**Applications of radioisotopes: Industry, environment, agriculture and food technology**

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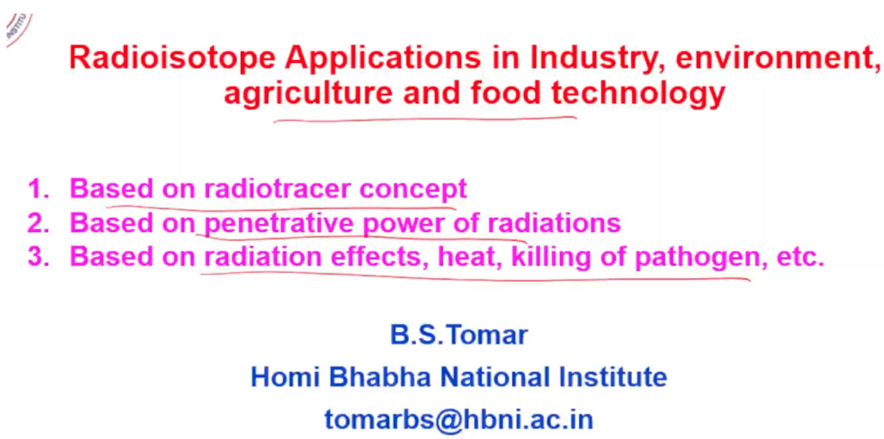
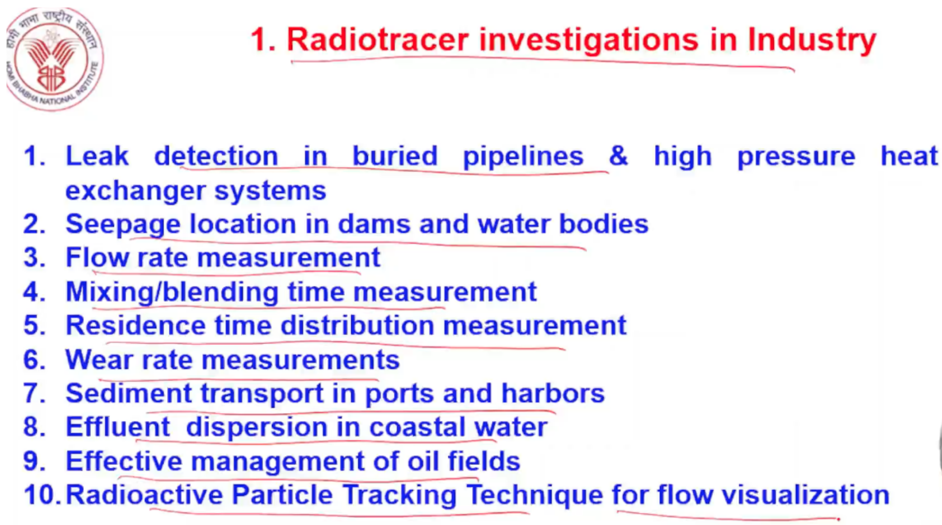
**Lecture-20, Module-2**

Hello everyone. In the previous lecture, I discussed the applications of radioisotopes in healthcare, both in diagnosis and therapy. And I also explained the three main concepts behind these applications. I will like to repeat those three concepts for the sake of continuity. And in the present lecture, I will discuss the applications of radioisotopes in industry, environment, agriculture and food technology. Though the topic is very fast, I will just take one or two examples in each area to bring home the point.



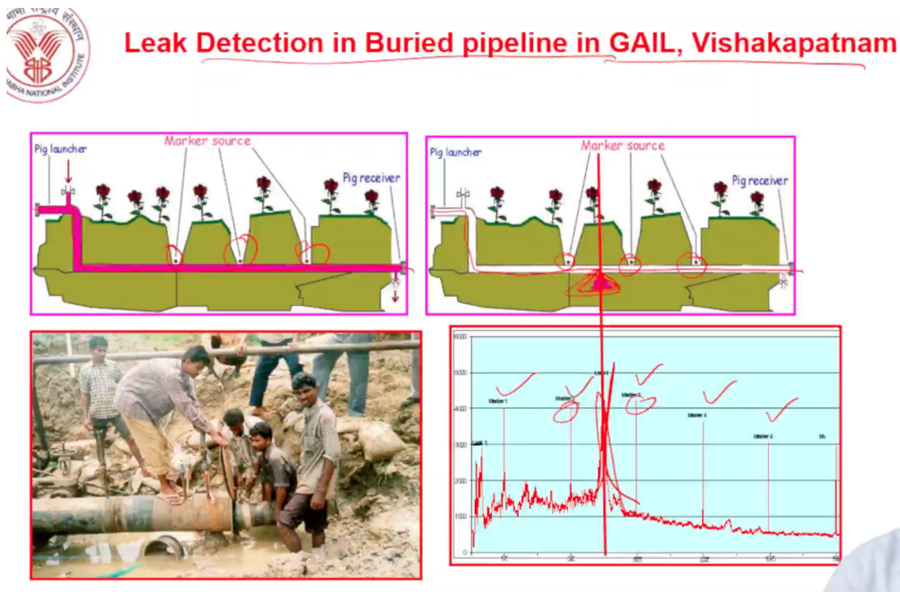

(i)So, as I mentioned previously, the radioisotopes can be used in the form of radiotracers. The radiotracer, can be used to trace the path of an element. So, that finds a lot of applications which will be clear when we discuss these applications. (ii) Radioisotopes are emitting radiations which are highly penetrating and this can be used like, we use x-rays for detecting the fractures in human body, in the bones. You can use radiations in many applications which will become clear subsequently. (iii) And the other aspect is that radiations can kill pathogens, they can generate heat, they can introduce defects in the materials. And you can even use polymerization of the material. So, you open up new areas for applications and one has to do a research, what way you can use radiations in different applications. So, atoms in the service of mankind, that is the concept we use that not only these radioisotopes can be used, we have to have in mind what is the benefit.

So, the benefit can be in terms of money, you save the money, you save the manpower, you save the time. So, unless you have the gain in terms of these three parameters, money, manpower and time, if there is an alternative methodology, then there is no point in using this. So, it should score over other techniques, in terms of all the three aspects that I just mentioned. So, I will just give some examples of each, these three previously one I have mentioned, radiotracer concept in industry and the list is endless. I will give you some examples also.




