and molecules present in food. The ejected electrons cause excitation of molecules present in food. The secondary effect of ionization radiation is to excite and ionize water and other molecules, present in food, which in term give rise to excitation, ionization and free radicals.

**Check Your Progress Exercise 2**

Your answer should include the following points:

1. Since viruses and prions do not contain cytoplasm and metabolic enzymes needed for growth, they are more resistant to irradiation in comparison to bacteria.

2. When living organisms are exposed to radiation structural and functional changes in macromolecules take place which result in cell injury or even death.

3. i) Vitamins A and E.
   ii) Vitamins C and D.
   iii) $D_{10}$ is the irradiation dose required to kill the 90 per cent population of microorganisms present in food.

4. i) T ii) F iii) F iv) T v) F

**Check Your Progress Exercise 3**

Your answer should include the following points:

1. The two important beneficial applications of irradiation are:

   i) it delays ripening in fruits
   ii) it inhibits sprouting in tubers and bulbs

2. i) F ii) T iii) F

3. The advantages of irradiation are:
   i) It is more effective.
   ii) It does not leave any toxic residues.
   iii) Sensory quality is not affected.
   iv) It is more safe as compared to ETO.
   v) Irradiated food is easy to pack.

## 8.11 SOME USEFUL BOOKS

1. Food and Drug Administration (HHS) (1997) Irradiation in the Production, Processing and Handling of Food. Final Rule Federal Register, 62, p.64107, & Federal Register 55, p. 18538.

2. Joint FAO/IAEA/WHO study group in High Dose Irradiation (1999) High Dose Irradiation: Wholesomeness of food irradiated with doses above 10 kGy. WHO technical report series 890. World Health Organization, Geneva.

3. Marsden, J.L. (1994) Issue: Irradiation and food safety. American Meat Institute Issues Briefings.