Indian Institute of Technology Madras

National Programme on Technology Enhanced Learning

NUCLEAR REACTOR AND SAFETY AN INTRODUCTORY COUR

Module 02 Lecture 02

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So good morning everybody! In the last lecture, we just saw what are the different sources of energy from which we get our electricity. We saw the coal, the hydro generation and nuclear power and we also had a look at the carbon emissions, from these which are very responsible for Reno's effect, then we went into some other aspects.

Utilization has been there like in the field of medicine in Environmental Protection in agriculture, then sterilization of most of the articles used in surgery then Radio pharmaceutical, and it’s utilization in cancer diagnosis, and treatment then of course industrial radiography, food preservation, and a variety of uses which we come across in our day to-day life .

Finally we saw an aspect of course, the story of three men and a tiger I told you that there's a risk perception of everybody but there is nothing like absolute risk zero risk, you have to compare the risks of different things and as you know returns you get more when you take risks in the investment business. However in the last lecture. I got some questions from some of the students. One was, I talked about treatment of waste water and Treatment of sewage water.

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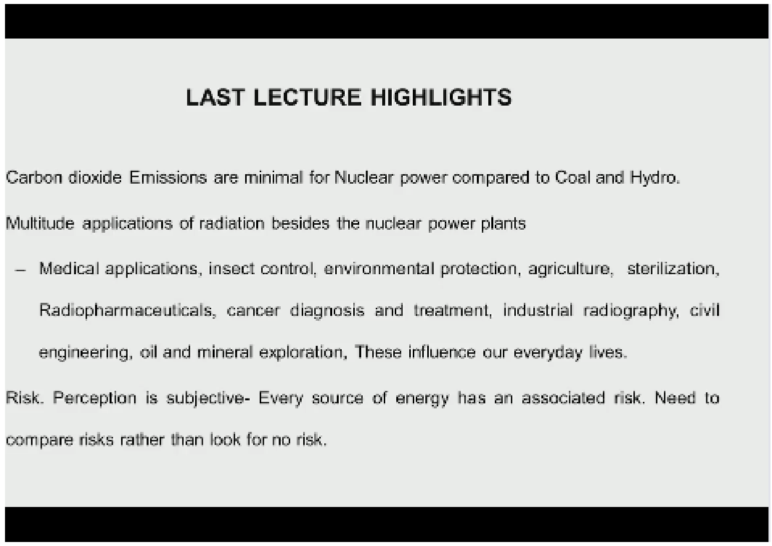

So the question was what is the difference between the two? Waste water refers to the water that is discharged from the industries like chemical industries could be leather industry, textile industry, mining or any other manufacturing process industry and this water it contains a lot of bacteria, chemicals and quite good number of contaminants and when you do treatment with radiation, it reduces the level of the contaminants to acceptable level then you can discharge it to the environment.

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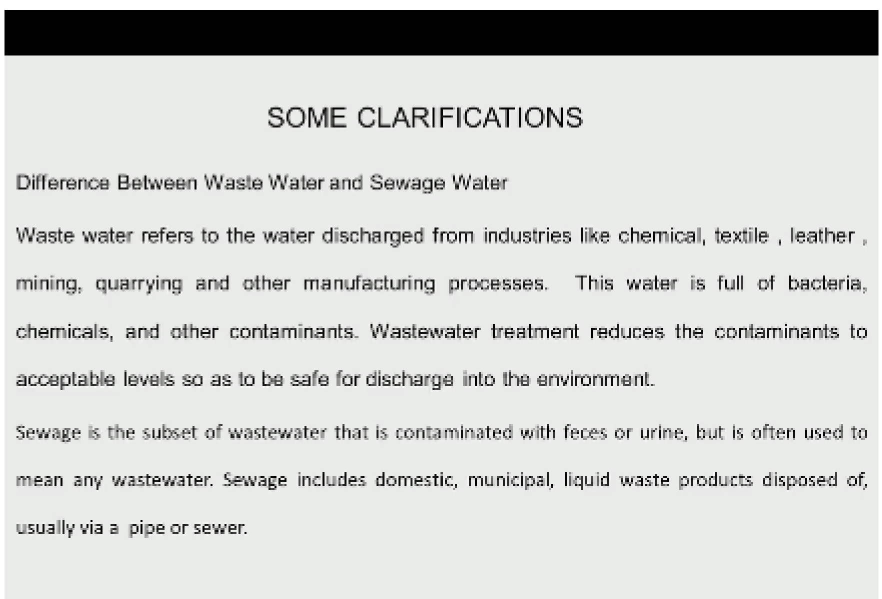

Whereas, the sewage water is that water which is contaminated with human fixes the urine, and not only which is harmful, it contains a lot of pathogens, lot of bacteria, so essentially it includes domestic waste, the municipal waste and waste products which are disposed of usually through your sewer pipes so that's why the name sewage. So, this I hope clarifies the difference between the sewage water, and the wastewater.

Now there is one more clarification asked talking about the radioactive releases from the thermal and nuclear power plants.

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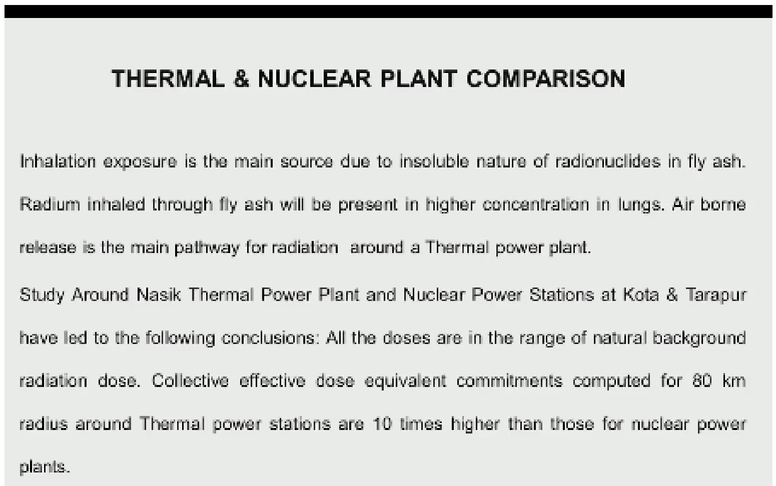

I had made a mention that coal contains through thorium and uranium when you dig it out, and this gets released when you burn it also gets to the fly bash etc. So, basically how doe s this get into our system? This release is basically due to the radio nuclides in the fly ash which are present in high concentration and they are inhaled. So inhalation is the main route by which these radioactive products get into our system and radium, of course, it has got a affinity for the lungs, it will l get sedated in the lungs, if it is iodine it will get in the thyroid. So this is the issue which needs to be kept in mind.