So, leak detection in buried pipelines and high pressure heat exchangers. So, the pipelines are going thousands of kilometres like from refinery, for example, from Gujarat to Mathura, there is a big pipe line going, the refinery is in Mathura and crude is going from somewhere in Jamnagar. So, if there is a leak in this, how you detect the leak, and if you have to dig out the whole thousand kilometre, it is a very, very herculean task. So, that is where the advantage of radioactive isotopes. Seepage, location in dams and water bodies, you can trace the path of the water by using radiotracers, flow rate measurements, at what rate the fluid is flowing, time of mixing and blending in the different types of industry, residence time distribution, there are mixers and many chemical reactors, wear rate measurements, you can introduce a radioisotope in the machine part and if it is wearing out, you can see how the wear rate takes place, sediment transport in ports and harbours, effluent dispersion in coastal waters, these are all very big experiments which the enormity of the experiments will be clear when we have some results.

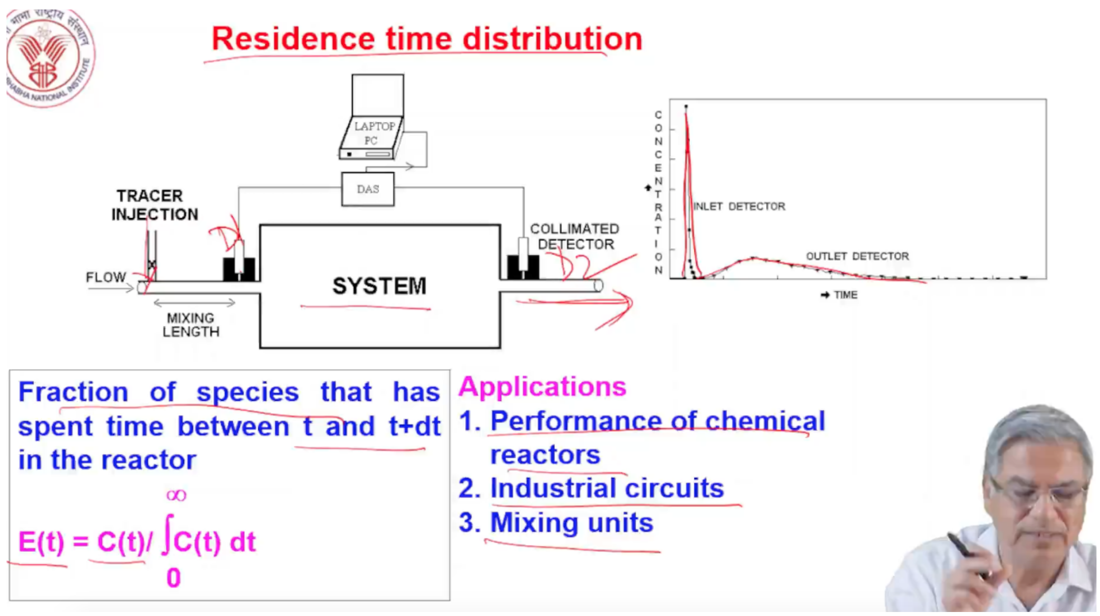
Effective management of oil fields, so oil field, you know, there you are taking out the oil and then the water will rush, so how much time we can continue to tap this oil field, there are techniques based on radiotracers, you can do the time management. And radioactive particle tracking technique for flow visualisation in the reactor which is monitored from outside, how the particles or the reagents are moving in the reactor, you can track and you can simulate the processes that are occurring inside that. These are some of the examples which I wanted to highlight, but I will take some of the from this and illustrate by these examples. One of them is leak detection in buried pipeline and I will give you the real examples from one of the Gas Authority of India Limited (GAIL) Visakhapatnam.




So there is a pipeline, very short explanation I will give, suppose you have got a pipeline here and the fluid is flowing from here to here, it can be hundreds of kilometers and suppose there is a leak somewhere here.

Now how do you find out where is the leak, you cannot dig the whole line. So what they do, they first put place the marker sources from the surface like Co-60 sources on the surface. From the surface you just dig them and put above the pipeline, they are outside the pipeline and now you inject the fluid containing the radio-isotope like ethyl bromide. If it is a liquid, you can use bromine-82 labelled liquid. Then wherever there is a leak, the activity will come in the soil and now you take a detector through this pipe at a particular rate.

The detector will detect not only the leak but also the gamma ray from the markers. So in the output of the detector, you will see these markers, they will tell you the position of these markers. So you can know, suppose there is a leak here, you will see a broad peak here. This broad peak is due to the leak and you know this is between these two positions. So in a very short span of time, you can identify at what place the leakage has taken place and you need to dig up only in that area to plug that leakage. So this way, we can save time, effort, money and manpower. And this is a typical photograph how people are injecting the radiotracer through this pipeline.



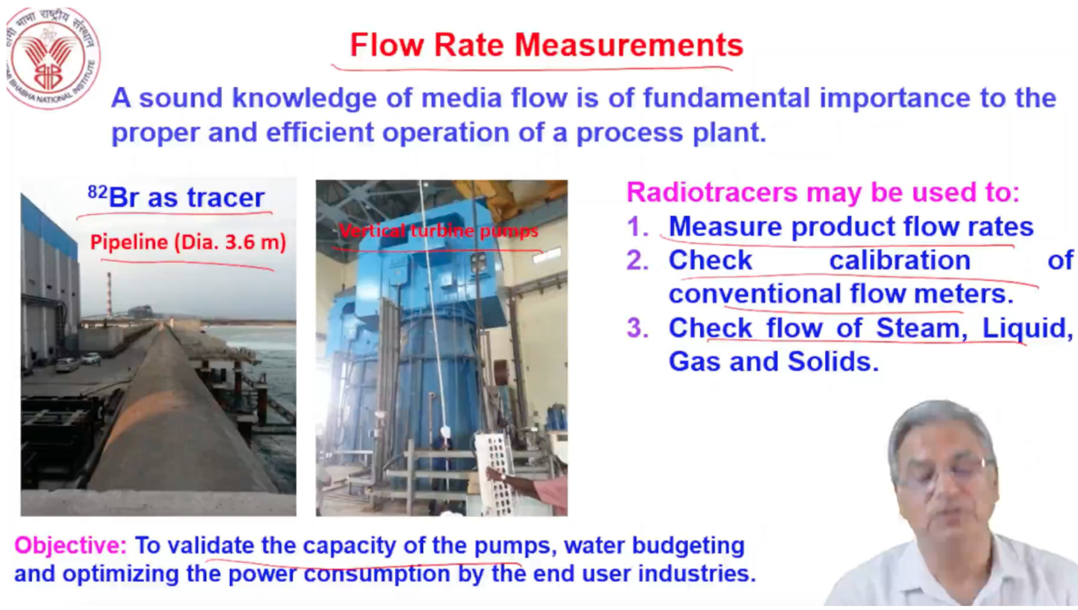

Another important application of this radio tracer is residence time distribution. There may be many different types of chemical reactors where you mix the reagents A plus B going to some system and there is some process taking place in the system and then there is the output. So you have an input and the output. Now inside the reactor from outside it is blank. You do not know what is the hydrodynamics of the material that is undergoing churning in the system. So you want to know what is the time during which the reactants stay or the product stay in the reactor. So you put a detector here, you put a detector here and then you inject the radiotracer. Radiotracer when it goes at inlet it will show a sharp peak because it is quickly flowing in the system and the outlet you will see you get a broad peak because inside the reactor the radioisotope labeled material will take some time.

