Novel Technologies for Food Processing and Shelf Life Extension
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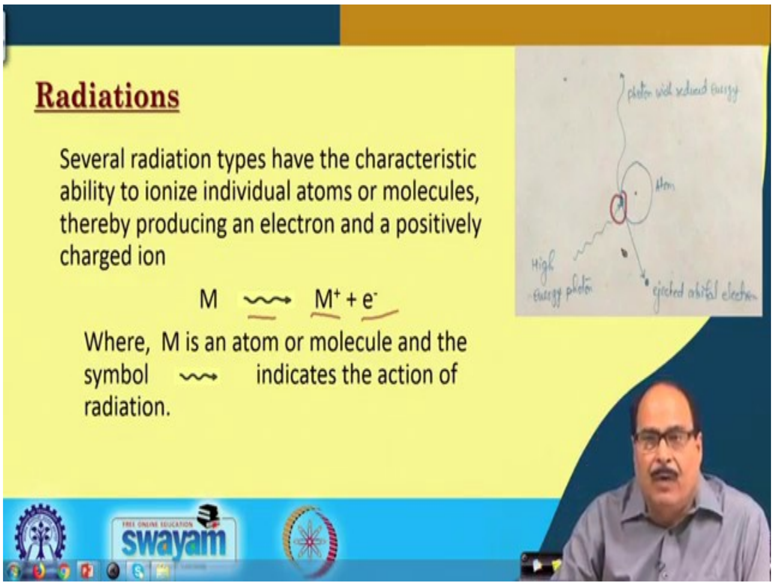
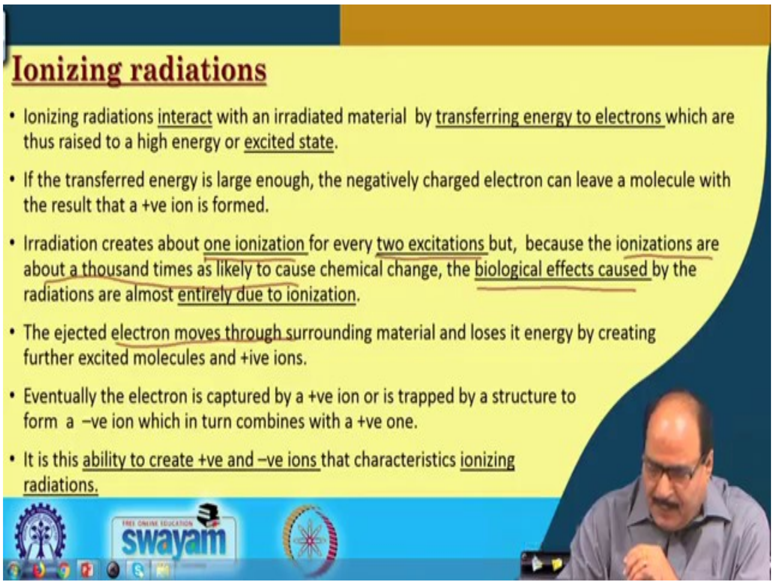
Lecture – 15
Food Irradiation: Part 1

This lecture will cover about the process principles and technological aspects of food irradiation. The 2nd part of the lecture will cover the effect of food irradiation on the constituents and characteristics of the food as well as application on the different types of food where these irradiation treatments can be done.



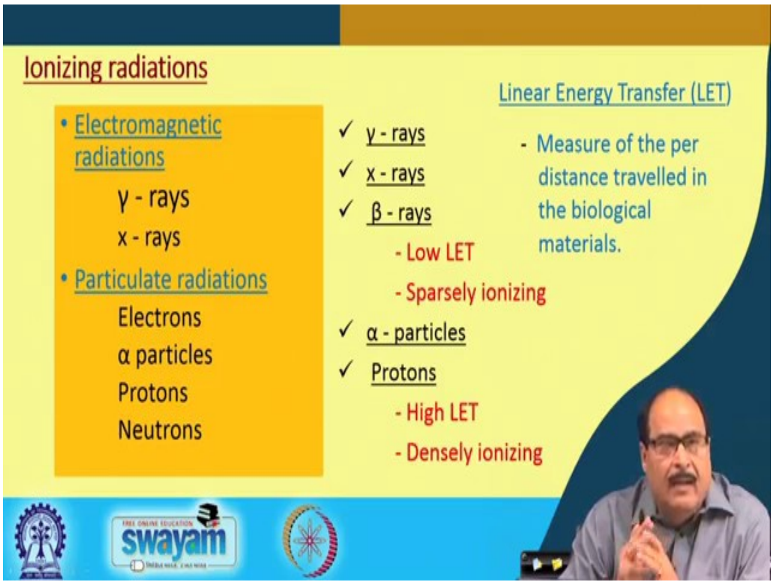
There are several radiation types which have the characteristic ability to ionize individual atoms or molecules, there by producing an electron and a positively charged ion. In this figure, high energy photon bombards the atom and excites the electron by absorption of energy. This electron gets ejected from the orbital resulting in a positively charged atom. Compton effect shows that when atom is bombarded by irradiation, positively and negatively charged ions are produced.