So overall for a thermal power plant and nuclear power stations in India, a research has been carried out and there are lot of measurements have been taken based on the IAEA’s guidelines and these studies -- to summarize have led to the following conclusions that the doses which you are receiving whether there is a nuclear power plant or a thermal power plant around that they are all around a natural background level but the collective effective doze if you compute, for a 80 kilometer radius around thermal power station, that is about 10 times than those of the nuclear power plant. It doesn’t mean that okay thermal power plant is more hazardous than this thing, it is higher. The only message which I would like to convey is there is nothing to fear about living near a nuclear plant that you are going to get radiations. So that’s the main thing which I want to convey.

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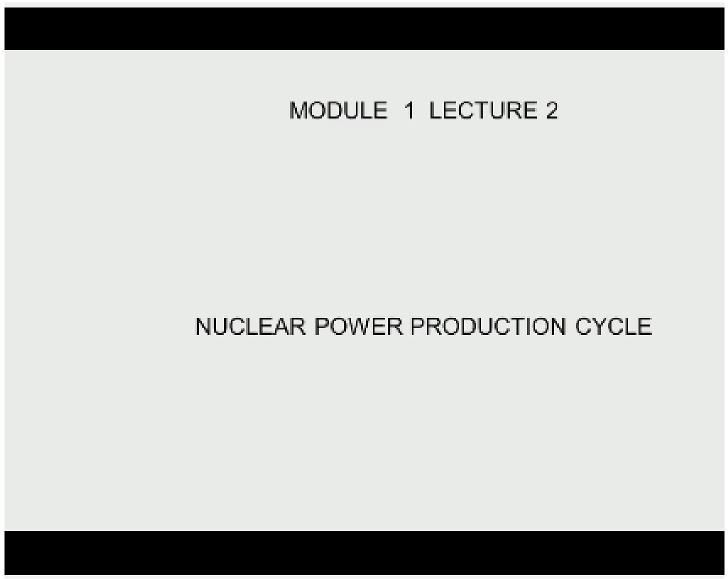

Now, having had an idea about the different uses of radiations, now let us go to the main thing about which our topic is on a nuclear power production.

Now to produce power basically we have one of the radioactive materials as Uranium-235 that is available in nature. There is only one element which can be fissioned, and that fission process produces heat and that heat is used to convert water into steam and run a turbine. Now let us have a look where is uranium come from?

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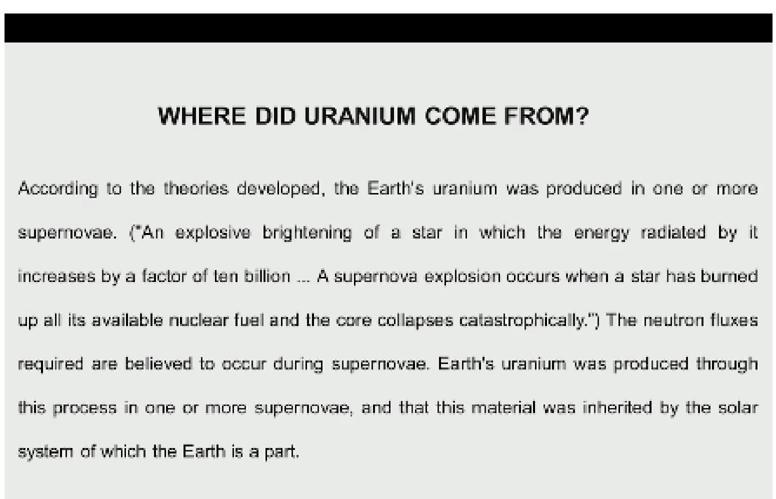

As I said it is naturally available but perhaps the Earth's uranium was produced in one or more supernova. What is a supernova? It is an explosive brightening of a star in which the energy radiated increases by a factor of ten billion, it's a huge release of energy and then when does a supernova occur? When a star has burned up all its available fuel, in fact this earth itself was formed by the Big Bang Theory in which the part of the sun exploded and formed the different planets. So the earth’s uranium was produced through one such process and it's a part of our earth, it is not in the whole solar system has, when I said the Sun there was a big bang. Sun is a fusion reactor unlike fission. We will talk about fusion and fission later in our lectures. So this uranium is not man-made, uranium has existed in a natural way in the earth.

Now let us see what does uranium does, you know we are living on the earth whereas people are not able to live on planets beyond the earth, Mercury, Venus may be the very hot. Mars, we are thinking that some people may live, Jupiter, Saturn, why? That means the earth’s temperature is very much suitable for us to live. So you require maintaining that temperature. If you look at the heat loss from the earth which it dissipates is about 42 to 44 terawatt-hours, terawatts of heat it is happening from there. But as the heat is lost surely the planet should be cooling but that is not happening. So what is happening? The heat is there because of the radioactive decay of the uranium, thorium and potassium which is in the Earth's mantle and this energy is getting transferred to the surface of the earth through the our soil and other areas.

So this way you can see and the measurements of this heat which is coming out have shown that they are somewhere between 30 to 44 terawatts and if you just compare this number with the heat loss, you can get an idea maybe that is why we are able to survive on this earth and the radioactive decay of uranium, the presence of uranium and its radioactive decay is one of the reasons we are able to survive on this earth. Look surprising but it's a fact.