So for example, you are mixing sand and cement. So you tag the sand with the radioisotope like scandium-46 and then you want the homogenized mixture coming out of this blender. So inside how much time it is residing and what is the uniformity you can know from this one. So residence time distributions are utilized in many chemical reactors. The performance of the chemical reactors is equally determined.

You can have even industrial circuits, there can be many other plants, the mixing units, I was telling the mixing units, cement and sand or there can be many other industries where the chemicals are being mixed. So how well the reagents are getting mixed, you can find out from the residence time distribution. So residence time distribution is given by

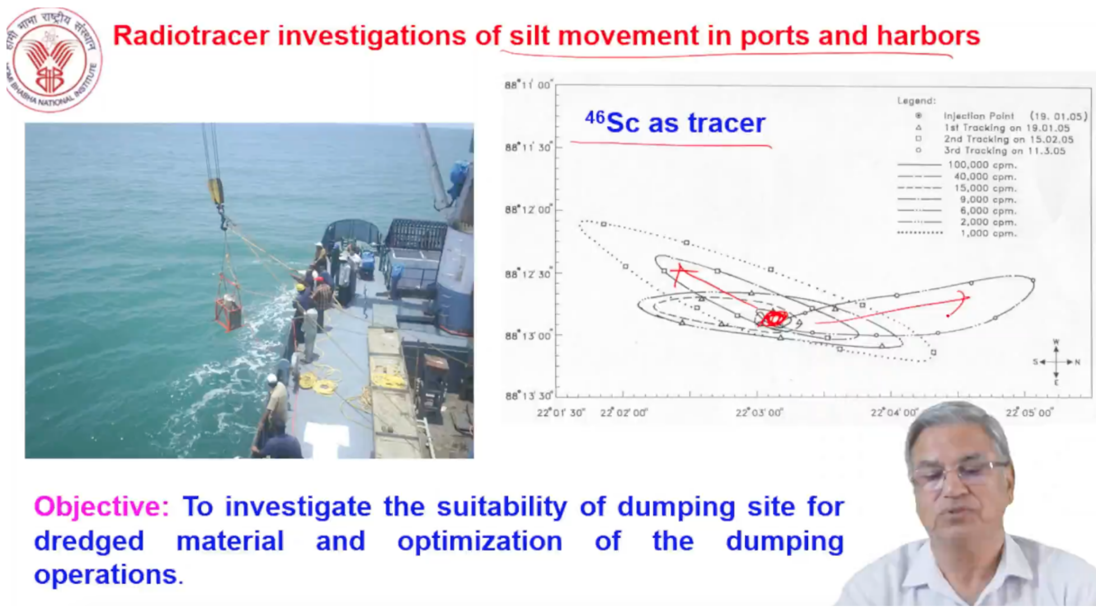
$$E(t) = c(t)/\int_0^{\infty} C(t)dt$$

Where $E(t)$ is the fraction of species that has spent time between t and t + dt in the reactor. So this is the concentration of the particular species that has come in the time t to t + dt and this is the integration in the denominator you have the entire concentration, total area. So this is the total area under this graph is the constant, total concentration and at a particular time what is the fraction of activity that is come. So this is the residence time distribution for how much time the reagent is residing in the reactor this study can be obtained.




Then you have flow rate measurements, you know, they are all big projects, very, very big projects involving hundreds of crores of rupees and we can see by one experiment one can save so much of money. In fact, sometimes you will find there is no alternative to these techniques. So for example, this is actually a hydro-electric plant, so there is some 3.6-meter pipeline which is taking the water to the turbine. Now these vertical turbine pumps, they have a rated capacity with how much water they will pump per minute or so. So that is the capacity of the pump. So you want to calibrate this because how much is the power consumption of this pump, what is the flow of the pump. So to calibrate these pumps, you require to do investigation and how to investigate the pump capacity, the flow rate and all that. So for this the bromine-82 can be used as a tracer.

So what you do, you measure the flow rates of water. So in water you can mix sodium bromide labeled with Br-82, and so what bromine will go with the flow of water. So you can use this technique and you can put suitable detectors at initial and final stage and you can see the activity that is flowing. So you can check the calibration of flow meters or you can check the flow of any fluid, steam, liquid or gas you can use. So in fact, these are the pumps made by the industry and when they are selling to the thermal power company, they want them to calibrate these pumps to ascertain, you have to give a certificate, this is the capacity of the pump and this is the wattage of the pump. So if you want to validate the capacity of the pump, water budgeting and optimize the power consumption, then the industry can come to the people who are doing this kind of investigation. So this is actually an example which the Department of Atomic energy in fact solved this problem for the industry.