This is the characteristic ability of the ionizing radiations. Radiations which when interact with the material and produce ions may be positive ion or negative ions, they are called ionizing radiations. These ionizing radiations interact with an irradiated material by transferring the energy to electrons and these electrons after getting the energy, get raised to a high energy or excited state and if the transferred energy is large enough that negatively charge electron can leave a molecule and therefore, it gives a positive ion.

The ionizations are about a thousand times as likely to cause chemical changes as the biological effects caused by the radiations are almost entirely due to this ionization effect. The ejected electron moves through surrounding materials and loses its energy by creating further excited and positive ions.

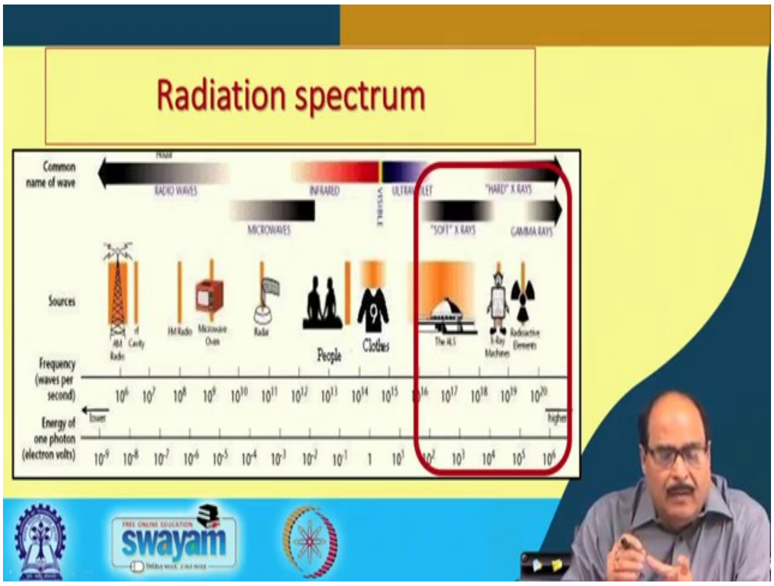
Eventually, in the process the electron is captured by a positive ion and is trapped by a structure to form a negative ion which in turn combines with a positive ion. It is this ability of ionizing radiations to create positive and negative ions is used for beneficial purposes in food processing operations.



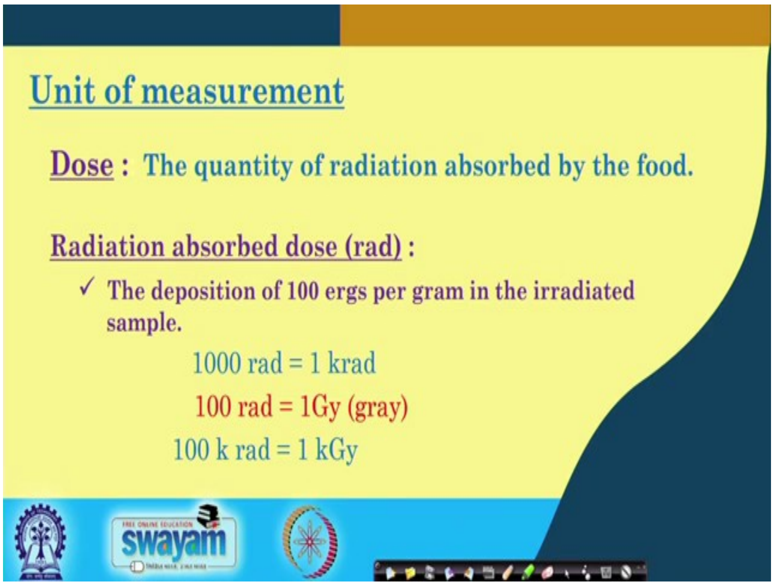
There are several types of ionizing radiations. It may be electromagnetic radiation, viz., gamma rays and x rays. Gamma rays are generally produced by decay of certain radioactive elements like cobalt 60. X rays can be produced by a fast moving particle such as electrons and they have range of energies. The other type of ionizing radiations may be particulate radiations like electrons, alpha particles, protons and neutrons. The energy values contained in these electromagnetic radiations particularly gamma rays and X rays are of such magnitude that once it comes in contact with the food material, for every primary ionization there are secondary ionization and tertiary ionization etc. The biological effect that is obtained in the food materials that is mainly because of the secondary and tertiary ionization and other chemical effects in the food constituents.

The gamma rays, X rays and beta rays can travel into the material little deeper. Because of their mass, they can penetrate deep into the material and therefore, they have low linear energy transfer. Linear energy transfer that is called LET value is the measure of the energy per distance travelled in the biological materials. So, since whatever the energy they are containing is dissipated over a long path because they can penetrate deep into the materials.

If the per distance energy dissipated is low, they are characterized by having low LET therefore, sparsely ionizing. On the other hand, the alpha particles, protons, etc. because of their high mass, they are frequently stopped by the biological materials and they are not able to penetrate deep into the materials. Due to this, their energy is dissipated over a small path and they have high LET value and high LET value means they are densely ionizing. These are the characteristics of these ionizing radiations which becomes beneficial in the process optimization purposes.

