Post Harvest Operations and Processing of Fruits, Vegetables, Spices and Plantation Crop Products

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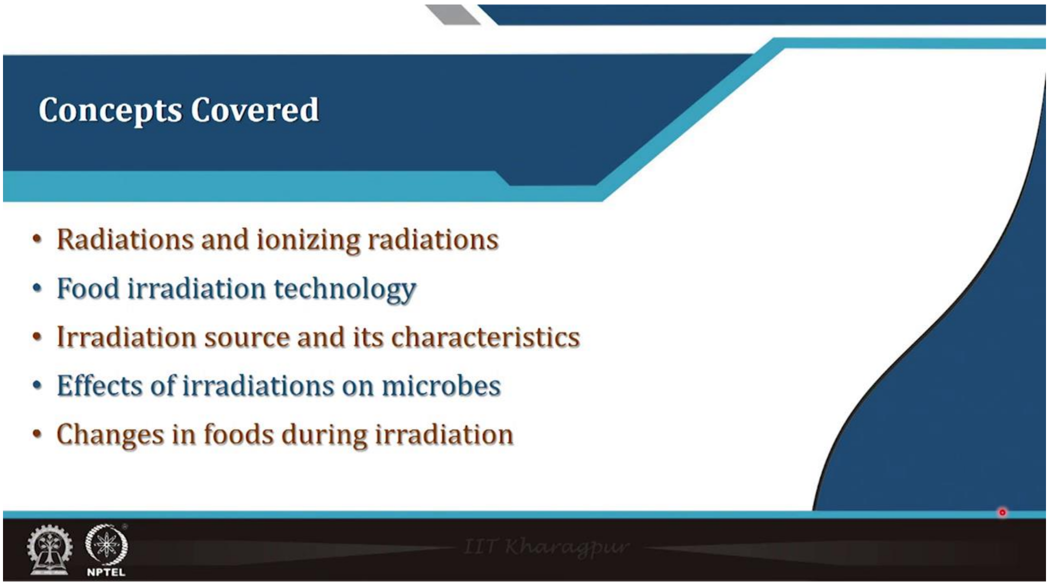
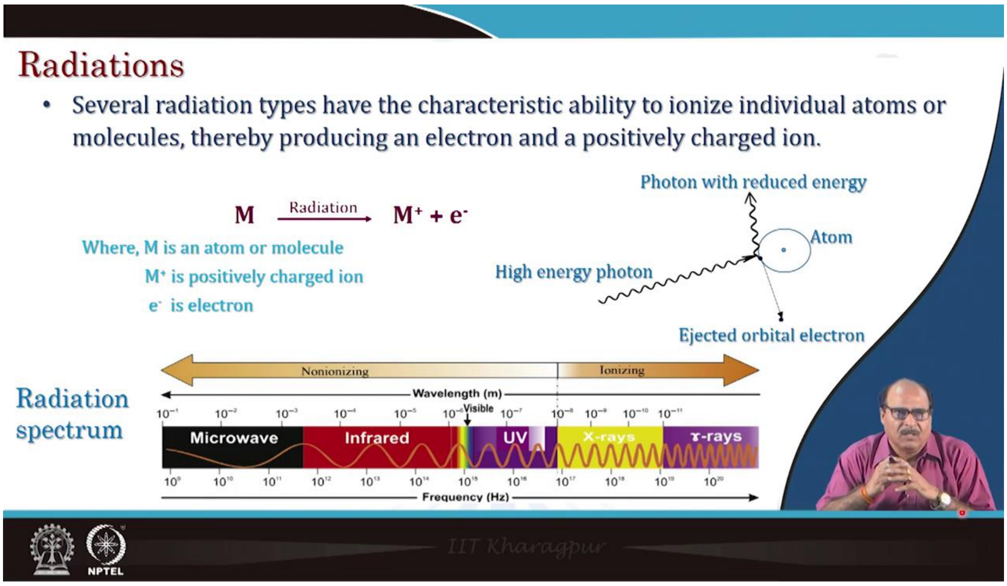
Lecture 15
Irradiation of Fruits, Vegetables and Spices



This lecture covers radiations and ionizing radiations, food irradiation technology, different irradiation sources and its characteristics, effects of irradiation and microbes, and changes in foods particularly in fruits, vegetables and spices during the irradiation process.



Radiations

Several radiation types have the characteristic ability to ionize individual atoms or molecules, thereby producing an electron and a positively charged ion. When the high energy photon bombards an atom, then it transfers its energy on the electron. The photon with reduced energy goes out and when energy in the outer orbital electron is increased above a certain level, it comes in the excitatory state and finally it ejects the orbital electron, so a positively charged atom and negatively charged electron is formed.

$$M \longrightarrow M^{+} + e^{-}$$

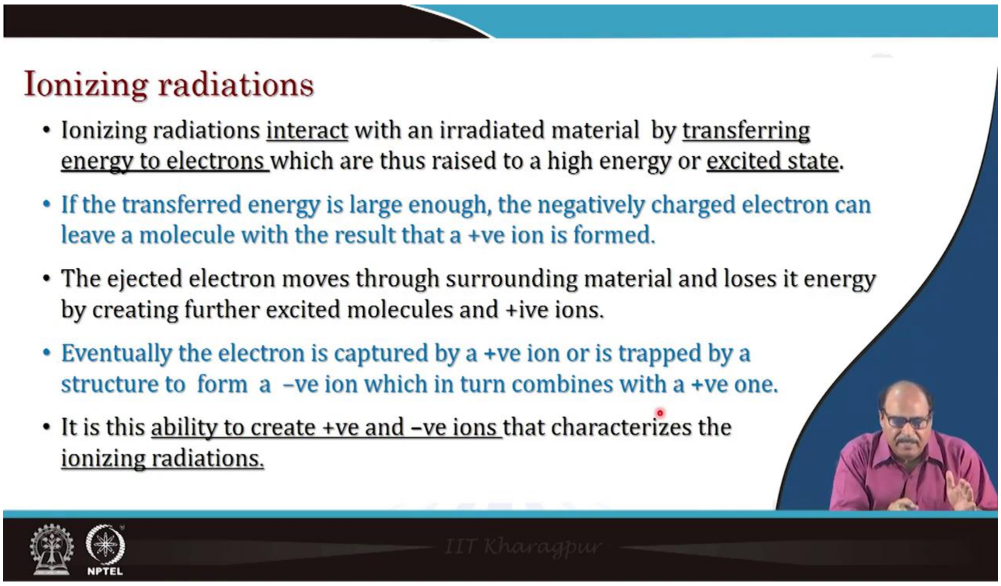
Where, M is an atom or molecule

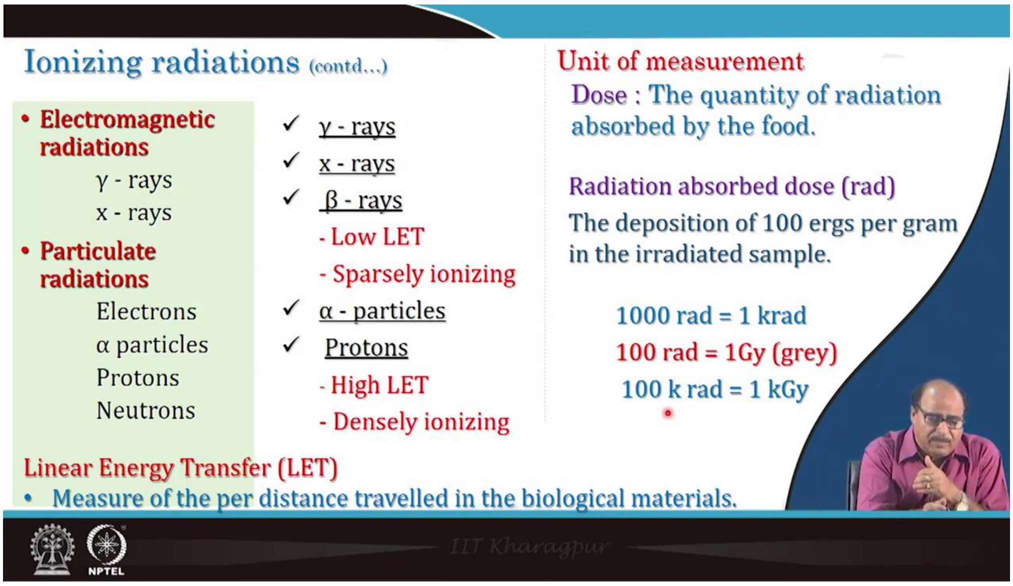
M^+ is positively charged ion

e^- is electron

Ionizing radiations

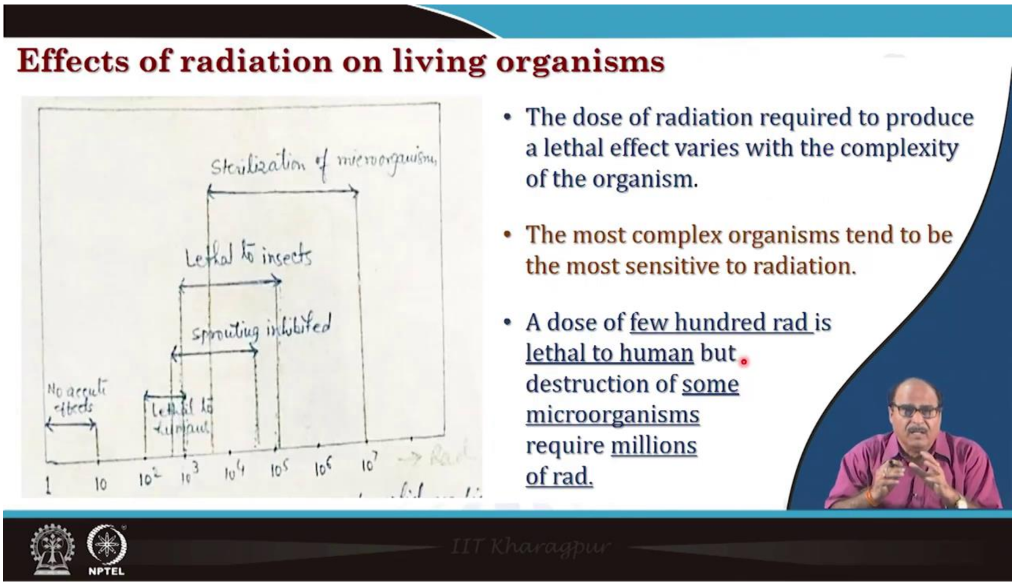
Ionizing radiations interact with an irradiated material by transferring energy to electrons which are thus raised to a high energy or excited state. If the transferred energy is large enough, the negatively charged electron can leave a molecule with the result that a +ve ion is formed. The ejected electron moves through surrounding material and loses it energy by creating further excited molecules and +ive ions. Eventually the electron is captured by a +ve ion or is trapped by a structure to form a –ve ion which in turn combines with a +ve one. It is this ability to create +ve and –ve ions that characterizes the ionizing radiations.