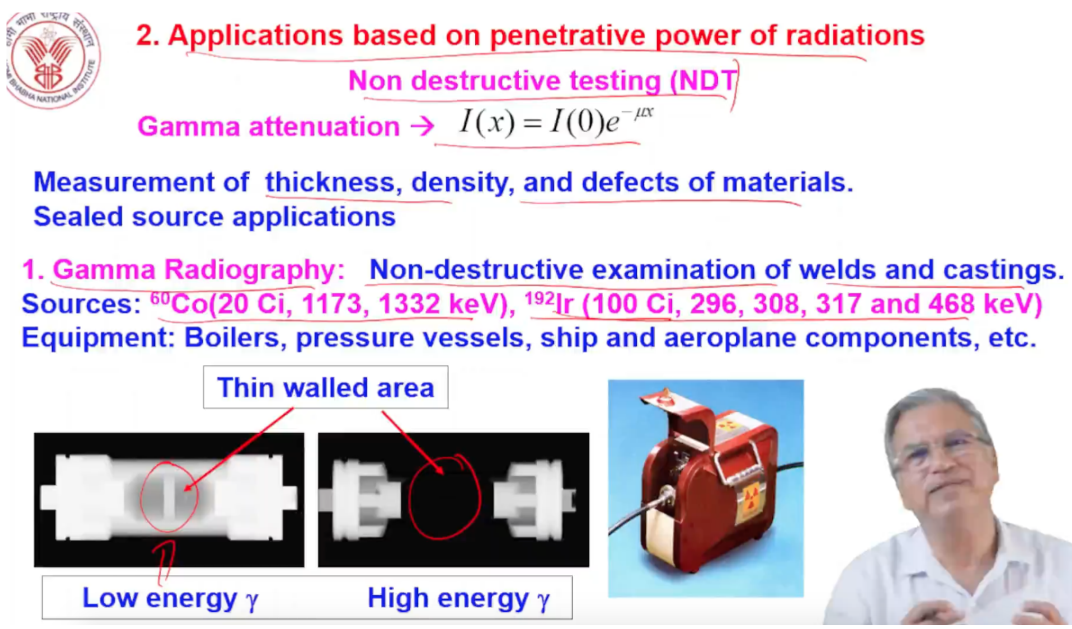



Another kind of investigation is silt movement in ports and harbors. So what is this silt? See in the big ports, you know, the big ships are coming to the dock and gradually you will find that this dock height will rise, the level will go up because there is a movement of the silt in the sea. And so what do they do? Dredging. Dredging means they remove that silt and park it somewhere in the sea so that the big ships can come to the shore. But over a period of time that silt will again come and you have to do the dredging again and again. So it is very time consuming. In fact, this is an experiment at Kolkata port. So what was done actually that the sand particles were labeled with scandium-46 as a tracer.

So the movement of the sand can be traced using this radioactivity of scandium-46. So what they do? They dredge this silt and park it somewhere quite far off. And so this is the place where they have placed the dredged sand which is now tagged with the radioisotope. And over a period of time, now you map, you measure the activity of scandium-46 in X-Y direction. And you can see here, these are the contours of activity isometric points.

And so essentially this tells that these tracers, this tilt can move in these directions. In this direction, there is no movement. And so you can identify in which place you should put that dredged silt so that it does not come to the port or harbor as a function of time. So these are the kind of mega experiments which you can do. So they are used to investigate suitability of dumping site for the dredged material and optimization of the dumping operation. So in what place they should place the dredged sand so that it doesn't come back to the place from where it was taken out. These are the kind of experiments we will be doing.

So these are the few examples of radiotracer application where you trace the path of the radioisotope. And then you can trace the path of sand, you can trace the path of a chemical, anything you can trace the path of a fluid, even water body you can trace the path.




Then other application is penetrating power of the materials. So when the gamma rays are penetrating through solid material and they follow this exponential decay,

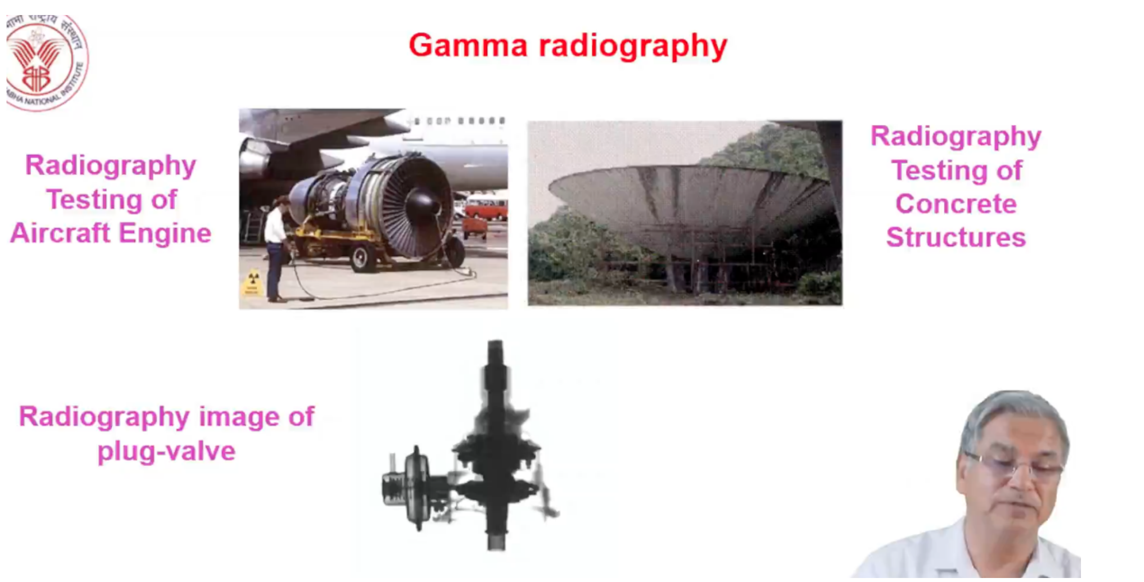
$$I(x) = I(0)e^{-\mu x}$$

where μ is the attenuation coefficient. So these techniques are called non-destructive testing methods (NDT). NDT is very useful in the industry for measurement of thickness, density, defects in the materials. For example, in the high technology materials there is some welding to be done. So how good is the quality of the weld because they are going to remain in the plant for long, long times. If the welding is not proper, it will affect the integrity of the system. And for that, gamma radiography is used extensively in industry. In fact, we train the people who do gamma radiography in the industry. So there is a training program in the Department of Atomic Energy, one can enroll for that and do the certificate course and then you can become a radiographer. So the non-destructive examination of welds and castings, this is not the only example, you can have many other examples.

You require, you have a high energy gamma source and low energy gamma source for radiography. If it is a heavy material, big equipment, you require high energy gamma, typically a cobalt-60 of 20 Curie. And if it is a smaller product, smaller machine, then you need to have low energy gamma emitter and 100 Curie of Ir-192. So like, boilers, pressure vessels, ships, aeroplane components, all can be investigated for their integrity, their structure, there is no crack inside, micro cracks, there could be micro cracks. The radiography can tell you even micro cracks.