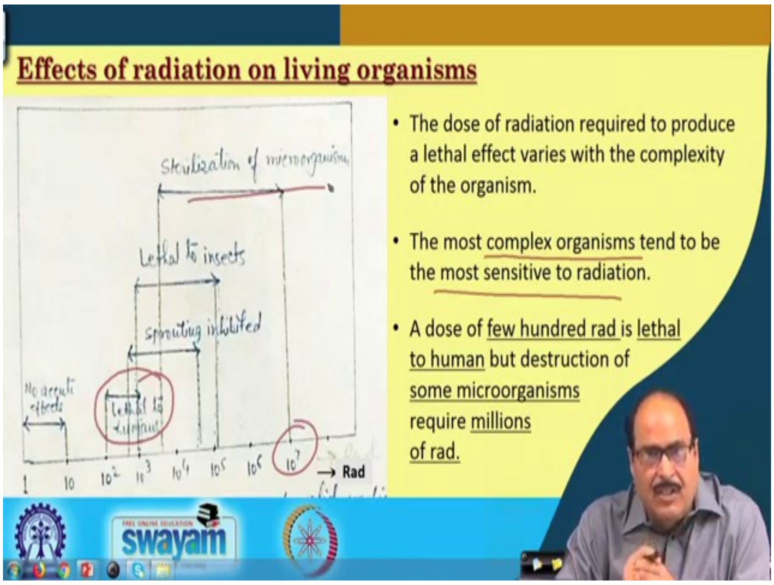


Radiation spectrum which is normally used in regard to the frequency of the waves per second or energy of one photon and the radiations which are used for food processing like X rays, gamma rays, etc. are normally towards the higher side having 10^{16} frequency waves per second.



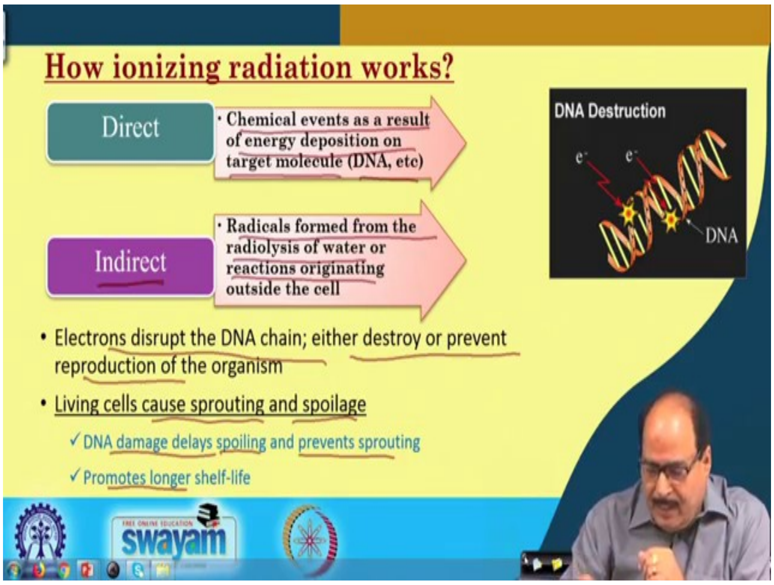
The dose of the radiation received by the food materials becomes an important consideration in finalizing the food irradiation processes. The dose is the quantity of radiation absorbed by the food. The unit which is normally used for measurement of radiation is rad.

Rad is radiation absorbed dose. One rad equals the deposition of 100 ergs per gram in the irradiated sample. Since that, there are certain microorganisms in some food process operations which require higher energy particularly when the inactivation of microorganisms is involved. So, expressing this in terms of rad yielded higher values. So, recently another unit was introduced, i.e. gray. 1 gray is equal to 100 rad.



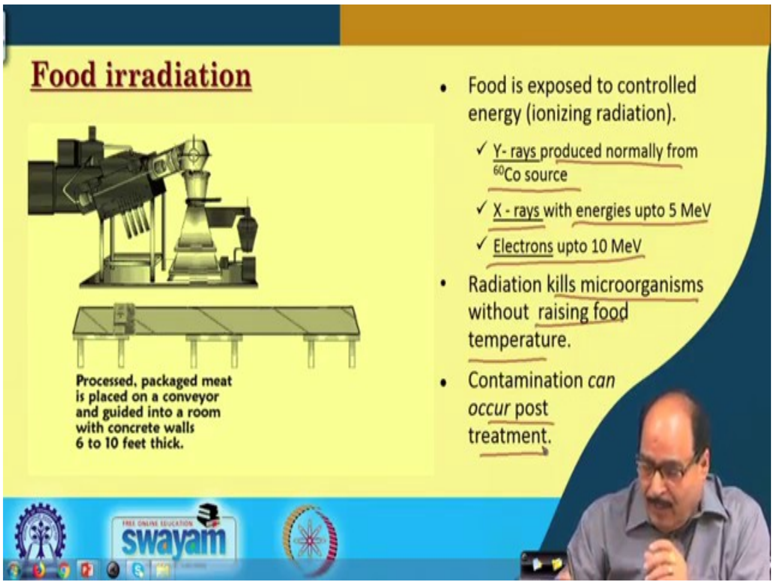
Potential lethal effect of radiations was realized soon after the discovery of X rays by Roentgen and radioactivity by Becquerel in the late 19th century. And it was established that the dose of radiation required to produce a lethal effect varies with the complexity of the organism.