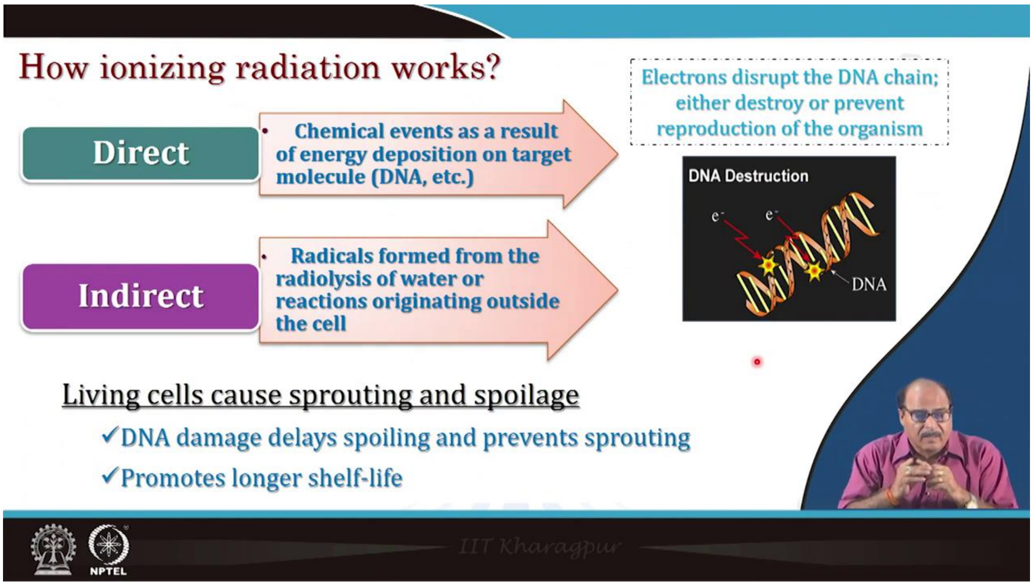
The electromagnetic radiations such as gamma rays, x rays and β-rays have low linear energy transfer (LET) are sparsely ionizing. The linear energy transfer (LET) is a measure of the energy dissipated per distance travel in the biological material, so this because of their high penetration power they can travel deep into the material so that the energy is dissipated over is a long path. So accordingly the per distance travel energy is dissipated is less and therefore they are less ironizing, whereas alpha particle and protons they have high LET value and therefore they are densely ionizing.

The dose of radiation is the quantity of radiation adsorbed by the food (in terms of rad). Rad is the deposition of 100 ergs per gram in the irradiated sample. So 1000 rad is equal to 1 k rad, but recently another unit grey has been used in the food irradiation technology, so 100 rad is equal to 1 grey (Gy). Accordingly 100 kilo rad will become 1 kilo grey.

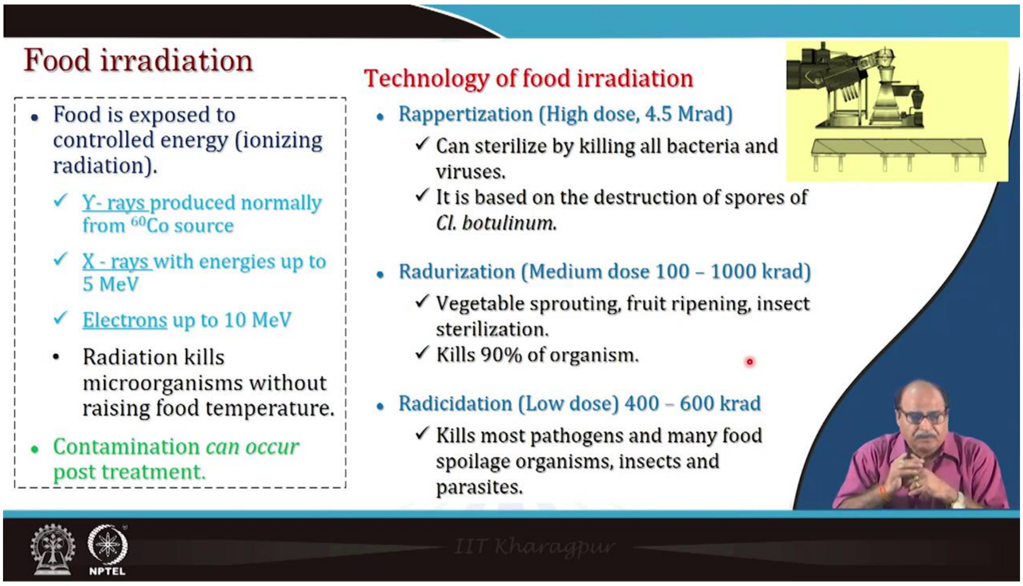


Effects of radiation on living organisms

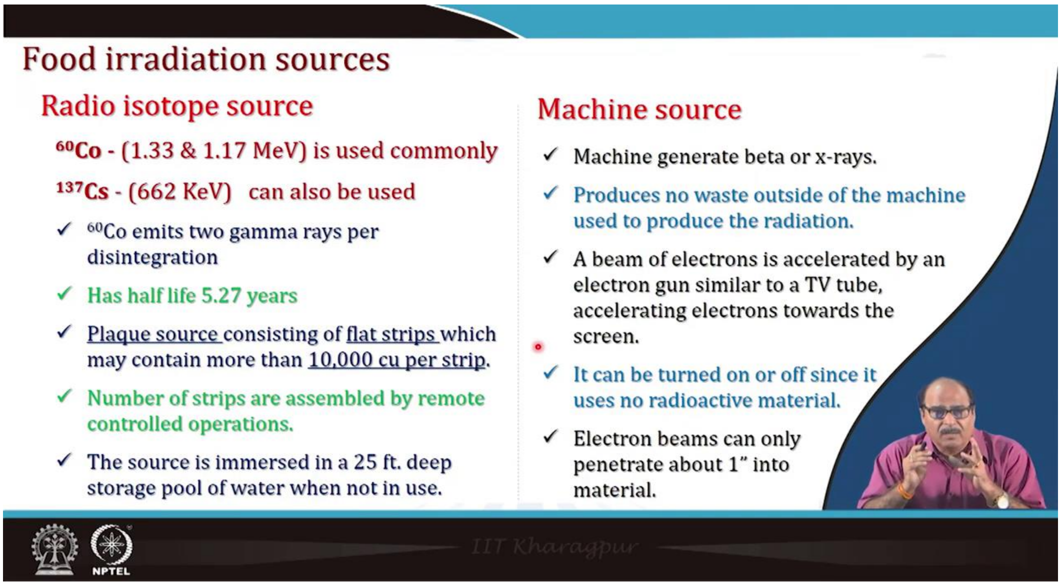
The dose of radiation required to produce a lethal effect varies with the complexity of the organism. The most complex organisms tend to be the most sensitive to radiation. A dose of few hundred rad is lethal to human but destruction of some microorganisms require millions of rad.



The ionizing radiation against microorganisms works on the two principles. In the direct action mechanism there is a chemical event as a result of the energy deposition on the target molecule (DNA etc.). It is considered that the ionizing radiation directly hits the genetic material of the organism in the genetic component like DNA, RNA etc and it produces the change. Whereas, in the indirect reaction, the radicals formed from the radiolysis of water or other reactions originating outside the cell. Living cells causes sprouting and spoilage. The DNA damage delays spoiling and prevents sprouting, it promotes longer self life, etc.



In food irradiation, food is exposed to controlled energy (ionizing radiation). Ɣ-rays produced normally from ^{60}Co source, x-rays with energies up to 5 MeV or electrons up to 10 MeV, they are used in the food processing operations for various purposes such as killing the microorganisms without reaching the temperature of the food. Contamination can occur post treatment. Rappertization is a higher dose application of 4.5 Mrad and used for sterilization by killing all bacteria and viruses. It is based on the destruction of spores of *Cl. botulinum*. Radurization is a medium dose application in the range of 100-1000 krad, where vegetable sprouting, fruit ripening, insect sterilization, etc is taken care of by radurization. Radicidation is a further low dose may be 400 to 600 krad which kills most of the pathogens and many food spoil microorganism insects and parasites etc.