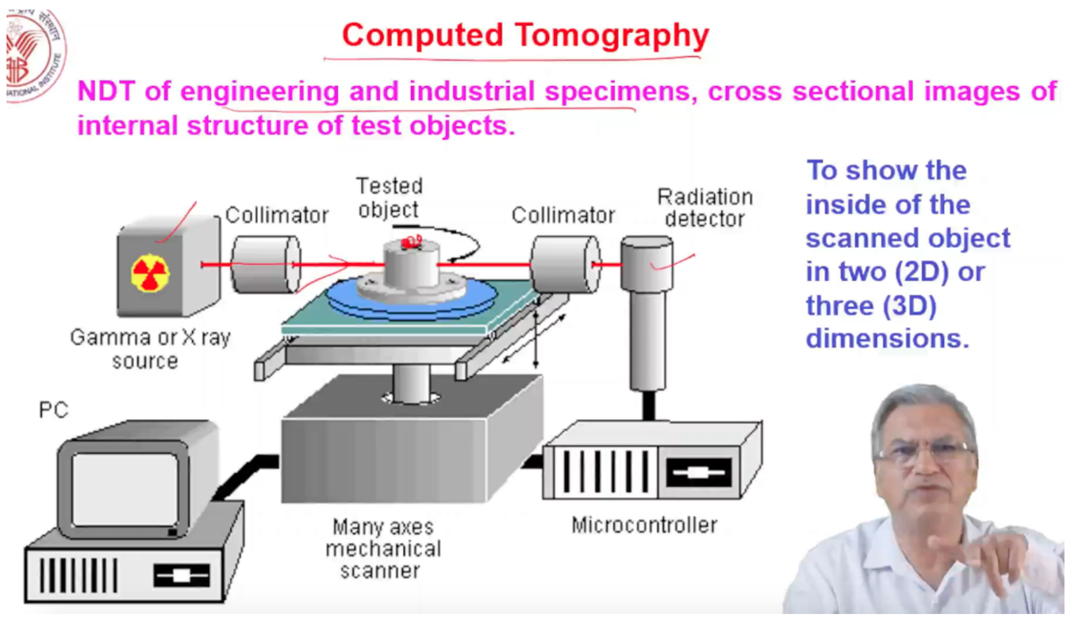
And so this is a typical example of a component, a component which has got thick parts and thin parts. This is the area where it is thin walled, that means it doesn't have much thickness. So when you do gamma radiography with low energy, Ir-192, you can see some opaque part. But when the same thing you see with cobalt 60, we don't see that part because gamma energy, cobalt 60 gamma will just pass through. So by playing with the gamma ray energy, you can investigate the different types of samples, small or big.

And this is a typical gamma camera called ROLI, developed by BRIT, the Board of Radiation and Isotope Technology, DAE. So this can be taken and the source is kept inside the shield. And when you want to do the radiography, you take out the source from the shield, expose the sample, and again, after the exposure, you take it back to the shield. So it can be transported in different places for NDT experiments. So these are the kind of big machines, radiography of aircraft engine, of corporate structures, or even the plug valves.




The small as well as the big machines can be done, you need to do radiography because as a part of the quality control, you have to assure the end user that this will meet their requirements. So when you say an aircraft, the probability of accident one in billion times, how that number comes? Because they have undergone through tough tests like this kind of testing.

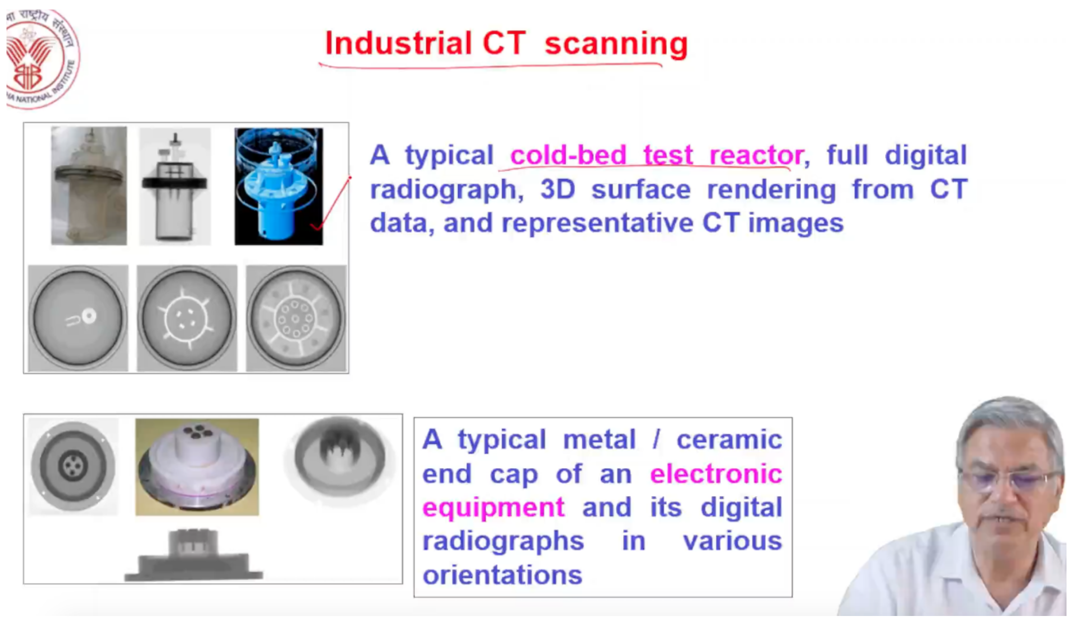
Now I come to another NDT technique called Computed Tomography, CT. The Computed Tomography is an advanced version of radiography, where you not only take the image, you get 3D image of the equipment. So NDT of engineering and industrial specimens, you can do even cross-sectional images of the internal structure of the object.




In radiography, you just expose the equipment to the gamma rays, and you take a film on which you can take the image of the aircraft, like you take an X-ray. So radiography is like X-ray, but tomography is much more advanced. So you have an object, you put the object here, and there is a source inside this shielding, so there it could come as a beam through this collimator, and you can do X-Y Z movement of the object by a goniometer, and then the gamma ray will go and by a collimator will fall in the detector. So what you do, you rotate the object in X-Y-Z direction so you get cross-sectional image of each slice of the object. So you can go take it up, you get the circular plates, circular images, you take in X-Y direction, you get different cross-sectional area, and those images are then constructed by the computer to develop the 3D image of the machine part.