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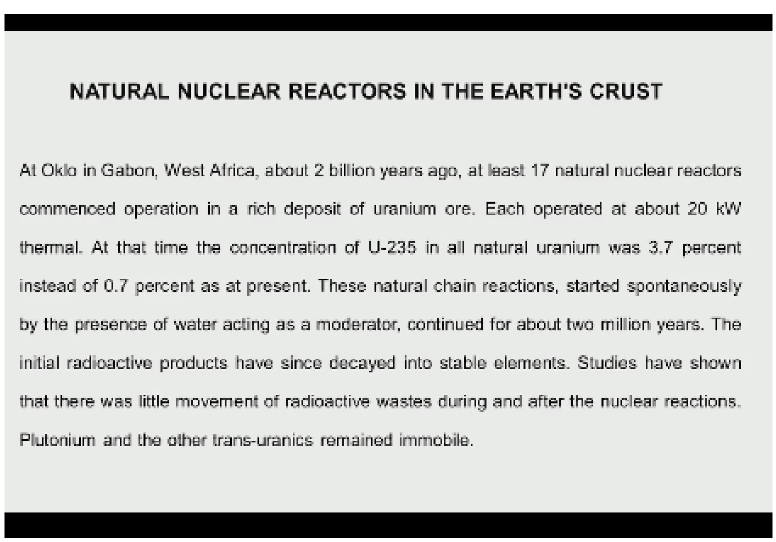

Then one might think okay the uranium is present there and this natural uranium in general contains 0.7% of Uranium-235 and 99.3% this uranium 238. This Uranium-235 is the only fissionable element which can be efficient by a neutron. So apparently in West Africa, there's a place called Oklo in Gabon people did a survey of the natural uranium deposits which are there and they were surprised to find that the it contained 3.7% of Uranium-235 and not 0.7%.

So apparently when they did further explorations, there appears to have been a natural reactor present and not only one reactor something like 17 natural reactors have been operating there and these have been like a spontaneous reaction water has been there and the water has acted as a moderator and has been able to give Philip to the chain reaction. And they just continued for some million years and many of the radioactive products that have decayed from these elements have been found in West Africa.

And one more thing which they found, they did find plutonium but this plutonium has not moved, it has been immobile this was again one of the -- what you call inputs that even though you may put a radioactive material in the earth in a place, the earth itself acts like a filter, it doesn't allow the radioactive products to move about. So this concept has been very useful in waste management.

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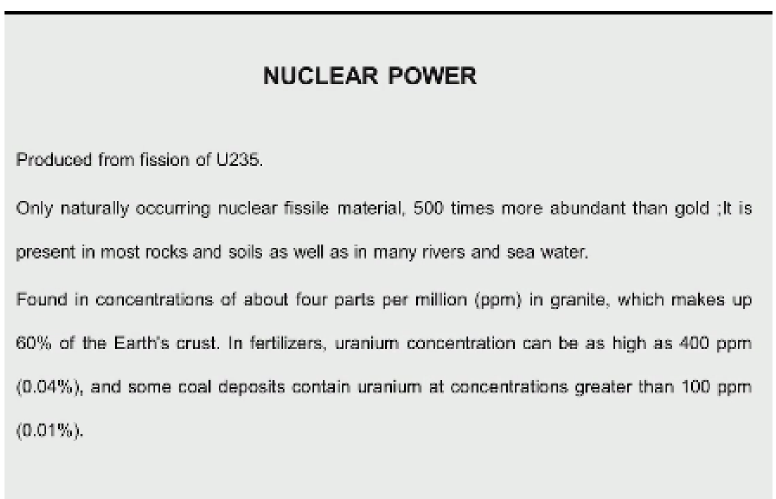

Coming to the nuclear power again, as I said it is produced from the fission of Uranium-235 and if you ask how much of uranium is there, it is 500 times more abundant than gold and it is present in rocks, soils and everywhere, in water also. And in granite it is about 4 parts per million and you remember granite makes up nearly 60% of the Earth's crust. If you take fertilizers uranium concentrations can be as high as 400 ppm and coal deposits as I mentioned they have concentrations greater than 100 ppm that is because all are ducked from under the earth and all of all these the uranium or thorium and potassium.

Now since the concentration of uranium as Uranium-235 to say it is only about 0.7%, there has been need to separate it from the other constituents which are not fissionable. So we have to dig out the uranium deposits and this where the concentrations are high level we call them as ore and then we start processing them to get the uranium.

Now the enrichment of uranium varies in the in the heavy water reactors, we use natural uranium itself as a fuel which contains about 0.7%. But most of the reactors in the world which are light water reactors, they use somewhere between 2.5% to 5% of Uranium-235 while the fast reactors use something like about 80% to 85%. So we have for developed unit of process to increase the content of Uranium-235 and they have all been developed then after its utilization in the fuel of course in the reactor it could be -- the fuel could be Uranium Oxide, Uranium Carbide or Uranium Metal. Uranium Metal was used in the initial reactors but due to its low melting point it was felt for -- to go to high temperatures we should use a ceramic so people went to Uranium Oxide which has been very widely used, Uranium Carbide also has been used.

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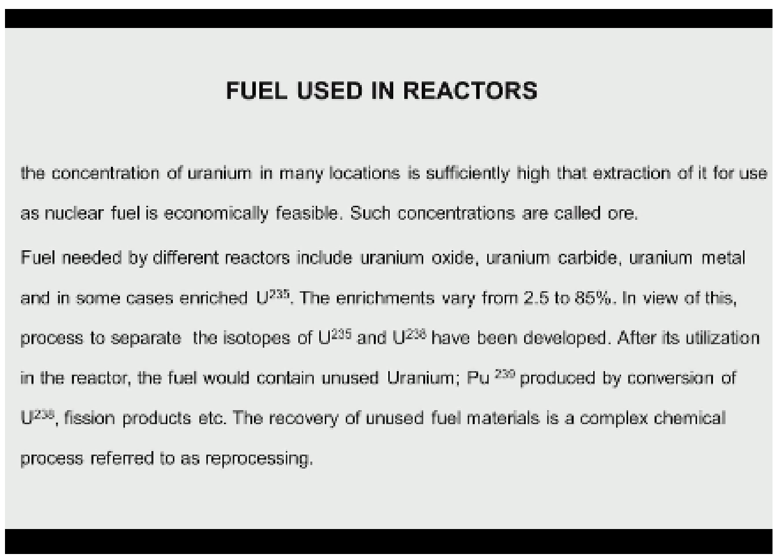

Now once the fuel has been utilized in the reactor it will surely contain some unused uranium, surely not all the uranium would have been utilized, and then Plutonium 239, which is produced by conversion of the Uranium 238 and some fission products. So this Uranium 238, which is 99.3% gets converted to plutonium 239, and this plutonium 239 luckily is again fissionable. So this is a man-made fissile material. They recovering of this plutonium 239 and unused uranium is what you call as reprocessing, these are what very frequently used, reprocessing.