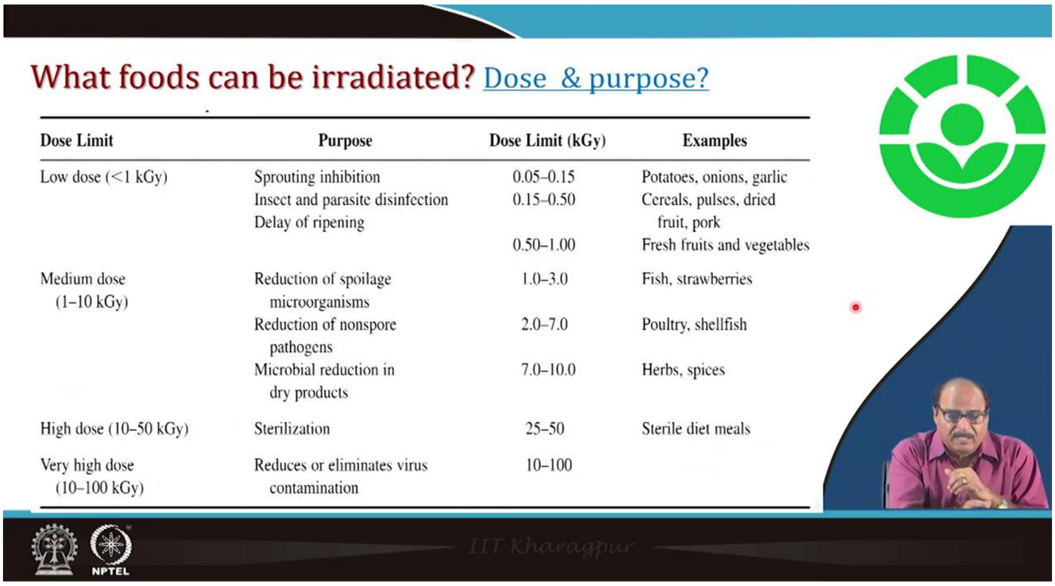
Food irradiation sources

Radio isotope source

^{60}Co having energy values of 1.33 and 1.17 MeV, and ^{137}Cs having energy value of 662 KeV are commonly used. ^{60}Co emits two gamma rays per disintegration and has half life 5.27 years. Plaque source consisting of flat strips which may contain more than 10,000 cu per strip. Number of strips are assembled by remote controlled operations. The source is immersed in a 25 ft. deep storage pool of water when not in use.

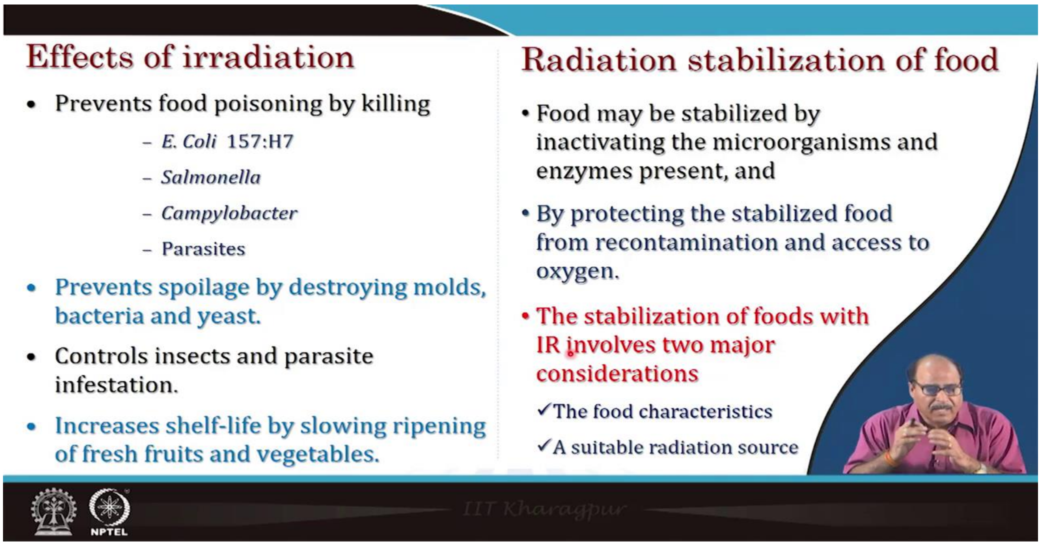
Machine source

Machine generate beta or x-rays. It produces no waste outside of the machine used to produce the radiation. A beam of electrons is accelerated by an electron gun similar to a TV tube, accelerating electrons towards the screen. It can be turned on or off since it uses no radioactive material. Electron beams can only penetrate about 1” into material.



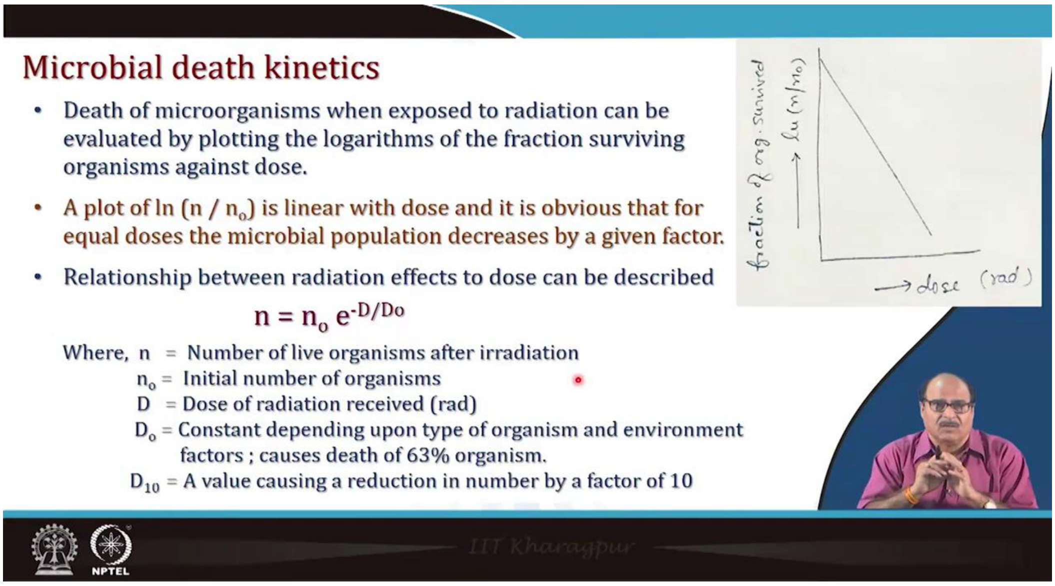
Dose Limit	Purpose	Dose Limit (kGy)	Examples
Low dose (<1 kGy)	Sprouting inhibition	0.05–0.15	Potatoes, onions, garlic
	Insect and parasite disinfection	0.15–0.50	Cereals, pulses, dried fruit, pork
	Delay of ripening	0.50–1.00	Fresh fruits and vegetables
Medium dose (1–10 kGy)	Reduction of spoilage microorganisms	1.0–3.0	Fish, strawberries
	Reduction of nonspore pathogens	2.0–7.0	Poultry, shellfish
	Microbial reduction in dry products	7.0–10.0	Herbs, spices
High dose (10–50 kGy)	Sterilization	25–50	Sterile diet meals
Very high dose (10–100 kGy)	Reduces or eliminates virus contamination	10–100	

The low dose (< 1 kGy) is used for sprouting inhibition of potato, onions, garlics, and to delay in the ripening of the fresh fruits and vegetables. The medium dose (1-10 kGy) is used for reduction of spoilage microorganisms, reduction of non spore pathogens, and microbial reduction in dry products. The high dose (10-50 kGy) is used for sterilization of the diet meals. The very high dose (10-100 kGy) is used for elimination or reduction of virus contamination.



Effects of irradiation

Irradiation prevents food poisoning by killing *E. coli* 157:H7, *Salmonella*, *Campylobacter* and other parasites, prevents spoilage by destroying molds, bacteria and yeast, controls insects and parasite infestation, increases shelf-life by slowing ripening of fresh fruits and vegetables. Food may be stabilized by inactivating the microorganisms and enzymes present, and by protecting the stabilized food from recontamination and access to oxygen. The stabilization of foods with IR involves two major considerations including the food charactertistics, and a sutable radiation source.



Microbial death kinetics

Death of microorganisms when exposed to radiation can be evaluated by plotting the logarithms of the fraction surviving organisms against dose. A plot of ln (n/n_o) is linear with dose and it is obvious that for equal doses the microbial population decreases by a given factor. Relationship between radiation effects to dose can be described as:

$$n = n_o e^{-D/D_o}$$

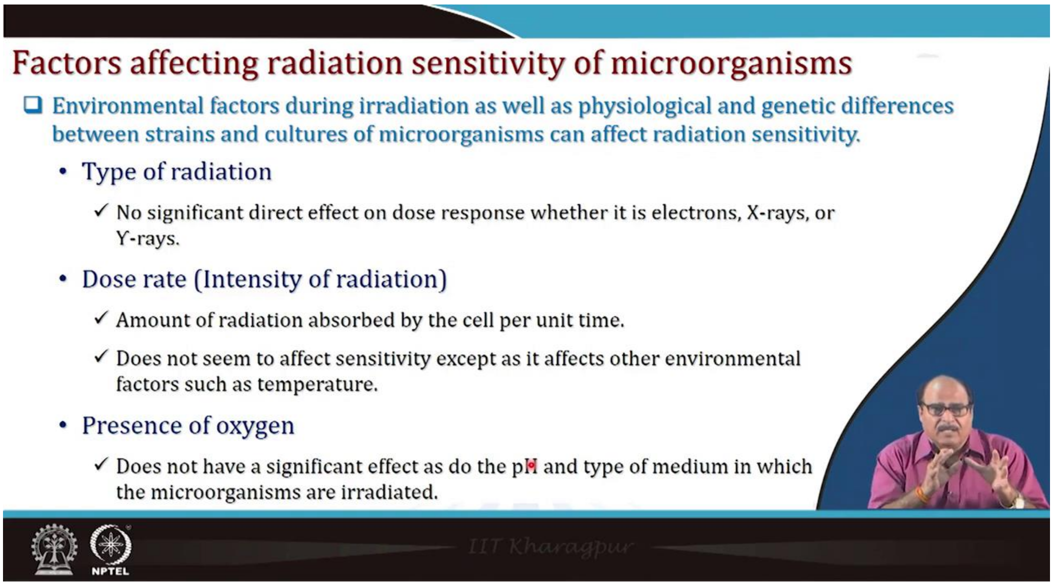
Where, n = Number of live organisms after irradiation,