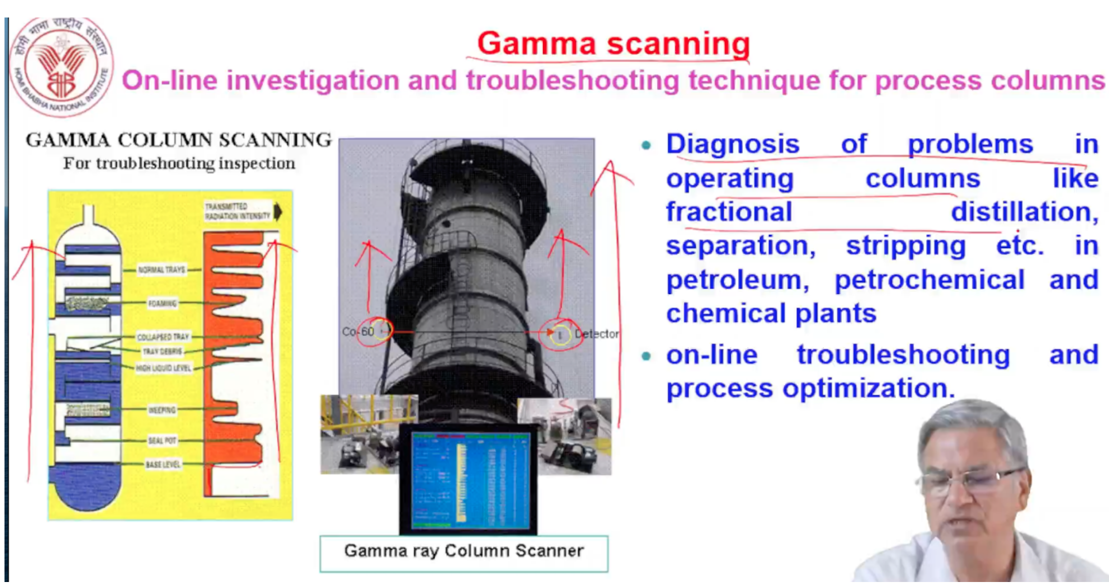
So this is the more advanced version of radiography where you get the 3D image. And these 3D images are then, you can see, such a crystal clear image you get after computed tomography. So this is a typically a cold bed test reactor. You can see the kind of image that you get by computed tomography. The full digital radiograph 3D surface rendering from CT data as a representative.

So you can see the kind of resolution that you get because you have a collimated beam of gamma ray and then you get the image. So in one scan you will get a particular plane of the system and you have thousands of scan in X-Y, Z direction. So that is the kind of resolution that you get. Micron levels of fractures you can detect using computed tomography.




This is the image of a typical metal or ceramic endcap of an electronic equipment. Again, the point I want to emphasize that by computed tomography you get much more well resolved images than the normal radiography.

Another application is in gamma scanning. Gamma scanning is another area for troubleshooting investigation.

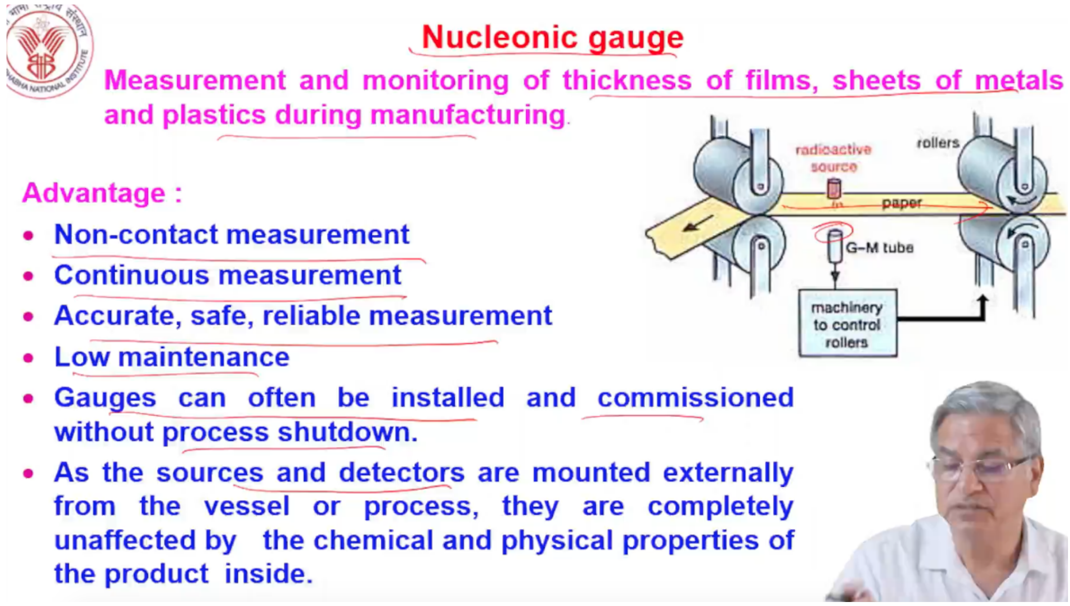


For example, for fractional distillation in the refineries, you have big towers. And these towers will have different collectors of different types of products, of the petroleum products. So they are working for a long, long time and suppose there is some defect inside. You are not getting the product of desired quality. So how do you rectify? You see, if you open it up for maintenance, it may require shutdown for a week or two and that is huge loss to the industry. So what you do non-invasively, you can do, you put one detector, you put a source, Co-60 source here and you put a detector, NaI(Tl) detector and they are moved synchronously. So if the source moves, detector also moves by the same distance, so they are joined together.

Now what you are getting is the attenuation of the gamma ray of Co-60 when it is passing through the internal parts of the column. So this column, so this is the cartoon of the column. There are different plates inside, different fittings are there. So the gamma ray intensity you will see, when the gamma ray is passing through a thick object, the intensity will be low. So that tells you the profile of the different objects inside the column.

Now if you have taken this profile in the beginning when the plant was started and you can periodically monitor, so as a function of, anytime there is a problem in the plant, you can immediately run the scan and find out if there is a flaw. So this scanning of this column and it is very low cost. A Co-60 source and a detector sodium iodide, thallium is not at all very costly. So manpower will be one or two personnel and even in a day you can do the whole investigation. So you save the time, money and the manpower and by very, very low cost, very short time, you can do troubleshooting of the problems that are occurring in the plant. So the diagnostics of problems in operating columns like fractional distillation, separation, stripping, etc., in petroleum plants. Very quickly, in fact many of these refineries of Hindustan petroleum, many petroleum companies employ these techniques to do troubleshooting whenever they have problems in the plant.