The most complex organisms tend to be the most sensitive to radiation. They can be destroyed by the exposure to a few hundreds of rads whereas, for some single cell microorganisms, it requires millions of rad, i.e. 10^2 to 10^7.



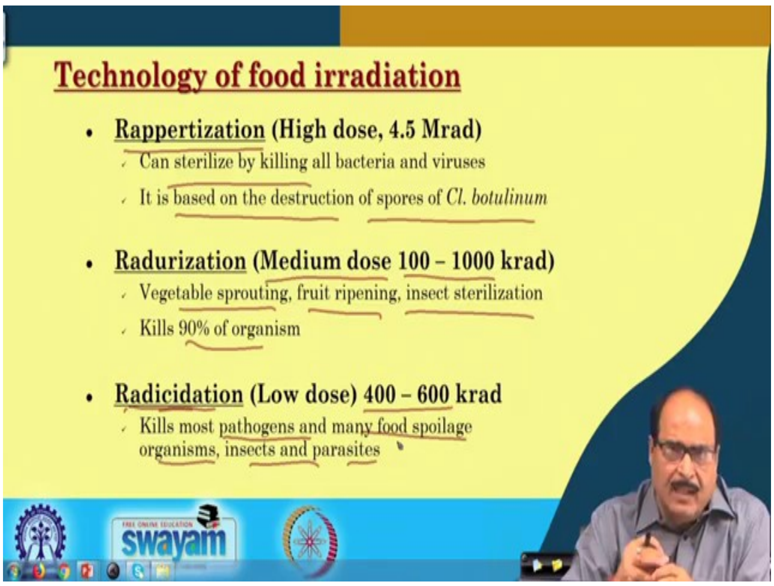
How does this ionizing radiation work? Two mechanisms of action have been proposed; one is the direct action mechanism, another is the indirect action mechanism. In the direct action mechanism, it is assumed that the radiation directly hits the target genetic materials or DNA of the molecule. But, this direct action mechanism does not hold true for the multi cellular organisms, if unless it is assumed that the multi cellular organism are a single entity.

In this case, the indirect action mechanism appears to be more correct where radicals are formed either by radiolysis of the water or the reactions originating outside the cell. It affects another cell and further cause ionization. In this manner multi cellular organism, get destroyed by indirect action mechanism. Electrons disrupt the DNA chain and either destroy or prevent reproduction of the organisms and the living cells. Spoilage in the biological material by microbial action or by enzymatic process is a physiological process in certain fruits and vegetable result to sprouting which is not desirable for its quality. So, this DNA damage also may delay the spoilage or prevent sprouting and may promote longer shelf life.



In the technological aspect of the irradiation, the sample of the food material packaged or unpackaged is taken through appropriate means to a source of radiation. In this technology, food is exposed to ionizing radiations like gamma rays produced normally from cobalt 60 source, X rays with energies up to 5 MeV and electrons up to 10 MeV.

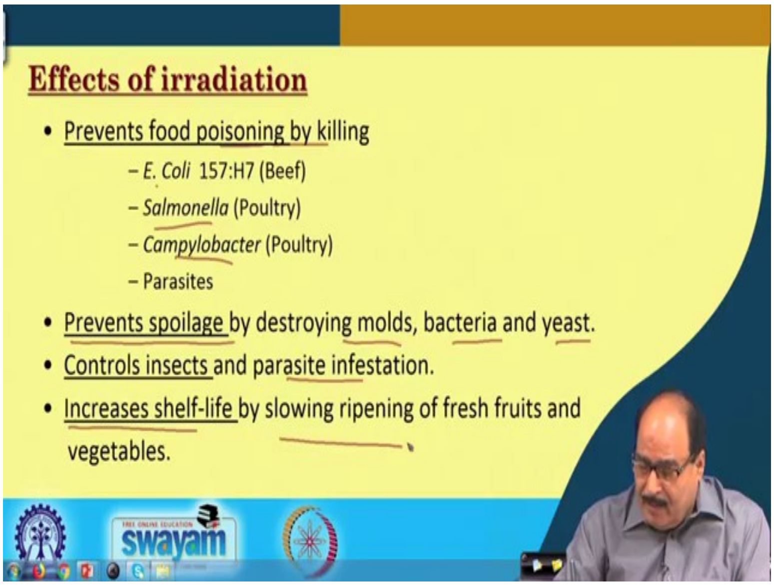
These radiations kill micro organisms, inactivate proteins, enzymes or it destroys other causative agents or inhibitory factors to spoilage without raising the temperature of the food. It is considered to be a cold process, non thermal process. However, one has to take care the contamination that can occur post treatment. So, after the food material is exposed to the irradiation, one must properly take care so that recontamination is avoided.