n_o = Initial number of organisms,

D = Dose of radiation received (rad),

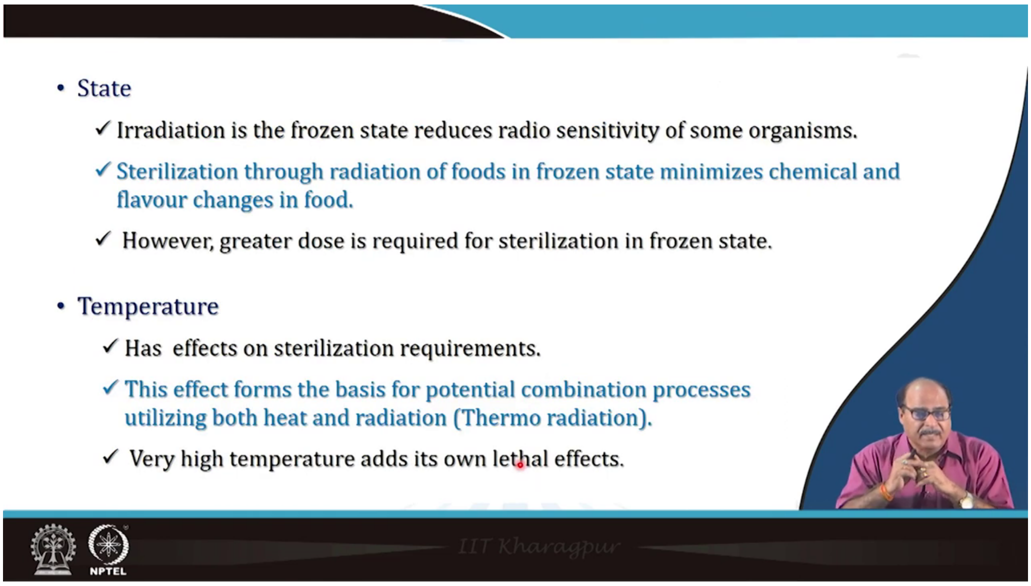
D_o = Constant depending upon type of organism and environment factors; causes death of 63% organism,

D_{10} = A value causing a reduction in number by a factor of 10.

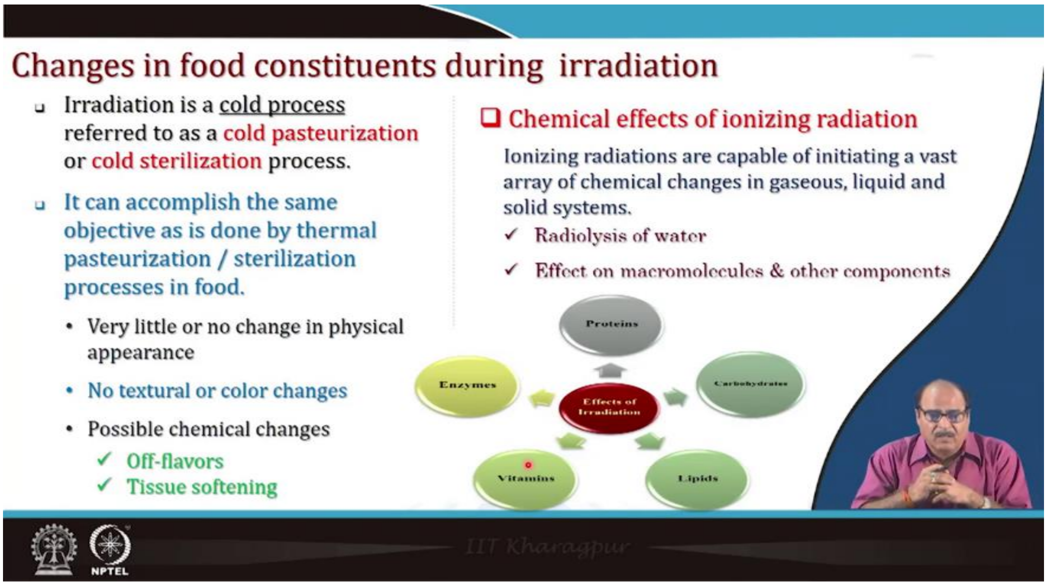


Factors affecting radiation sensitivity of microorganisms

Environmental factors during irradiation as well as physiological and genetic differences between strains and cultures of microorganisms can affect radiation sensitivity. Types of radiation has no significant direct effect on dose response whether it is electrons, X-rays, or Y-rays. Dose rate (Intensity of radiation) does not seem to affect sensitivity except as it affects other environmental factors such as temperature. Presence of oxygen does not have a significant effect as do the pH and type of medium in which the microorganisms are irradiated.

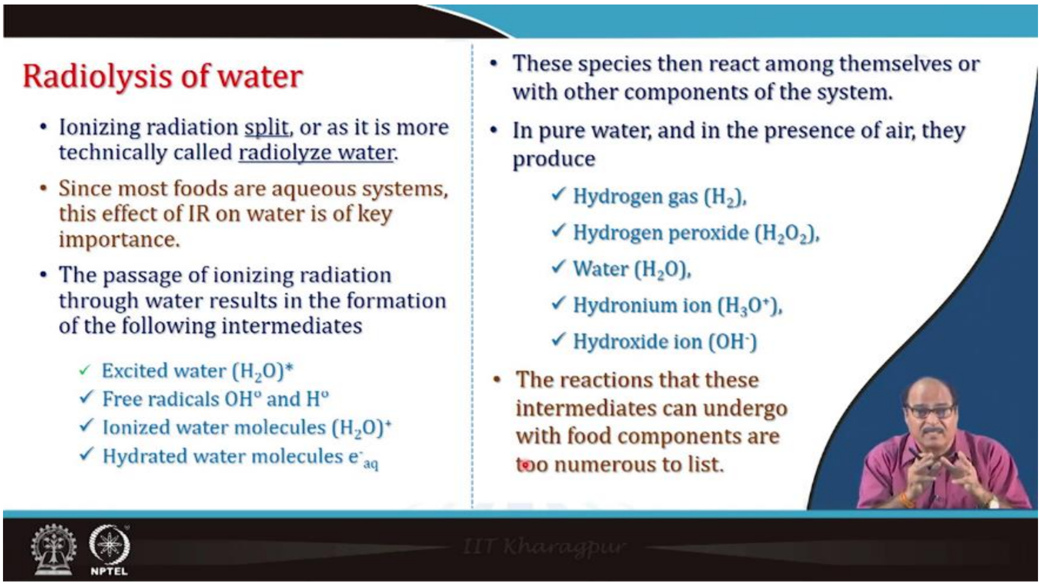


Irradiation in the frozen state reduces radio sensitivity of some organisms. Sterilization through radiation of foods in frozen state minimizes chemical and flavour changes in food. However, greater dose is required for sterilization in frozen state. Temperature has significant effects on sterilization requirements. This effect forms the basis for potential combination processes utilizing both heat and radiation (Thermo radiation). Very high temperature adds its own lethal effects.



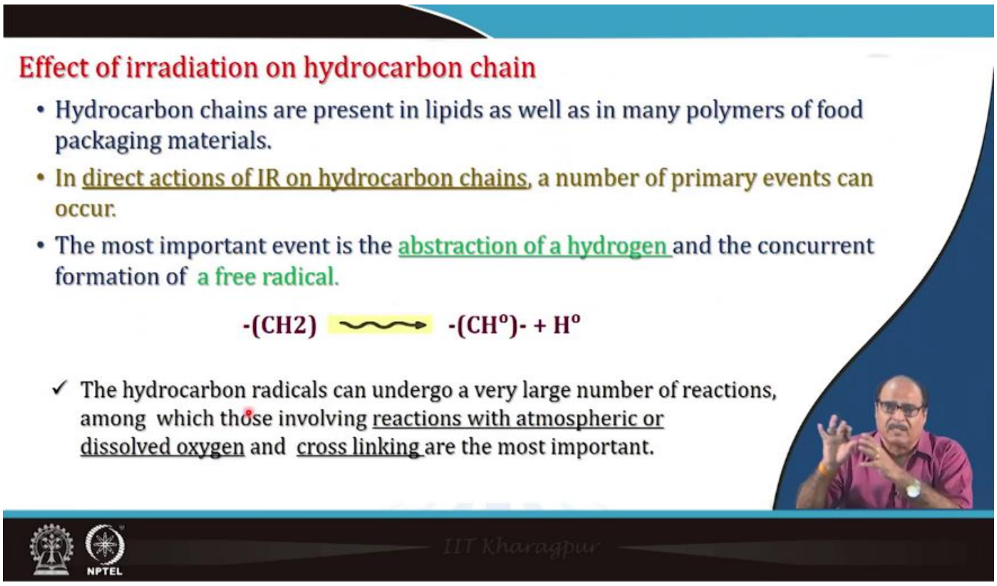
Changes in food constituents during irradiation

Irradiation is a cold process referred to as a cold pasteurization or cold sterilization process. It can accomplish the same objective as is done by thermal pasteurization/sterilization processes in food. There is very little or no change in physical appearance, no textural or color changes, and possible chemical changes such as off-flavour and tissue softening. Ionizing radiations are capable of initiating a vast array of chemical changes in gaseous, liquid and solid systems. It may include radiolysis of water or the effect on macromolecules & other components such as proteins, carbohydrates, lipids, vitamins, and enzymes.