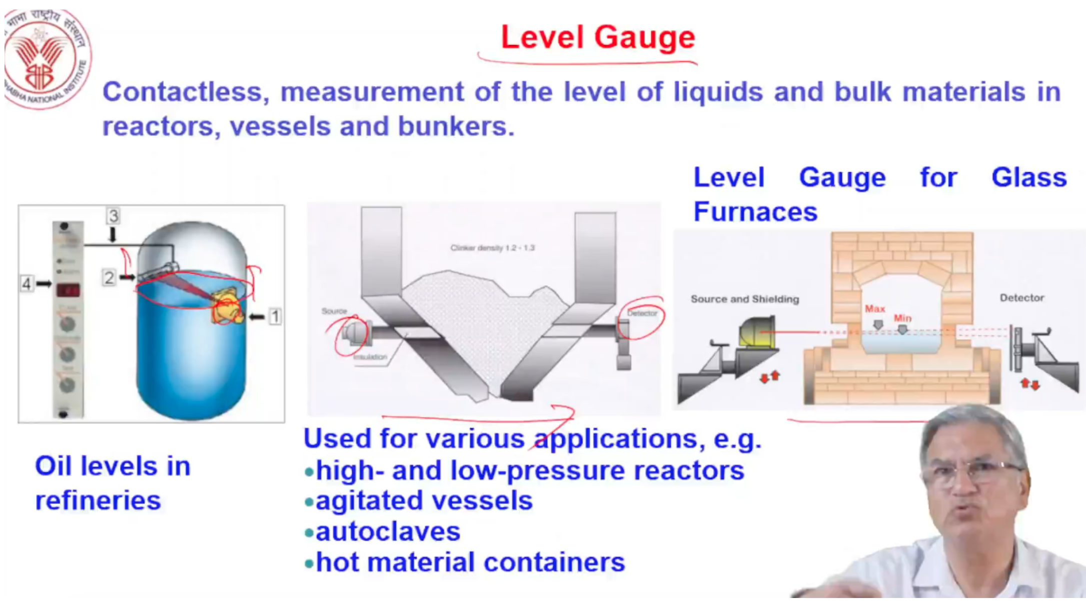
Now I come to another aspect based on the penetrative power of the radiation, called the thickness gauge, Nucleonic gauges. So you can determine the density, thickness, level of a compound and so on. So measuring and monitoring the thickness of films, sheets and metals and plastics during manufacturing.




In the paper industry, the paper is prepared and it is moving through a conveyor belt and the paper quality you say this much gram per square meter, GSM, 100 GSM, 50 GSM and so on. So how do you maintain that quality control? For that you can have a very simple system. You have a radioactive source outside, this is the paper which is moving, above the paper you have a source, below the paper you have the GM, Geiger-Muller counter, very cheap equipment and if you have a metal plate you can put beta, if you have a thicker plate you can put gamma, if it is a thin paper you can put alpha source and then measure the activity as a function of time. So suppose the thickness is constant, you will get constant activity in the counter. But whenever there is a change in the thickness, the intensity will change.

So beta and gamma can be used to find out the change in the thickness. But in case of alpha, there is the change in alpha energy because alpha intensity will not change as a function of thickness. But alpha energy will change. So very thin foils, micron thick or less than that, you can use alpha and for millimeter thick, you can use beta or gamma sources.

So they have the advantage of non-contact movement. You can place it even while the plant is running, you can do continuous measurement, accurate, safe and reliable. There is hardly any maintenance, the plant need not to shut down. Gauges can be often installed and commissioned without process shut down. And as the sources and detectors are mounted externally from the vessel or process, they are completely unaffected by the chemical and physical property of the plant. So, it is non-invasive, the plant is running, you can do all modification in this system to determine the thicknesses without affecting the plant. That is the kind of advantage with this. The examples are level gauges, oil level in refineries, refinery the vessels are few lakhs of liters plant.




So this level of the fluid you can do, you have a source and a detector, you put a source and detector. So when the gamma ray source is below the level, you will see the high attenuation and when it is above the level, there is less attenuation. So you can see there will be a discontinuity at the level. Similarly, you know this when you have the mixers and so there is an uneven level inside like clinkers as in cement industry. We put a source and a detector here and from the attenuation, the intensity of the gamma ray in the detector, you can see the level of the material inside this plant.

The glass furnace, the glass, the molten glass, what is the level of molten glass, you do not know from outside. But if you put a source and a detector, the attenuation in the gamma ray when it is going through the molten glass will be more and if it is above the molten glass level, it will be less. So very precisely you can find out the level of the glass furnace. So level gauges, similarly you have density gauges and so on. There are many, many areas where you can use these radioisotopes.

## 3. Applications based on radiation effects, heating, killing of pathogens

1. Agriculture→ Crop improvement by radiation induced mutation
2. Food technology: Food preservation by irradiation
3. Radiation Sterilization of medical products
4. Radiation processing: Radiation induced polymerization, Sewage sludge hygienization, Curing of surface coating and heat shrinkable foams, treatment of flue gases, etc.

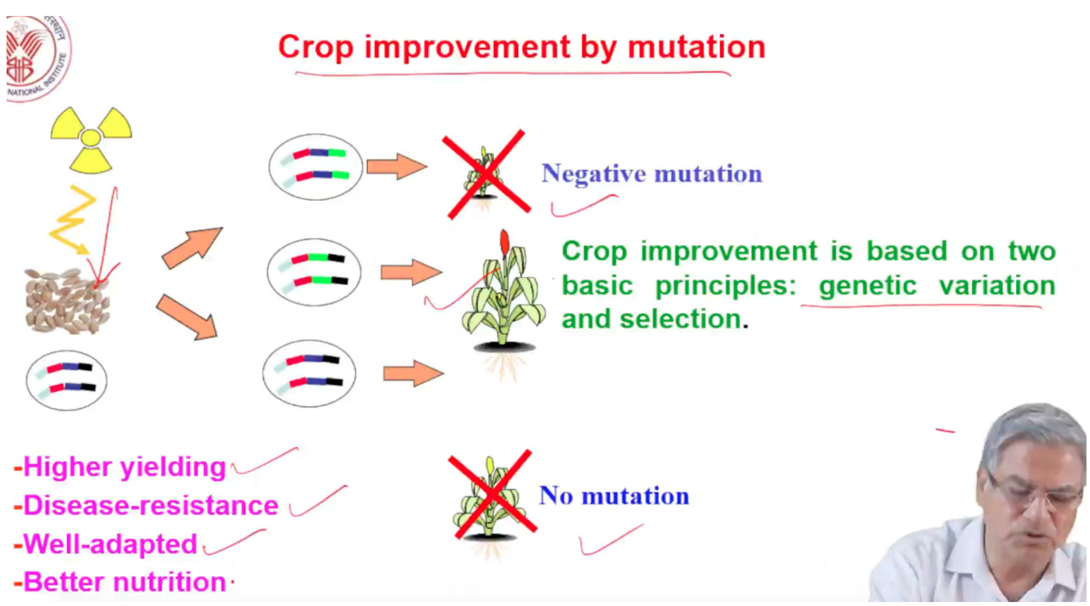
Okay, lastly, I will discuss the application based on radiation effects, the heating, the killing of pathogens and so on. And there are, I will talk about three areas.