Depending upon the objective of the process, different doses are given to the food material and accordingly, the processes are given different names. Like in the case of thermal processing, pasteurization, sterilization and blanching processes are there depending upon the intensity of the heat given to food material.

Similarly, here Rappertization, Radurization and Radicidation are there. Radappertization is called radiation sterilization where complete removal of the microorganisms or biological forms of the causative agents is targeted here. This process needs a higher dose may be to the tune of 4.5 million rad or even more. It sterilizes the food by killing the bacteria, viruses in the low acid food or in the other foods. The process normally is based on the destruction of the spores of *Clostridium botulinum*.

Radurization is the radiation pasteurization. It needs medium dose, may be 100 to 1000 kilo rad and about 90 percent destruction of the organism. The other term is the Radicidation which is a comparatively lower dose treatment particular may be in the range of 400 to 600 kilo rad. It kills most pathogens and many food spoilage organisms, insects and parasites and in fact, it is very suitable process for killing of *Salmonella*, a food poisoning microorganism which more frequently affects the poultry.



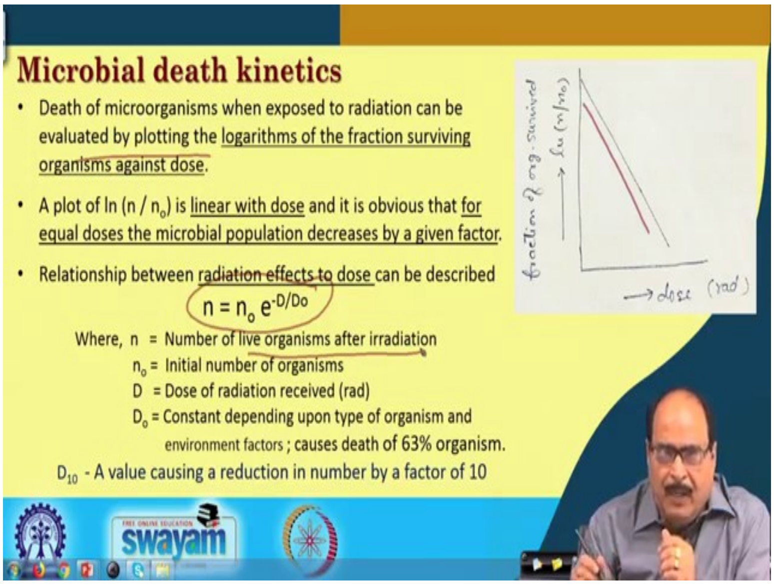
Ionizing radiations or irradiation of food can prevent food poisoning by killing pathogenic or toxin producing microorganism like *E coli*, *Salmonella*, Campylobacter, Parasites, etc. It can prevent spoilage of the food materials by destroying molds, bacteria, yeast, etc. It controls insects and parasite infestation. It increases shelf life by slowing down the ripening of fresh fruits and vegetables.

So, another important consideration is the stabilization of radiation process for food. In the heat treatment process, the food may be stabilized by inactivating the microorganisms and enzymes in broader sense that is the causative agents for spoilage. Other factors which cause spoilage of food are toxin produced in food. It is more important to protect the stabilized food from recontamination and their access to oxygen.

Once they are treated with the ionizing radiations, proper care should be taken post treatment that they are not again exposed to contaminated environment or oxygen rich environment. Otherwise, oxidative reactions may take place and cause spoilage of the food. So, the stabilization of food with ionizing radiations accordingly involves two major considerations.

1. The characteristics of the food and 2. A suitable radiation source. The characteristic of the food that is its acidity, moisture content, its other components present and the form in which the macro molecules and other things are present decides what type of microorganism will grow in a particular food.

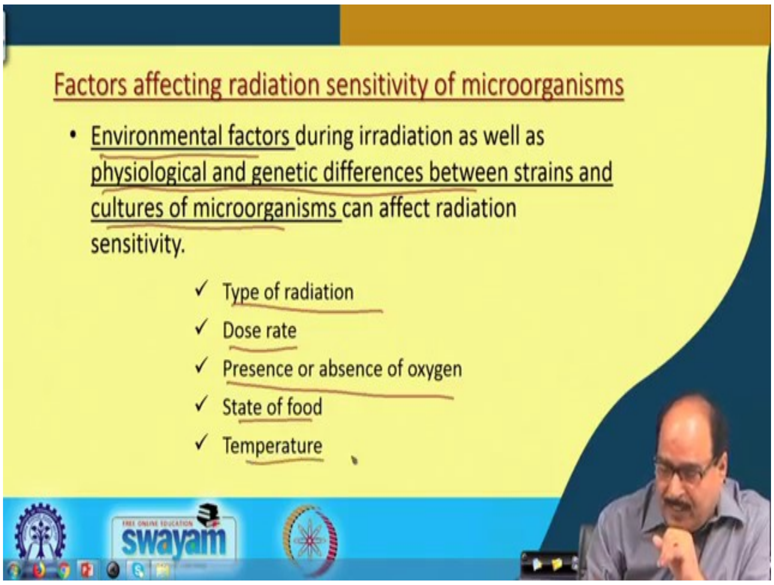
On the basis of the food characteristics, information about microorganisms it supports the radiation process that is how much radiation energy is required to be given for a specific purpose.