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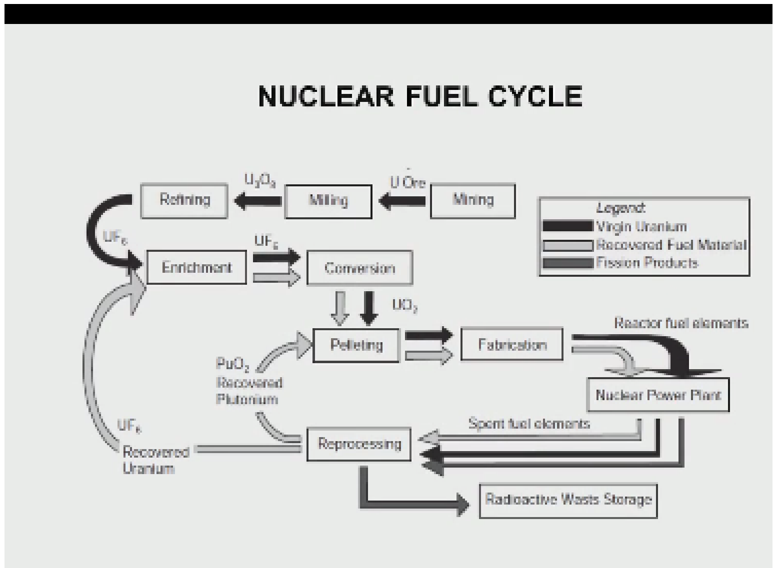

So now we can get an idea about the full cycle through which the fuel goes. You start with the mining, get the mined, get the uranium ore then you go through a process of crushing and refining, then you have an a stage of enrichment, then in case you need to have to more than 0.7% you are enriched it, then you have to convert it into the form of oxide, then these fuel which are in the powder form they have to be put into pellets, and then pelletizing is one and then made into fuel elements and used in the nuclear power plant. And from the nuclear power plant it goes to the reprocessing where the plutonium 239 and unused uranium are extracted and they are sent back for reconversion and again fabrication to be used in the reactor.

And whatever is not the fission products and all which are after the reprocessing, they have to be called as a radiation waste and stored properly. So this is the nuclear fuel cycle in a very brief manner.

To get an idea of the quantities involved because, that is very much important, you must know what you are material amount of material you are dealing with.

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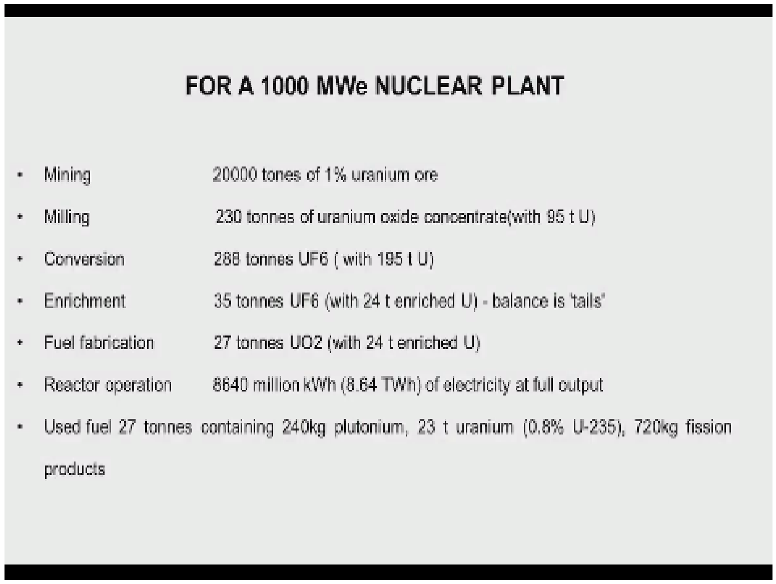

Let us take a 1000 megawatt electrical nuclear power plant. Now for that you have to -- suppose we consider a ore containing about 1% uranium you require about 20,000 tons of uranium ore you have to mine and 230 tons of uranium oxide finally you will get and when you convert it, we have the uranium fluoride process it gets converted to 288 tons of uranium UF6 then this when enriched gives about 35 tons and when you fabricate it, it leads to about 27 tons and this 27 tons of uranium oxide when you put in the reactor it gives you some 8,640 million kilowatt hours and after all the thing what is left is the use of fuel which contains about 27 tons. So this gives you an idea of from 20,000 tons what is finally we are losing about 27 tons. So this is an idea of the material used involved in the nuclear cycle.

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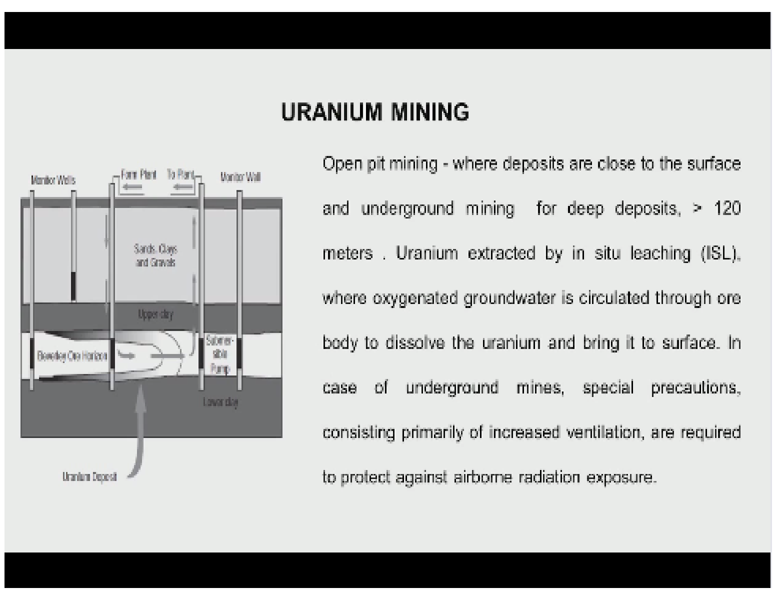

Just to get a bit more idea about how we do the mining, we generally have open pit mines where deposits are close to the surface, and in case they are deep, they we go for underground mining like any other coal plant. And, we do a process of in situ leaching wherein water is circulated through the ore to dissolve the uranium and bring it to the surface and we take of course special precautions basically ventilation so that the people working there should not be put to any airborne exposure from the radiation.