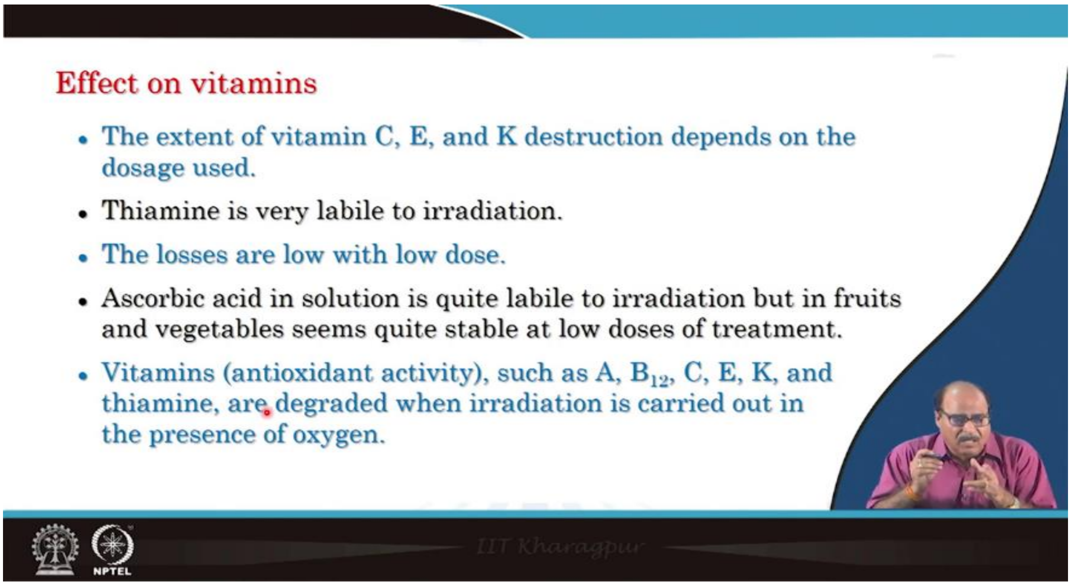
Radiolysis of water

Ionizing radiation split, or as it is more technically called radiolyze water. Since most foods are aqueous systems, this effect of IR on water is of key importance. The passage of ionizing radiation through water results in the formation of the intermediates such as Excited water $(H_2O)^*$, free radicals OH° and H°, ionized water molecules $(H_2O)^+$, and hydrated water molecules e^-_{aq}. These species then react among themselves or with other components of the system. In pure water, and in the presence of air, they produce hydrogen gas (H_2), hydrogen peroxide (H_2O_2), water (H_2O), hydronium ion (H_3O^+), and hydroxide ion (OH^-). The reactions that these intermediates can undergo with food components are too numerous to list.



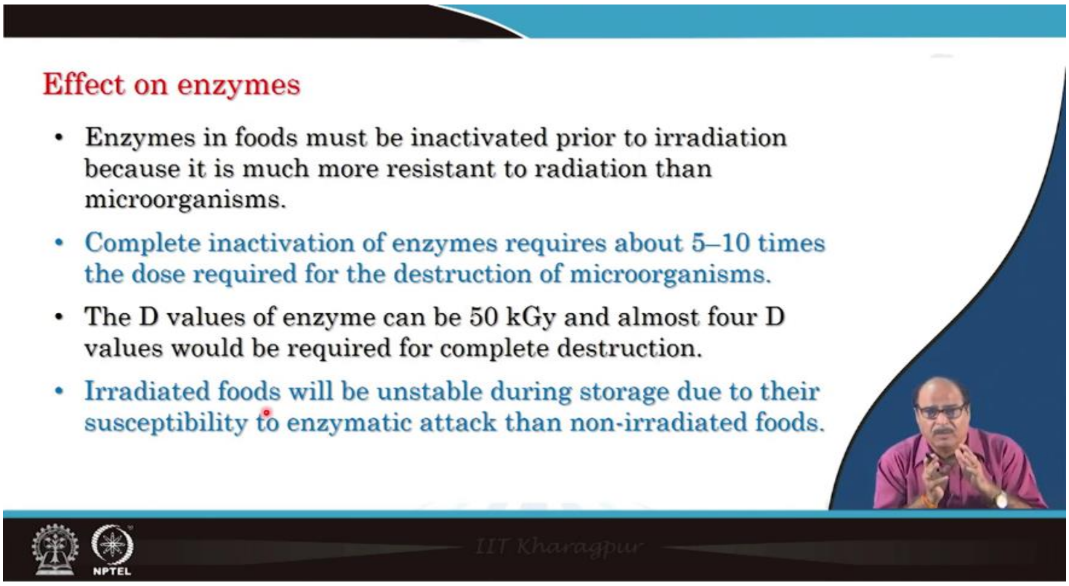
Effect of irradiation on hydrocarbon chain

Hydrocarbon chains are present in lipids as well as in many polymers of food packaging materials. In direct actions of IR on hydrocarbon chains, a number of primary events can occur. The most important event is the abstraction of a hydrogen and the concurrent formation of a free radical. The hydrocarbon radicals can undergo a very large number of reactions such as among those involving the reactions with atmospheric or dissolved oxygen, cross linking, condensation, polymerization so many reactions can take place.



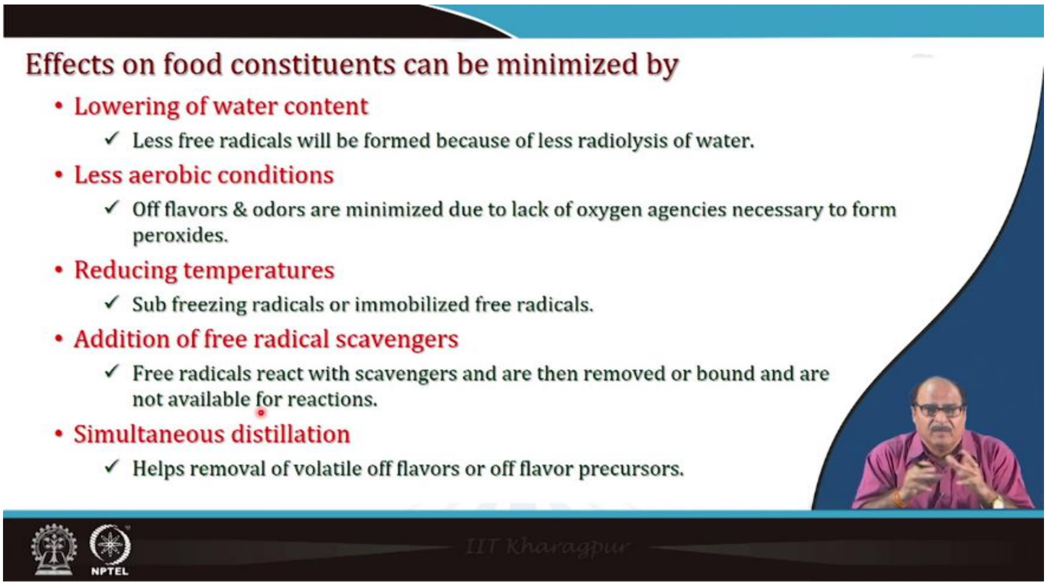
Effect on vitamins

The extent of vitamin C, E, and K destruction depends on the dosage used. Thiamine is very labile to irradiation. The losses are low with low dose. Ascorbic acid in solution is quite labile to irradiation but in fruits and vegetables seems quite stable at low doses of treatment. Vitamins (antioxidant activity), such as A, B_{12}, C, E, K, and thiamine, are degraded when irradiation is carried out in the presence of oxygen.

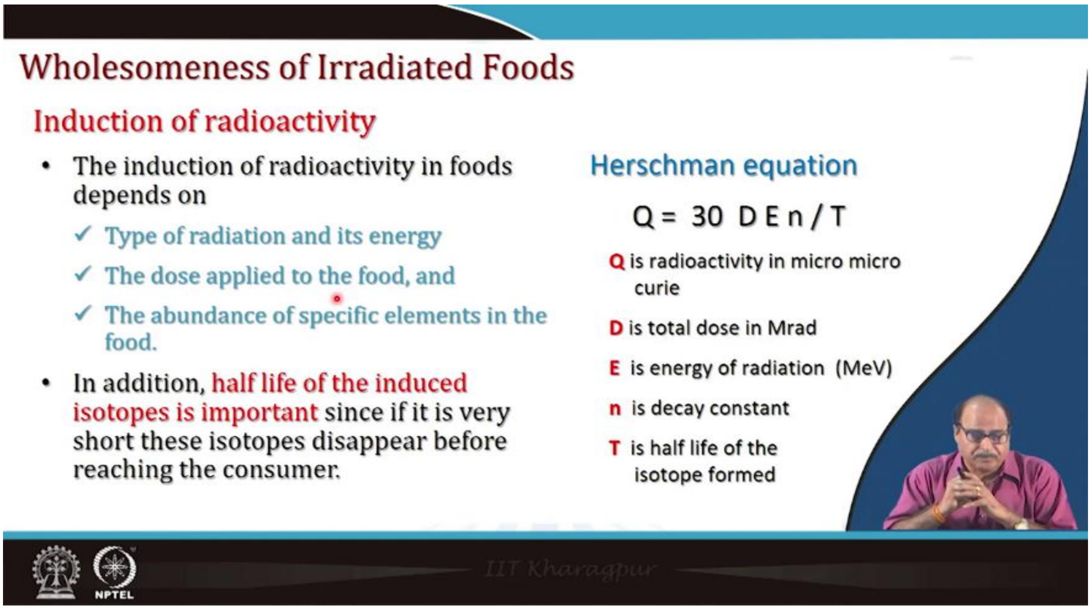


Effect on enzymes

Enzymes in foods must be inactivated prior to irradiation because it is much more resistant to radiation than microorganisms. Complete inactivation of enzymes requires about 5–10 times the dose required for the destruction of microorganisms. The D values of enzyme can be 50 kGy and almost four D values would be required for complete destruction. Irradiated foods will be unstable during storage due to their susceptibility to enzymatic attack than non-irradiated foods.