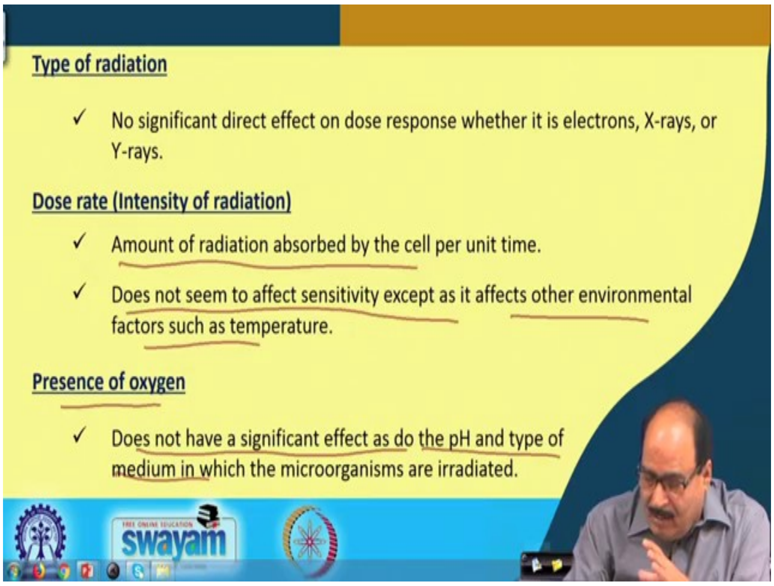
The death of the microorganism basically when exposed to radiation can be evaluated by plotting logarithm of the fraction of survival organisms against dose as in the case of thermal processing. A plot of logarithm of no. of live organism after irradiation divided by initial number of organism i.e. ln (n / no) 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 follows: $n = n_o e^{-D/Do}$

Where, n = no of live organisms after irradiation
n_o = initial no. of organisms
D = Dose of radiation received (rad)
D_o = Constant depending upon type of organism and environment factors (causes death of 63% organism).

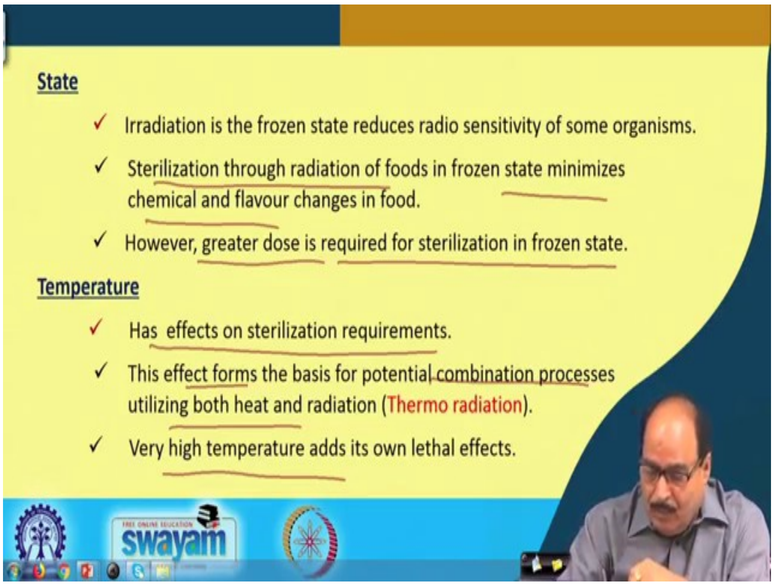
Of course, depending upon the process, several other factors can also be considered, like D_{10} value, a value causing a reduction in number of microorganism by a factor of 10.



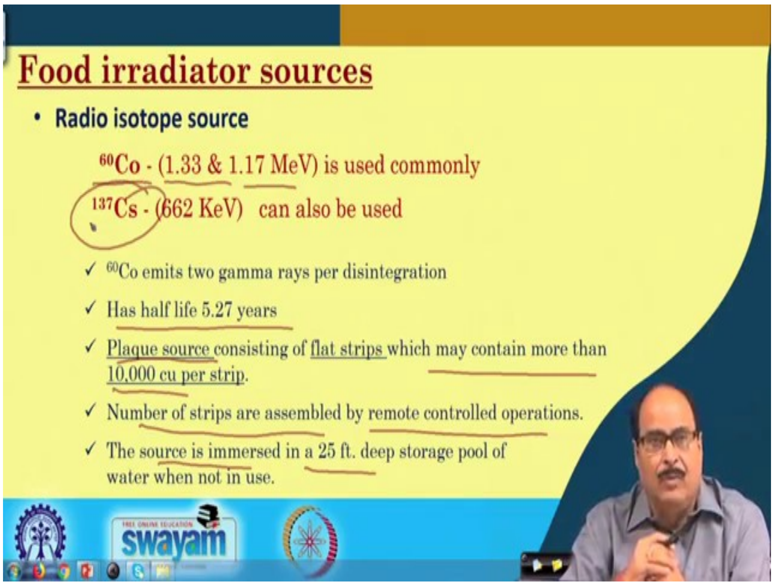
What are the different factors that affect the radiation sensitivity of the microorganisms? Both the environmental factor as well as the physiological and genetic differences between the strains and cultures of microorganism can affect the radiation sensitivity. The major factors in this regard include type of the radiation, dose rate, presence or absence of oxygen in the irradiating medium, state of the food and temperature.