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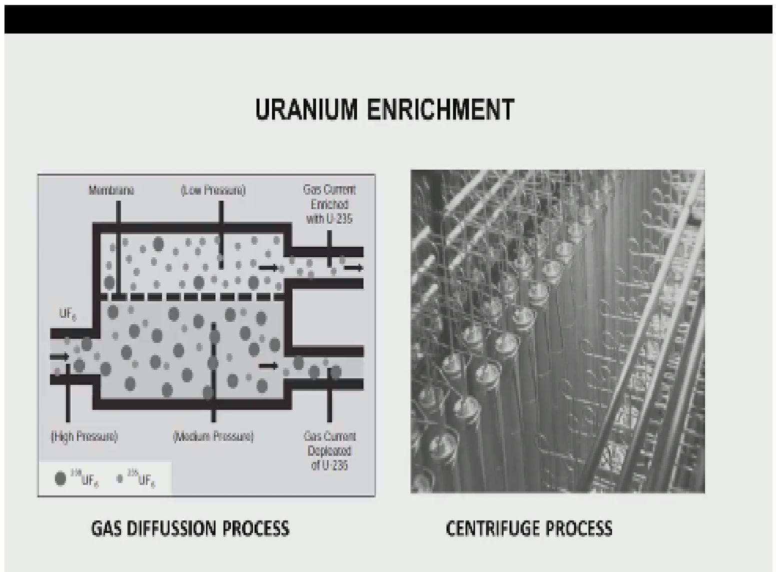

Then we have the enrichment process. The enrichment consists of two methods, one is the gas diffusion process and the other is a centrifuge process. Now in the case of gas diffusion process, we use basically principle of diffusion and it has been quite effective.

The other process is basically using the centrifugal force, what we call is a centrifuge running at about 70,000 rpm wherein the Uranium-235, and uranium 238 gets separated a then you are able to take out the enriched uranium but the centrifuge process is quite power intensive. So there is a reason why many countries have not been able to go ahead with this, already they are in need of power.

Then this fuel has to be transported. When I mentioned to you about the carbon dioxide emissions from the new -- in case of nuclear power plants, whenever we manufacture and transport a component, it has to come on a diesel vehicle which is going to have carbon dioxide emission. So transport is very important stage in which the nuclear fuel will move between different parts of the cycle.

So you have to be very careful that during the movement this radiation exposure should not affect the people who are involved, it should not affect the public. So we have to see that they are packed properly, shielded properly .We use the word shield, radiation shielding materials we use so that effect of the radiation is not felt outside. So these are the safety measures, which need to be involved in the transportation.

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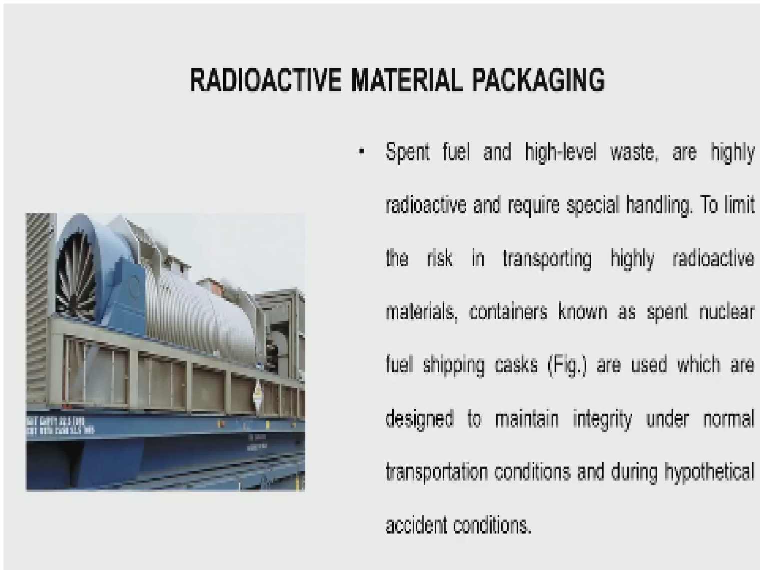

Just to give you an idea, how a cask containing radioactive material looks like, this as you see the cask which is mounted on the train you see it's a goods train. It is mounted and this contains waste or raw materials also. This particular one contains waste, nuclear waste which is also radioactive and this design is done in such a way, that these casks even if they fall down they won't break. You will be surprised in the United Kingdom, in the 90s there was one person raised the question, suppose this train carrying this radioactive material or radioactive waste meets with an accident, what will happen? Believe it, they took a train with one or two containers and containing the radioactive material and the train really was meet to have an accident and the cask fell down and nothing happened. So one thing is sure the methodologies which we are adopting for radioactive materials are good, and we have to need to -- the need is that safety at every level of this we should be safe so that radioactive releases or the reactive contamination to the public and workers is minimal.

Then the spent fuel, let us take the spent fuel the fuel has been used now you have to take it out but it is at a high temperature, there is not -- temperature in which you can handle immediately. So it needs to be cooled, it has to be put in a -- with proper of cooling then only, if you don't cool it that fuel itself can melt.

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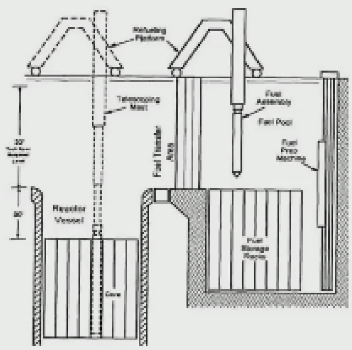
SPENT FUEL STORAGE



Spent fuel from reactor is at a high temperature with production of heat due to fission product decay and continued cooling is required . So fuel is stored in a bay with cooling by water. Generally this storage is at the reactor site itself. Once the temperatures have come down it can be stored in dry cask with atmospheric air cooling by natural convection.

So normally we have a spent fuel way in which we put the fuel, and you can see a simple system wherein from the reactor core the fuel is handled, and then put to the spent fuel bay.

One more thing is important that the geometry of the fuel bay and water should be such that it should not become critical. We will see about this later. So this storage, it has to be kept for some time until the temperature comes down. Then in a dry cask you can transfer it to the reprocessing and during that time and you transfer it even natural consumption of air could be sufficient to cool the cask.