Effects on food constituents can be minimized by lowering of water content as less free radicals will be formed because of less radiolysis of water, less aerobic conditions as off flavors & odors are minimized due to lack of oxygen agencies necessary to form peroxides, reducing temperature as sub freezing radicals or immobilized free radicals, addition of free radical scavengers as free radicals react with scavengers and are then removed or bound and are not available for reactions, and simultaneous distillation for removal of volatile off flavors or off flavor precursors.



Wholesomeness of irradiated foods

Induction of radioactivity

The induction of radioactivity in foods depends on the type of radiation and its energy, the dose applied to the food, and the abundance of specific elements in the food. In addition, half life of the induced isotopes is important since if it is very short these isotopes disappear before reaching the consumer.

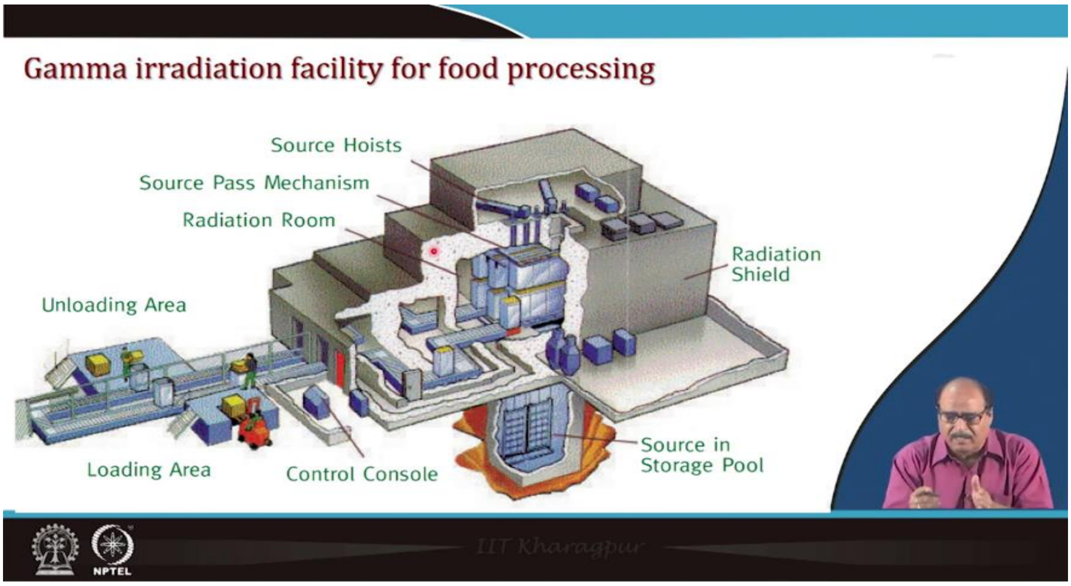
Herschman equation

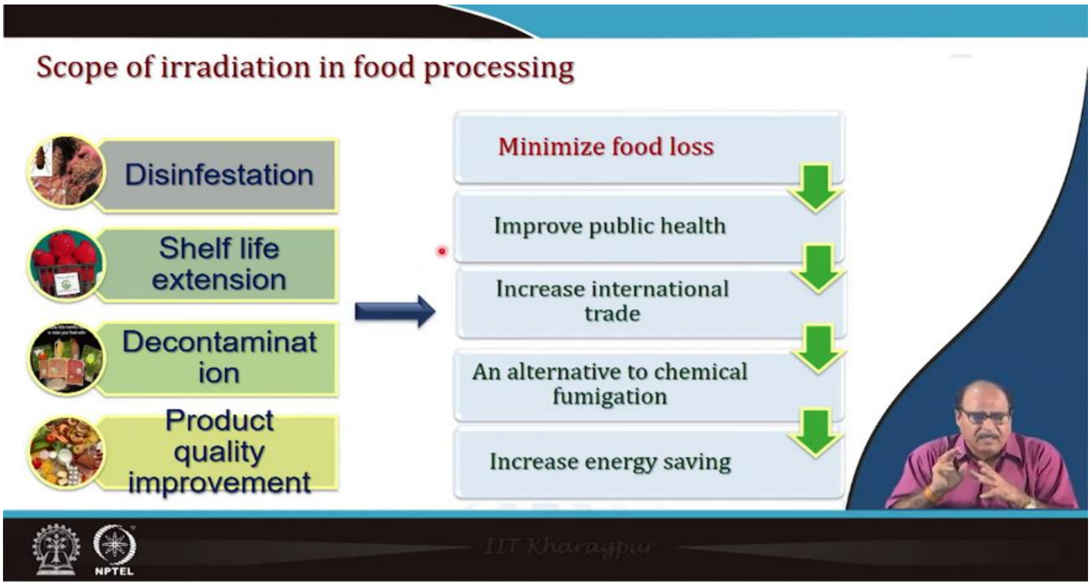
$$Q = \frac{30 \text{ x } D \text{ x } E \text{ x } n}{T}$$

Where, Q is radioactivity in micro micro curie, D is total dose in Mrad, E is energy of radiation (MeV), n is decay constant, T is half life of the isotope formed.

Gamma irradiation facility for food processing

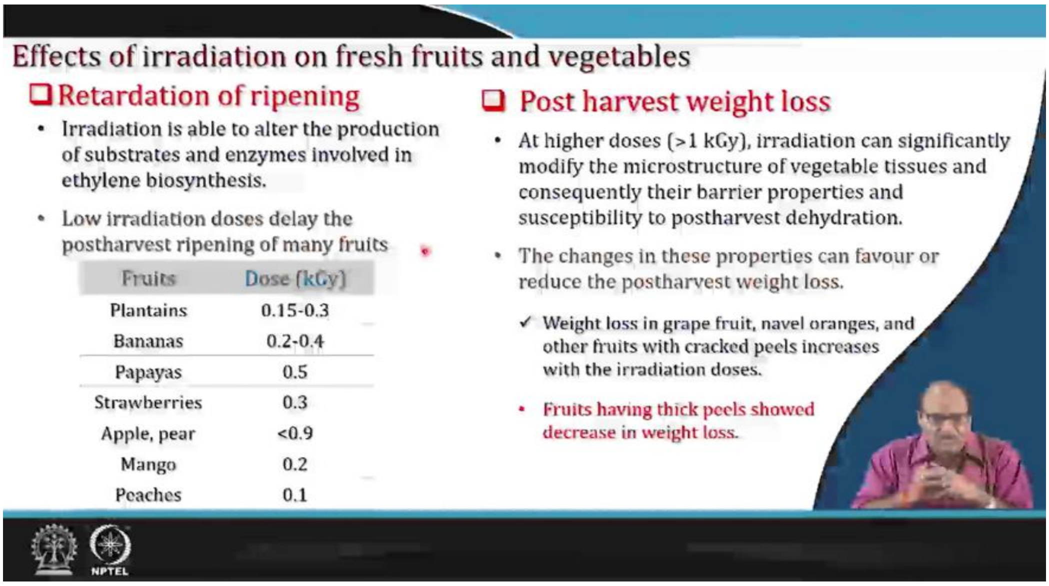
The facility includes unloading area, loading area, control console, radiation room, source pass mechanism, source hoists, radiation shield, and storage pool.





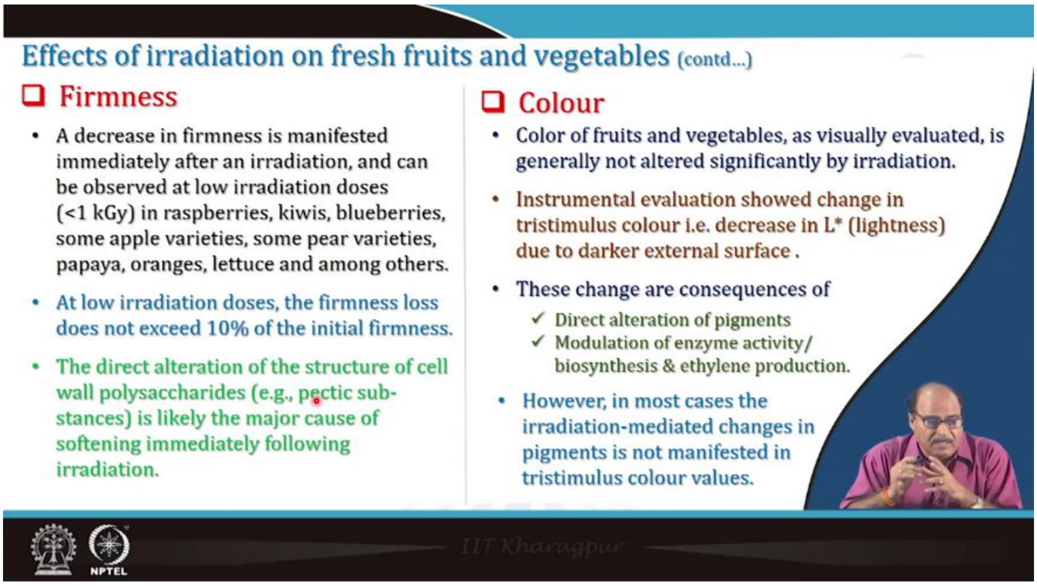
Scope of irradiation in food processing

The irradiation can be effectively used for disinfestation, shelf-life extension, decontamination, and product quality improvement in order to minimize the food loss, improve public health, increase international trade, avoid chemical fumigation, and increase energy saving. India has already signed an MOU with the US that is the Singh-Obama agreement under this the alphanso mango is irradiated in bark and then it is shipped to US irrigated mango is available it to improve public health, minimize food losses, etc.