As far as the type of the radiation is concerned, it has no significant effect on the dose response whether the irradiation is given in the form of electrons or X rays or gamma rays. At least required amount of energy has to be given to the food for the desired use. Regarding dose rate, it is the intensity of the radiation, the amount of the radiation absorbed by the cell per unit time. It does not seem to affect sensitivity except as it affects other environmental factors e.g. temperature. Presence of oxygen does not have a significant effect as do the pH and type of medium in which the microorganisms are irradiated.

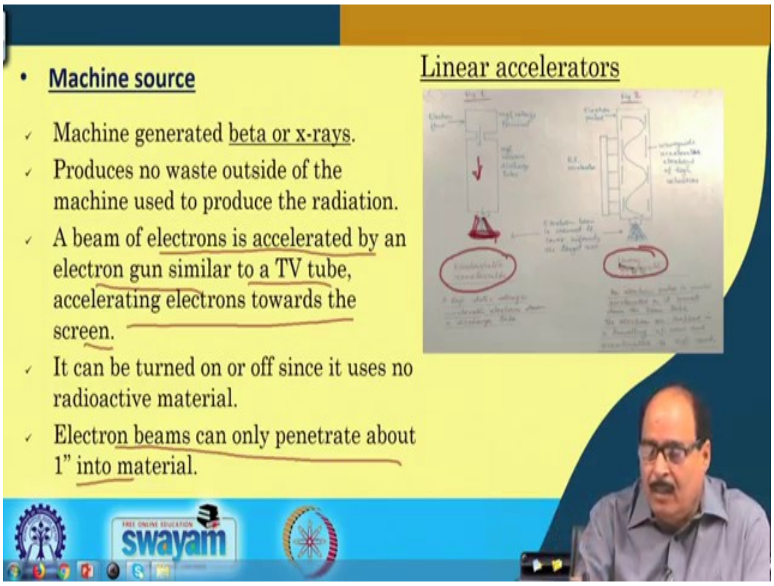


Irradiation is the frozen state reduces radio sensitivity of some organisms. However, sterilization through radiation of foods in frozen state minimizes chemical and flavour changes in food. Greater dose is required for sterilization in frozen state. As far as the temperature is concerned, it has effects on sterilization requirements. This effect forms the basis for potential combination processes utilizing both heat and radiation. Very high temperature adds their own lethal effects on those of irradiation.

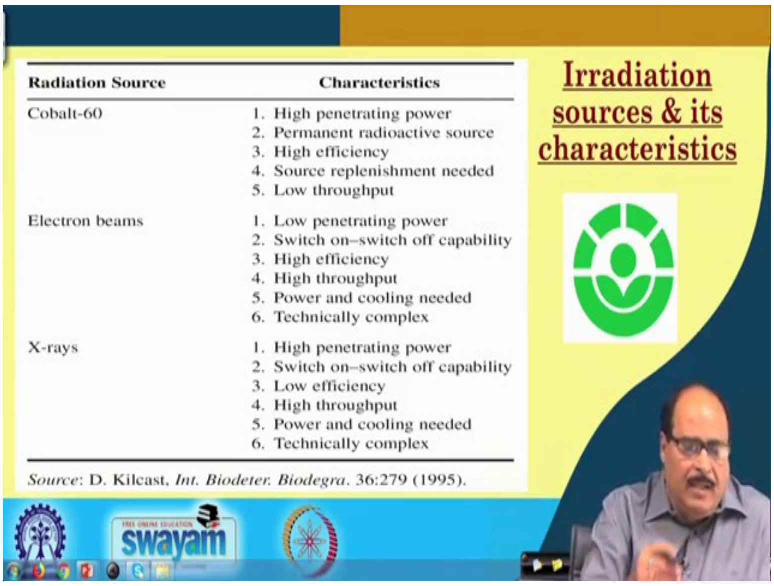


Regarding food irradiators and sources, there are normally two types of sources; one is the radio isotope source, another is the machine source. In the radio isotope source, presently the cobalt 60 radio isotope is used. It emits two gamma rays per disintegration having energy value 1.33 and 1.17 MeV. It has a half-life of 5.27 years. It is produced in a plaque source consisting of flat strips which may contain more than 10000 curie per strip and several such strips can be assembled together in steel wafers or other such material wafers and the number of strips are assembled by remote controlled operations.