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REPROCESSING

- Spent fuel is about 95% U^{238} but it also contains up to 1% U^{235} that has not fissioned, about 1% plutonium and 3% fission products, including neutron poisons which are highly radioactive. In a reprocessing facility the used fuel is separated into its three components: uranium, plutonium and waste, containing fission products. Reprocessing enables recycling of the uranium and plutonium into fresh fuel, and produces a significantly reduced amount of waste (compared with treating all used fuel as waste).

Then as I mentioned reprocessing and the spent fuel is about 95% uranium-238 because all the uranium-238 doesn't get converted into plutonium, only a part of it gets converted. So also it contains about 1% of uranium-235 which is not fission, 1% plutonium and about 3% fission products. Besides you have Neutron poisons, like xenon etc which may be there and they are highly reactive. So in the reprocessing you separate the components basically we are looking for taking out uranium, plutonium and the waste containing the fission products and based on the reprocessing output we can use the uranium and plutonium into fresh fuel and so that it is effectively we are reducing the waste.

Now you might wonder that in the media there has been always thing that a reprocessing should not be there. Reprocessing that can lead to proliferation, and people can take the plutonium. Now USA has adopted this attitude that whatever is coming out of the reactor it is not used again. It is just kept as a waste but in this process the waste activity is high because of the presence of uranium and plutonium. If you can separate it and then use it in another reactor you are effectively replacing the resources. In fact this type of approach without reprocessing is called generally, as open fuel cycle whereas what I was talking about the nuclear fuel cycle which is used back, it is called a closed fuel cycle. And India per say has gone in for a closed fuel cycle, because we want to effectively utilize all our natural resources of uranium.

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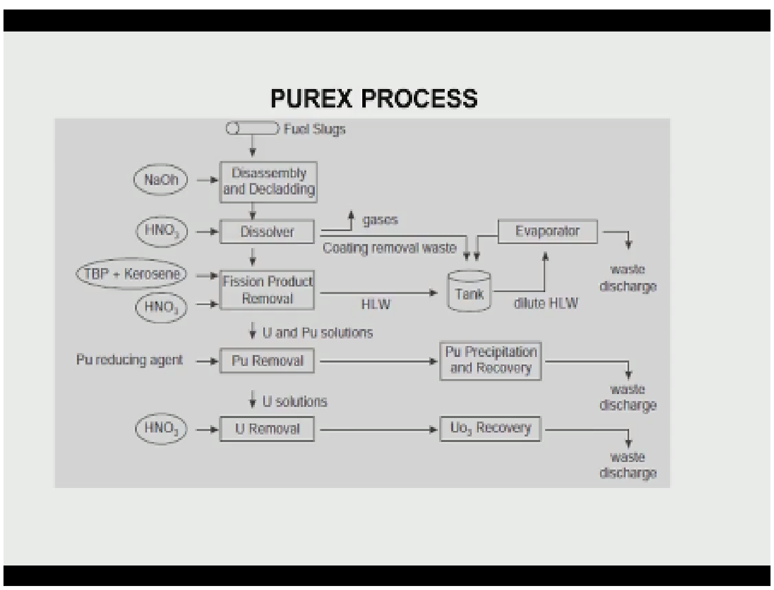

There is a process which is a well known Purex Process which is used in reprocessing and just to get an idea, what is the components of the Purex Process you can have a look at this figure, it's a schematic figure in which involves the disassembly of the fuel, the decladding, remove the cladding material of the fuel, then dissolve it using nitric acid, then to extract the fission products they use TBP plus Kerosene, It is Tributyl phosphate and Kerosene along with nitric acid then whatever is removed then goes further uranium and plutonium come in solution form, then you remove the plutonium and uranium separately. Whatever is the rest in the second stage after the TBP, what is doesn't get dissolved is sent the high level waste and of course the rest of the process is as shown.

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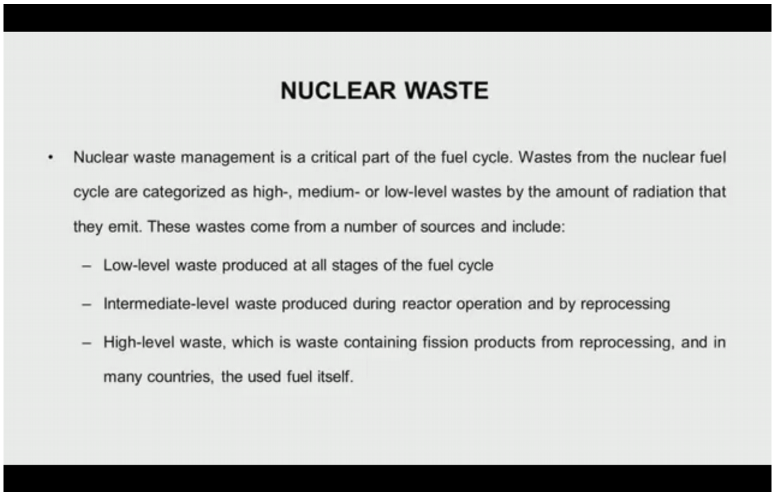

Okay now the waste which is coming out from the reprocessing plant, what we do? It’s a very important part of a fuel cycle. We normally try to categorize them as high level, medium level or low level based on the amount of radiation.

Now low level wastes are practically produced at all stages like right from mining, then your fuel fabrication, everywhere they are produced. Then intermediate level wastes are produced during reactor operation or by reprocessing, and the final high level waste is basically from the fission products which are taken out in the reprocessing plant and that is which is called as a high level waste.

Now this high level waste is the one which we are saying that we can use back in the reactor, so that we don't have any high level waste. To get an feel of this high level waste, how much would be the quantity of high level waste, very simple example I can give you. Suppose one person's requirement of electricity throughout his life was to be produced only through nuclear power then the high level waste will be equal to one fist that's all, and that itself if you again put in to the reactor there is no high level waste. So there is a fear that this high waste management is a very difficult and things, it is not the quantity is very much less.