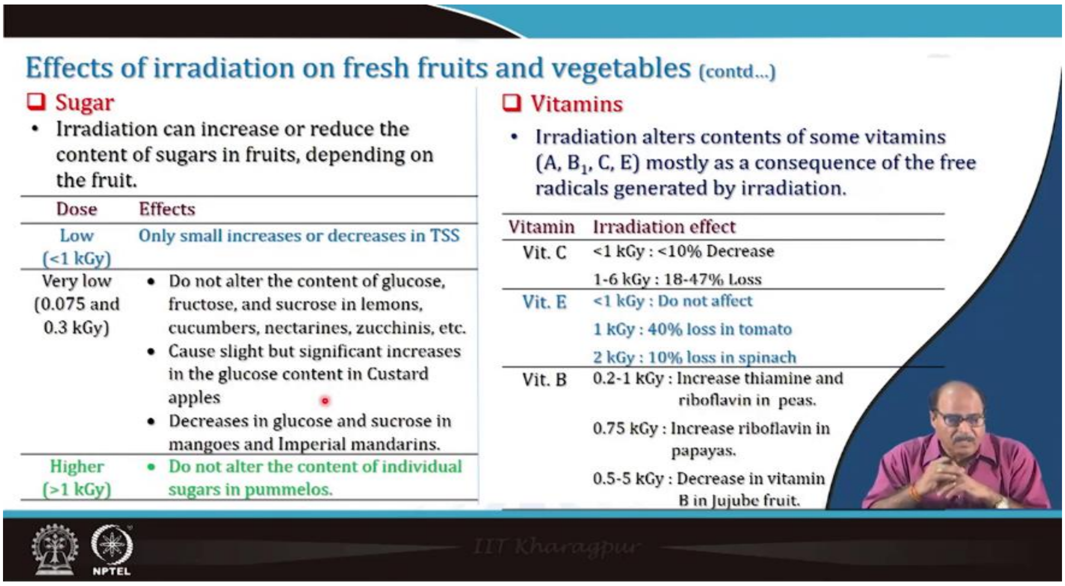


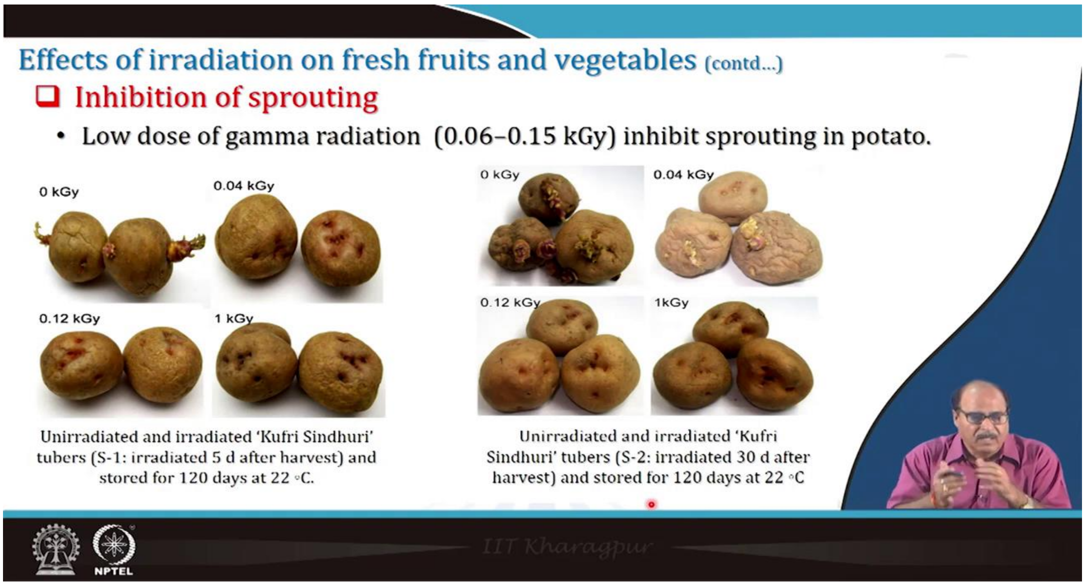
Effects of irradiation onfresh fruits and vegetables

Irradiation is able to alter the production of substrates and enzymes involved in ethylene biosynthesis. Low irradiation doses delay the postharvest ripening of many fruits such as the dose of 0.2-0.4 kGy is sufficient for bananas, less than 0.9 kGy for apple and pear etc. At higher doses (>1 kGy), irradiation can significantly modify the microstructure of vegetable tissues and consequently their barrier properties and susceptibility to postharvest dehydration. The changes in these properties can favour or reduce the postharvest weight loss. Weight loss in grape fruit, navel oranges, and other fruits with cracked peels increases with the irradiation doses. Fruits having thick peels showed decrease in weight loss.

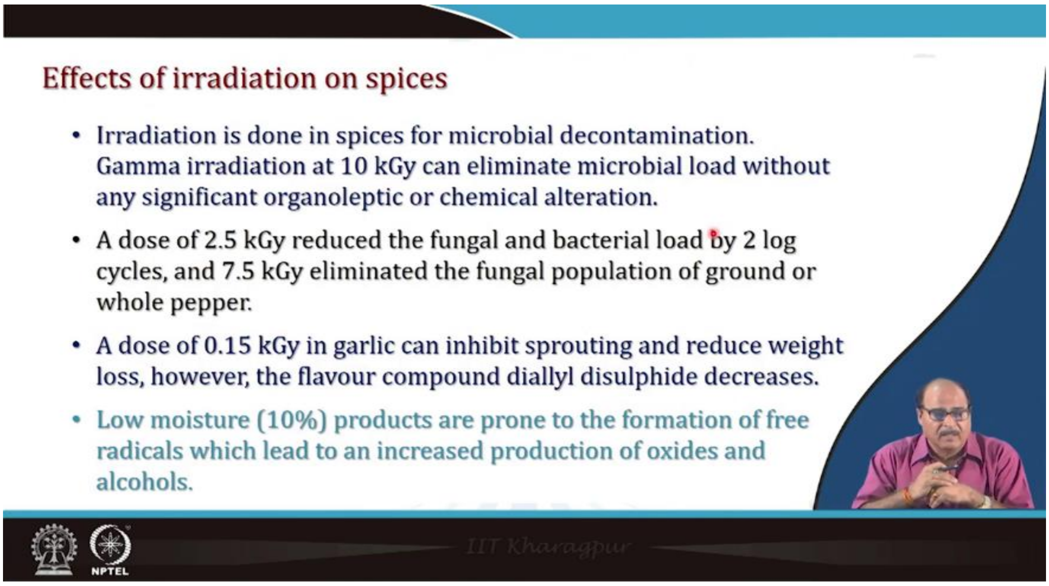


A decrease in firmness is manifested immediately after an irradiation, and can be observed at low irradiation doses (<1 kGy) in raspberries, kiwis, blueberries, some apple varieties, some pear varieties, papaya, oranges, lettuce and among others. At low irradiation doses, the firmness loss does not exceed 10% of the initial firmness. The direct alteration of the structure of cell wall polysaccharides (e.g., pectic sub-stances) is likely the major cause of softening immediately following irradiation. Color of fruits and vegetables, as visually evaluated, is generally not altered significantly by irradiation. Instrumental evaluation showed change in tristimulus colour i.e. decrease in L* (lightness) due to darker external surface. These change are consequences of direct alteration of pigments, modulation of enzyme activity/ biosynthesis & ethylene production. However, in most cases the irradiation-mediated changes in pigments is not manifested in tristimulus colour values. Irradiation can increase or reduce the content of sugars in fruits, depending on the fruit. The lower dose (< 1 kGy) causes small increases or decreases in TSS. Very low (0.075 and 0.3 kGy) dose applications do not alter the content of glucose, fructose, and sucrose in lemons, cucumbers, nectarines, zucchinis, etc., cause slight but significant increases in the glucose content in Custard apples, decrease in glucose and sucrose in mangoes and Imperial mandarins. The higher dose (> 1 kGy) applications do not alter the content of individual sugars in pummelos. Irradiation alters contents of some vitamins (A, B1, C, E) mostly as a consequence of the free radicals generated by irradiation. There is 10% decrease in vitamin C at dose of less than 1 kGy, whereas 18-47% loss occurs at a dose of 1-6 kGy. Less than 1 kGy causes no effect on vitamin E, dose of 1 kGy causes 40% loss of vitamin E in tomato. The dose in the range of 0.2-1 kGy increases thiamine and riboflavin in peas, at 0.75 kGy, there is an increase in riboflavin in papayas.