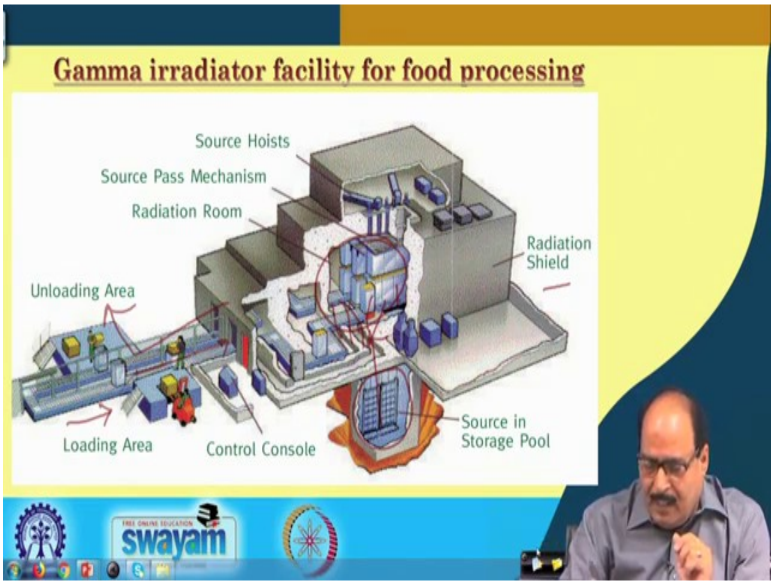
The source is immersed in 25 feet or more deep storage pool of water when not in use as to prevent the escape of radiation into the environment. Cobalt 60 is used presently but Caesium 137 can also be used as it also has good potential for application in food processing.



There are several types of linear accelerators which have been used. Machine can generate beta rays or X rays. Machine sources produce no waste outside 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. The working principle of two commonly used accelerators like linear accelerator and electrostatic accelerator is shown here. In the case of electrostatic accelerator, electrons move through a high voltage terminal and come down to high vacuum discharge tube where they are accelerated finally and scanned to cover the target area. In the linear accelerators, electron pulse is accelerated as it moves downwards and is trapped in waveguide. It is accelerated and electrons move with the higher velocities with the radio frequency accelerator. The electron is scanned finally through the scanner to cover the uniform area.

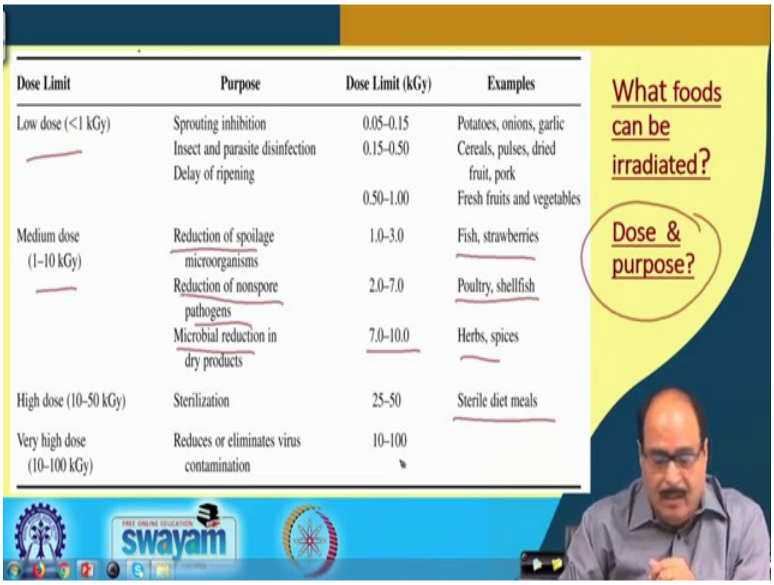


Commonly used radiation source includes cobalt 60 source, electron beam, and X rays. Cobalt 60 has a high penetrating power, permanent radioactive source, high efficiency, source replacement needed after sometime and when this energy is low, low throughput. Whereas, the electron beams have a low penetrating power. It has the switch on/off capability, it has high efficiency, high throughput power and cooling is needed and technically complex process. X rays have high penetrating power, switch-on/off capability. It has comparatively low efficiency, high throughput, power and cooling needed. Like electron beams, technically it is complex process.



The figure shows a gamma irradiation facility for the food irradiation. Gamma irradiation source cobalt 60 is kept in storage in the deep pool of the water. The food material depending upon its type in the packaged or unpackaged form is exposed to the irradiation.

The food in the packaged or unpackaged form is sent through the loading area and comes out through the unloading area. The material passes through the irradiation chamber where there are radiation shields at different layers of concrete walls. Depending upon the type of the food and requirement of the process, the speed of the conveyor belt is controlled by a remote control operation. The food is exposed to the gamma rays. There are factory systems where the food can be exposed from both side to the gamma rays and after it is exposed and given the desired energy for the required operation it returns back to the unloading section. This is how irradiation technology is commercially performed.



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 of may be less than 1 kilo gray can be used for sprouting inhibition, insect and parasite disinfestation, and delay in ripening in the case of potatoes, onions, garlic, cereals, pulses, dried, fruit, pork etc. Medium dose may be 1 to 10 kilo gray can be used for reduction of spoilage of strawberries. Reduction of non-spore pathogens in poultry, shell fish and microbial reduction in dry products like herbs and spices can be achieved by using 7 to 10 kilo gray. High dose or very high dose in the order of 25 to 50 or 10 to 100 kilo gray is particularly used for sterilization purposes or for elimination of viruses to produce sterile diet meals.