One is agriculture. In agriculture, you can do crop improvement by radiation induced mutations. Radiations when they are bombarding the seeds, then they can induce mutations. Normally, the seeds are undergoing mutations. Even our bodies are undergoing mutations, but that is happening at a very, very small rate $10^{-5}$ or $10^{-6}$ scale. But you can accelerate the mutation by radiation, by orders of magnitude, 1000 to 10,000 times faster mutations can take place.

Food technology, the radiations will kill the pathogens, you can do disinfestation and you can delay the ripening of the fruits and you can do sterilization of medical products. Again, the pathogens can be killed. And also the radiation processing. You know, radiations can induce polymerization in materials. So like rubber, the vulcanization of the rubber can be done by radiations. You can hygienize the sewage sludge and use it for the manure. In cities now, there is a big problem of sewage sludge. So you can make it hygienic by using radiation and then you can use it as manure.

Curing of surfaces, coatings, heat-shrinkable foams. So you know, radiation technology is a vast area. There are a lot of applications. You can modify materials, you can graft a compound on a solid support. There are a lot of modification processes using radiations. You know, radiations can induce cross-linking in polymers. It can even cause chain reaction. Like Teflon can be powdered by radiation, but the normal polythene will become hard by cross-linking. So I will not touch upon this aspect. I'll just quickly give you the example of the first three.

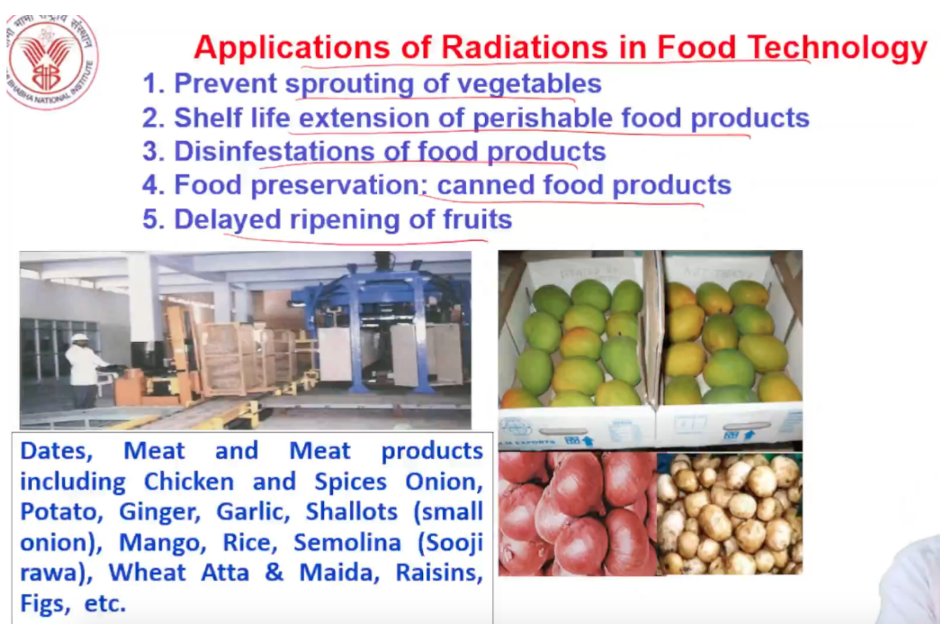
First application is in agriculture, you can do crop improvement by mutation. As I mentioned, radiation induced mutations, you can enhance the mutation by radiation.



So you irradiate the seeds by gamma rays. The gamma ray will cause genetic changes in the seeds and then you will sow these seeds. So a priori, we cannot say what will happen to the seed. We cannot selectively generate positive mutation. The mutation can be negative. So you will come to know after you harvest the seeds. The mutation can be positive. That means the fruits that you generate out of these mutated plants, they can have good traits, positive traits, or there may not be any mutation, no effect. So once you sow them, once you harvest them, then you pick up the ones which have the positive traits.

So the genetic variation you see and select them and multiply them five, six cycles. So once the genetic changes have become stabilized, then the variety is released to the government agencies which will approve that this is now certified to be used by the farmers. So what are the traits? What are the attributes that you can have? High yield variety, so per hectare, how many tons, that is a parameter. Disease resistance, after genetic modification, they can adapt to the adverse weather conditions or better nutritional value. So these are the parameters which you can see. If they are improved, then you know that we have produced a good crop variety.

Second is the applications in food technology. You can prevent the sprouting of vegetables because the radiation will kill the bacteria, they will deactivate the enzymes, you can extend the shelf-life of perishable products because you can delay the growth of the microorganisms, you can disinfest the food products, spices, meat products, canned food products you can preserve for a longer time and you can delay the ripening of fruits like mangoes.



So this is a typical plant for irradiations and so many products have been certified, approved for irradiation by gamma rays: potato, onions, several types of food products are now certified for irradiation by the gamma rays. So there is a long list of products I have listed here, meat, meat products, chicken, spices, onion, potato, ginger, garlic, shallots, mango, rice, semolina. All these products are now certified for irradiation to improve their shelf-life.

Lastly as I was mentioning you can sterilize the medical products using an irradiation plant and so you pack the implements, the medical devices like, use and throw, types of medical syringes, surgical gloves, tools used in surgery, tweezers, scissors and so on and you pack them in cardboard boxes.


These are the cardboard boxes and you put them so there is a source in the plant and this in the conveyor belt, the packets will go, stay there for some time and after proper dose has been delivered they will be taken out and then sent to the hospitals or industry. So there are several plants in the country now running and one of the first plants was ISOMED at Trombay for the last more than four decades it has been working and this industry is very much growing now. Now people have various plants not only for medical sterilization but also for food preservation. So combination of medical sterilization and food technology are making the throughput high and many private industries are now developing these irradiators for the benefit of mankind.

So that's all I have to say I wanted to bring home the point that not only the research should be done for understanding the systems or phenomena but the research that is going on in the laboratory must reach the land and for that you need to have innovation, development of technologies. So you do the research then develop, demonstrate and deploy. So any research should be ultimately going to be useful for the mankind. Thank you very much. Thank you.