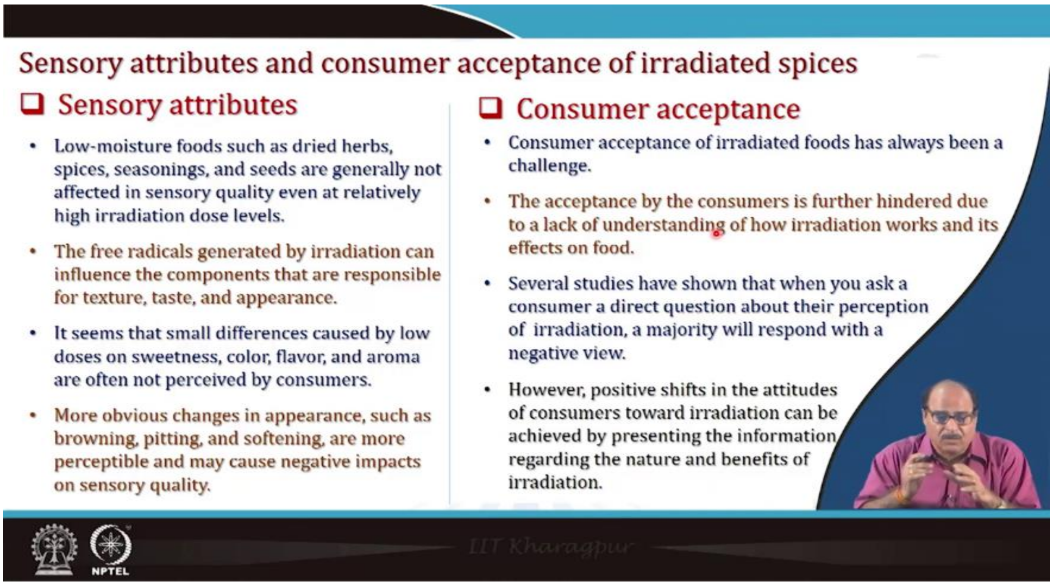


Low dose of gamma radiation (0.06–0.15 kGy) inhibit sprouting in potato. The left hand side figure shows the unirradiated and irradiated 'Kufri Sindhuri' tubers (S-1: irradiated 5 d after harvest) and stored for 120 days at 22 °C. The right hand side figure shows the unirradiated and irradiated 'Kufri Sindhuri' tubers (S-2: irradiated 30 d after harvest) and stored for 120 days at 22 °C.



Effects of irradiationon spices

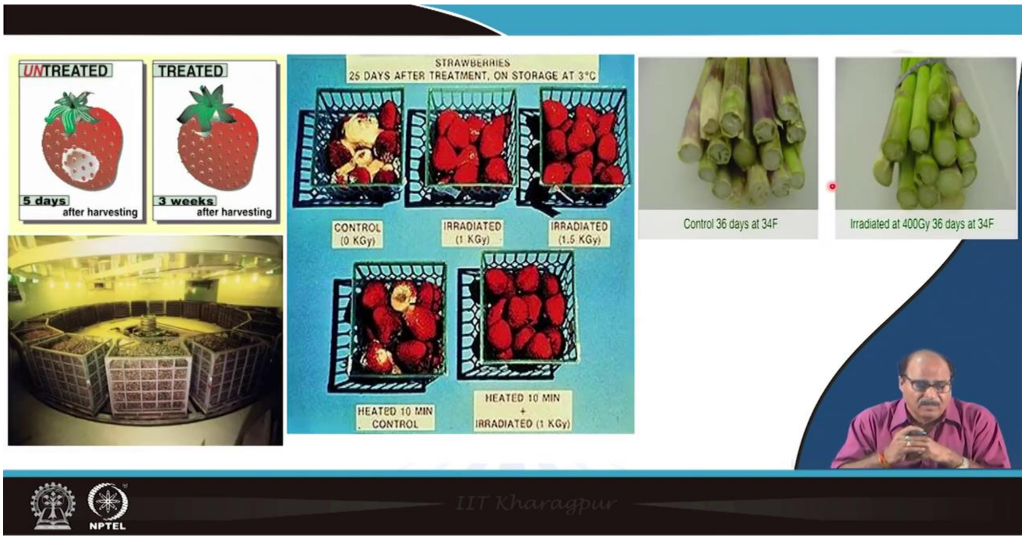
Irradiation is done in spices for microbial decontamination. Gamma irradiation at 10 kGy can eliminate microbial load without any significant organoleptic or chemical alteration. A dose of 2.5 kGy reduced the fungal and bacterial load by 2 log cycles, and 7.5 kGy eliminated the fungal population of ground or whole pepper. A dose of 0.15 kGy in garlic can inhibit sprouting and reduce weight loss, however, the flavour compound diallyl disulphide decreases. Low moisture (10%) products are prone to the formation of free radicals which lead to an increased production of oxides and alcohols.



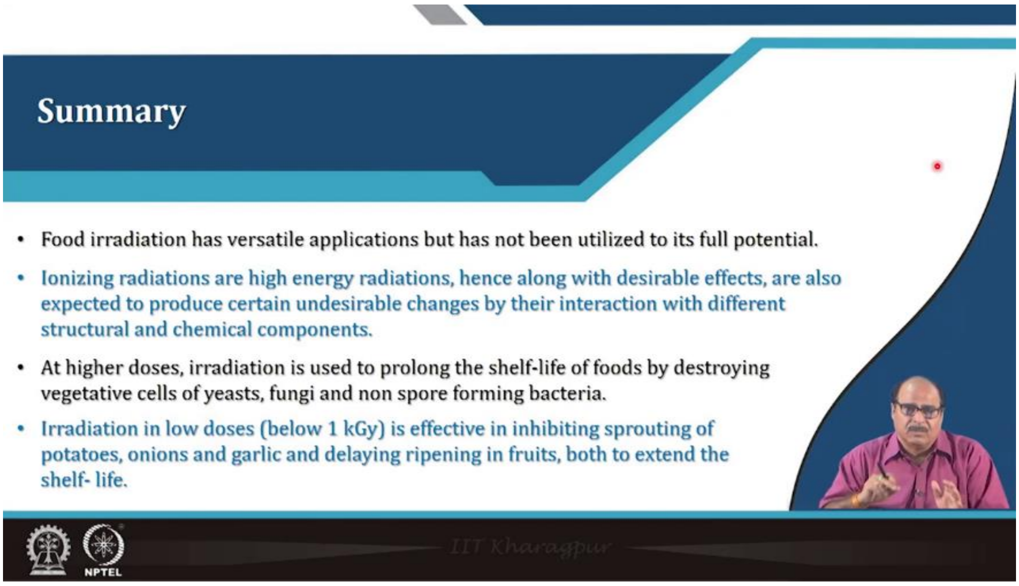
Sensory attributes and consumer acceptance of irradiated spices

Low-moisture foods such as dried herbs, spices, seasonings, and seeds are generally not affected in sensory quality even at relatively high irradiation dose levels. The free radicals generated by irradiation can influence the components that are responsible for texture, taste, and appearance. It seems that small differences caused by low doses on sweetness, color, flavor, and aroma are often not perceived by consumers. More obvious changes in appearance, such as browning, pitting, and softening, are more perceptible and may cause negative impacts on sensory quality. Consumer acceptance of irradiated foods has always been a challenge. The acceptance by the consumers is further hindered due to a lack of understanding of how irradiation works and its effects on food. Several studies have shown that when you ask a consumer a direct question about their perception of irradiation, a majority will respond with a negative view. However, positive shifts in the attitudes of consumers toward irradiation can be achieved by presenting the information regarding the nature and benefits of irradiation.

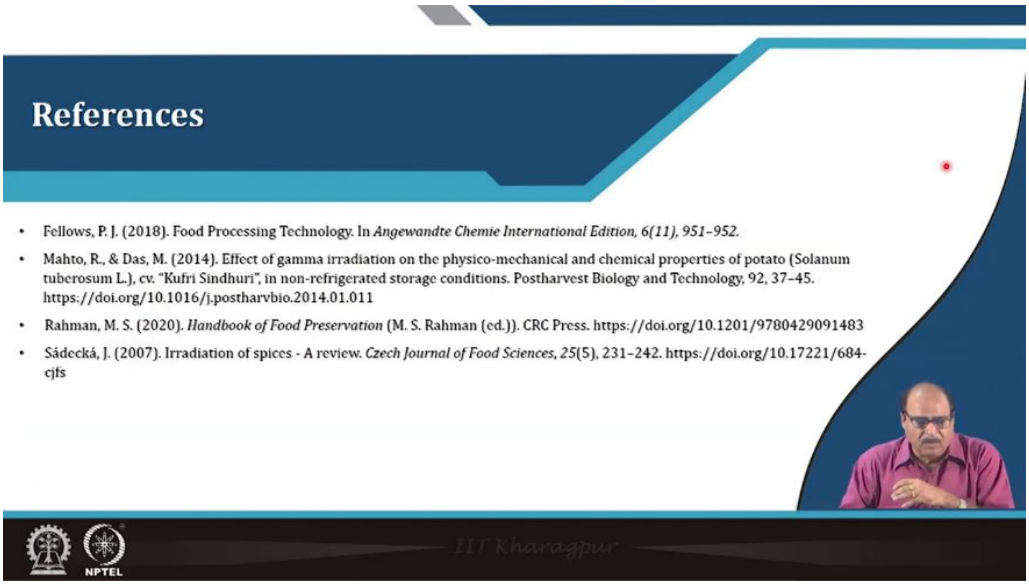
The FDA requires that irradiated foods bear the 'radura' label and state on the label 'Treated with radiation' or 'Treated by irradiation'. Many countries have their own regulatory requirements for food irradiation. There is no statutory requirement specific to irradiation in many countries.



These are some of the picture of the irradiated strawberries and sugar cane sticks showing the difference between the irradiated and non-irradiated forms.



In summary, Food irradiation has versatile applications but has not been utilized to its full potential. Ionizing radiations are high energy radiations, hence along with desirable effects, are also expected to produce certain undesirable changes by their interaction with different structural and chemical components. At higher doses, irradiation is used to prolong the shelf-life of foods by destroying vegetative cells of yeasts, fungi and non spore forming bacteria. Irradiation in low doses (below 1 kGy) is effective in inhibiting sprouting of potatoes, onions and garlic and delaying ripening in fruits, both to extend the shelf- life.



These are the references for further study. Thank you.