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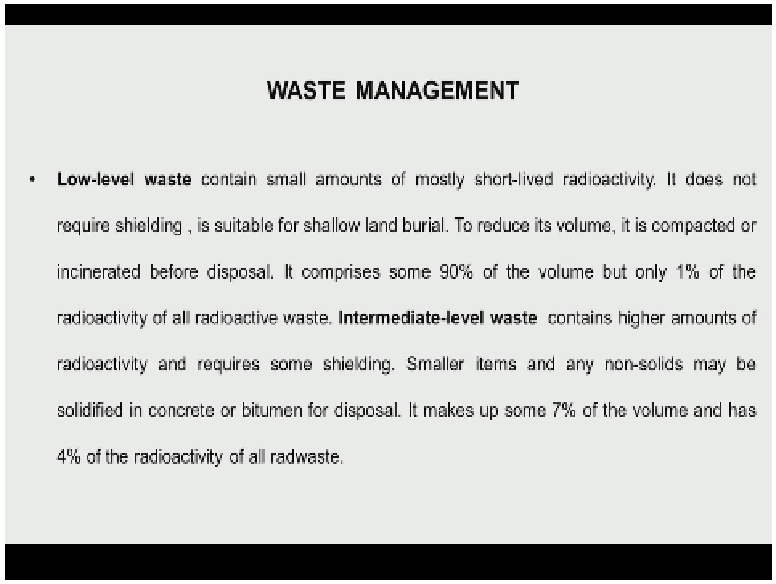

Now how do you manage these wastes? Low level wastes contain radioactivity but this radioactivity is having a very short life, so it is not very much -- it does not require a shielding and it can be jus buried under the earth. But before burying up we just try to compact it so that and we also incinerate so that those material which can be burnt they will all become ash and become very compact.

So it will have only about 1% of the radioactivity of the whole waste, 1% would be present in intermediate waste. Then coming to the intermediate level waste it will be higher, surely it requires shielding you can't do without shielding then it makes up about 7% of the volume and has about 4% of the radioactive wastes again in this.

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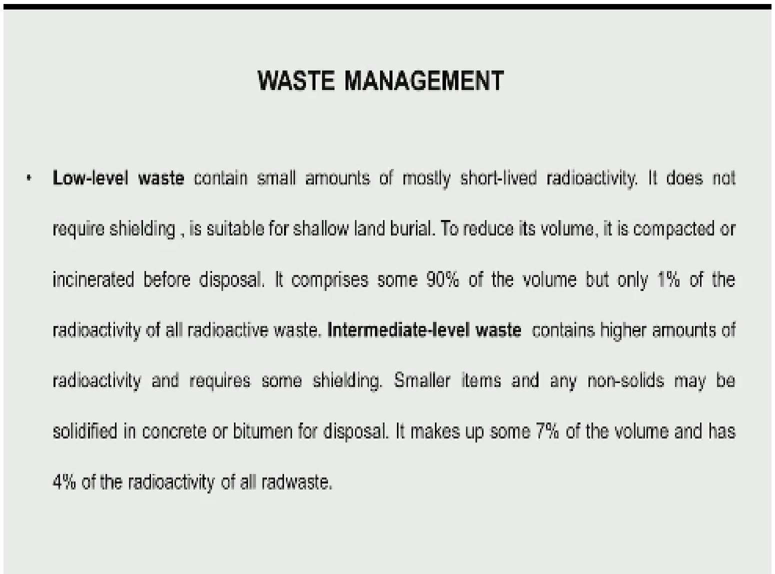

So this again has to be dealt with, again stored for some time then the high level waste about we should be really worried, it is highly radioactive. As I mentioned it requires cooling and lot of amount of shielding also and it contains about 95% of the total radioactivity. So this waste is the one which we need to be concerned about. So what we do? We have to immobilize the waste that is -- we have to see that the waste is not able to move. So how to make it immobile? Put it in some other material matrix in which it can it get bonded and it doesn't move and that is where we find this borosilicate glass has been very good as a medium and borosilicate glass mixed with the fuel is able to hold the high level waste fuel very well, bonded very well. So this is remain stable for a very long time because they contain some of the long-lived waste.

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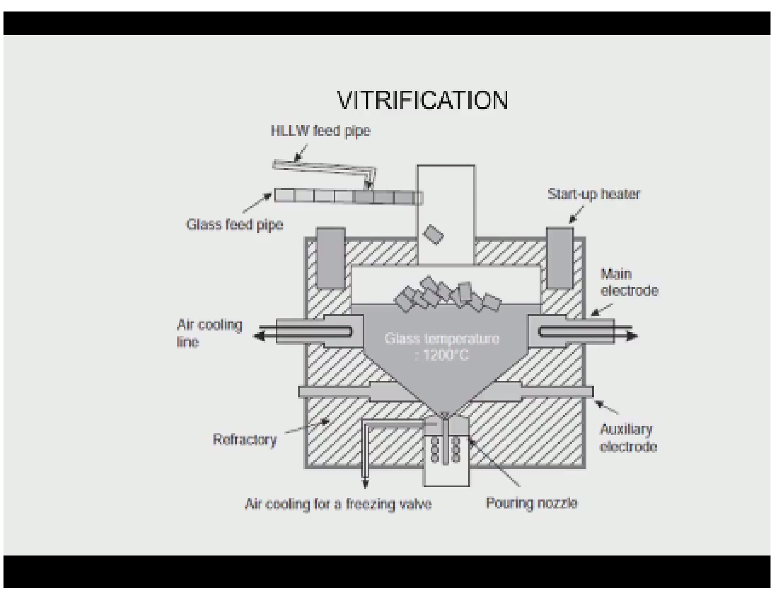

This is just to give a figure of the process. This process is called the verification. There is mixing glass and the fuel, high level waste and then trying to make this thing . So the glass is molten at about 1200* centigrade and we add the waste high level waste and then we pour it and then make it into a solid form and this solid form we put in radiation shielded casks and put it under the ground.

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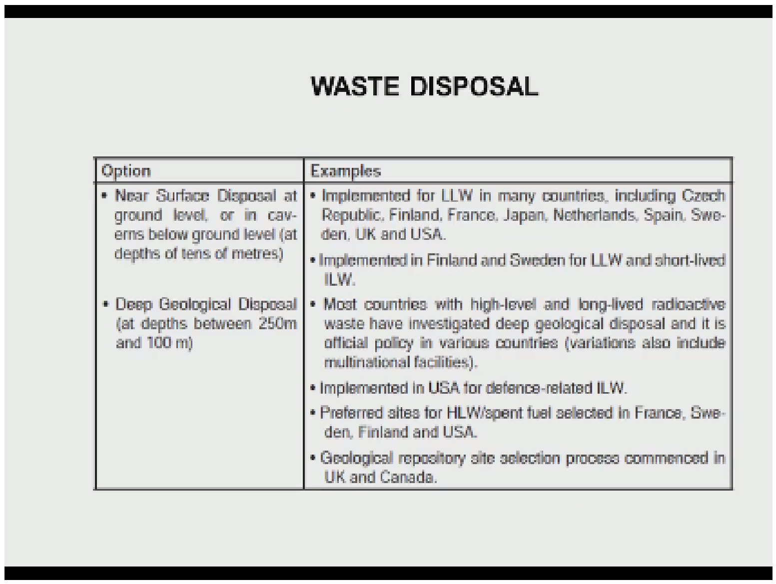

WASTE DISPOSAL

Option	Examples
• Near Surface Disposal at ground level, or in caverns below ground level (at depths of tens of metres)	• Implemented for LLW in many countries, including Czech Republic, Finland, France, Japan, Netherlands, Spain, Sweden, UK and USA. • Implemented in Finland and Sweden for LLW and short-lived ILW.
• Deep Geological Disposal (at depths between 250m and 100 m)	• Most countries with high-level and long-lived radioactive waste have investigated deep geological disposal and it is official policy in various countries (variations also include multinational facilities). • Implemented in USA for defence-related ILW. • Preferred sites for HLW/spent fuel selected in France, Sweden, Finland and USA. • Geological repository site selection process commenced in UK and Canada.

Now coming to the waste disposal there are different types as one is near-surface disposal and as I mentioned this is done for low-level waste in all countries, it has been done then deep geological disposal we are looking for basically for the high level waste because they are going to remain for a very long time. So we are looking at what you call geological areas where sites are such that they are not going to be approachable for a very long time. In the USA that you come Yucca Mountain was the place chosen for putting these high-level waste casks, but they have been delaying due to so many reasons. In fact because of that the high level wastes are lying in the plants and it is not a good thing.

In our own country we have looked at some geological repositories where the Colar gold fields where there now practically its all – there's lot of place available where so -- this is one of the areas which we think could be utilized but till now even though our power program is not a very big now, it has not come to a level where it have to be -- that need to be a concern.

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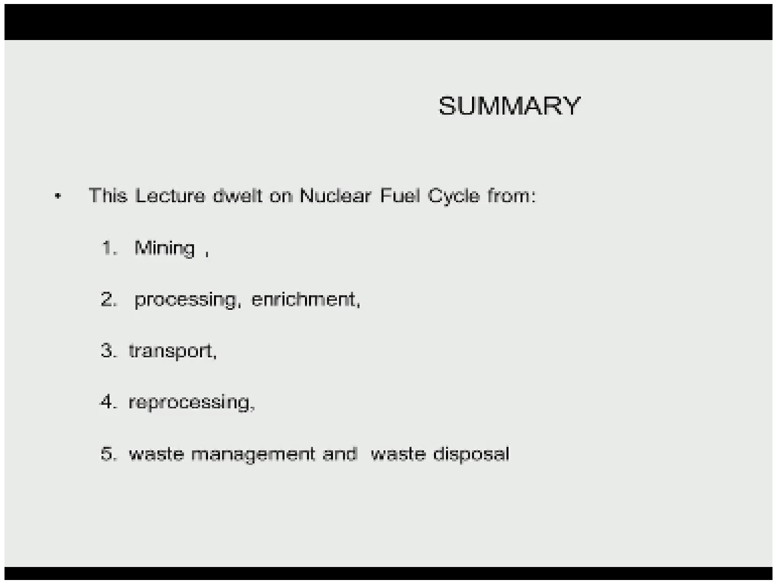

In brief, I can say that this part of the lecture we covered mining, we covered about the processing of the ore, then the enrichment of Uranium-235 using the centrifuge and the diffusion process. We also had a look at the transportation aspect that we need to transport things properly in a radiation shielded casks so that it does not affect.

So at the mining level also we need to be safe processing everywhere every step we need to be safe reprocessing. It is quite a bit of higher activity. Wherein ,we have to be very careful, we deal with solutions also. Then finally the waste management wherein high-level waste is involved and the waste disposal.

So this lecture practically I have taken you through the different stages of how the fuel from its inception on its birth to its -- I shouldn't say death, and it's reuse. So this gives an idea about the thing. So safety is involved at each and every step of this fuel cycle.

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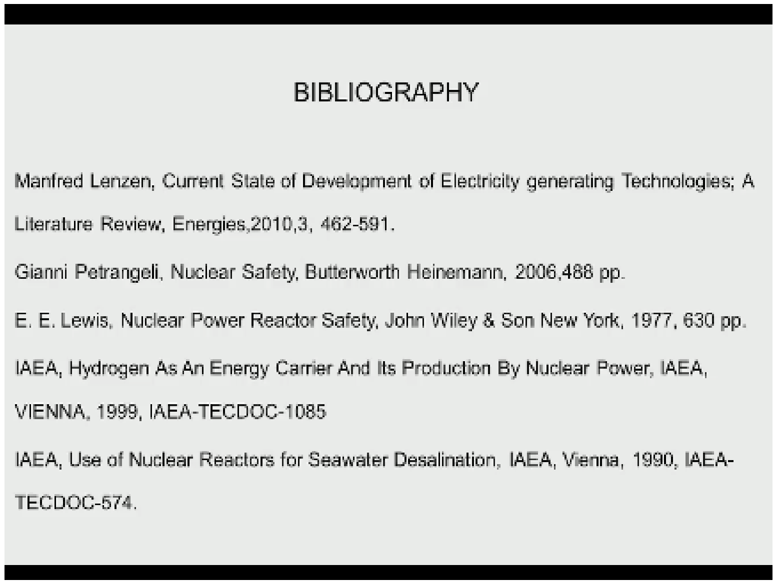

Many of you might be interested to read through some of the literature. So I just given the Bibliography related to my these first two lectures and there are books, many of them published by IAEA on sea water desalination, hydrogen production, then on nuclear safety by Gianni Petrangeli and Lewis and the World Health Organization has produced some booklets on Irradiated Food, it is not that we say that okay irradiated food is not bad, it is all the result of research done over decades. So be sure irradiation not only results food, it avoids food wastage, it avoids bacteria in the food and you are able to have food at any time you want.

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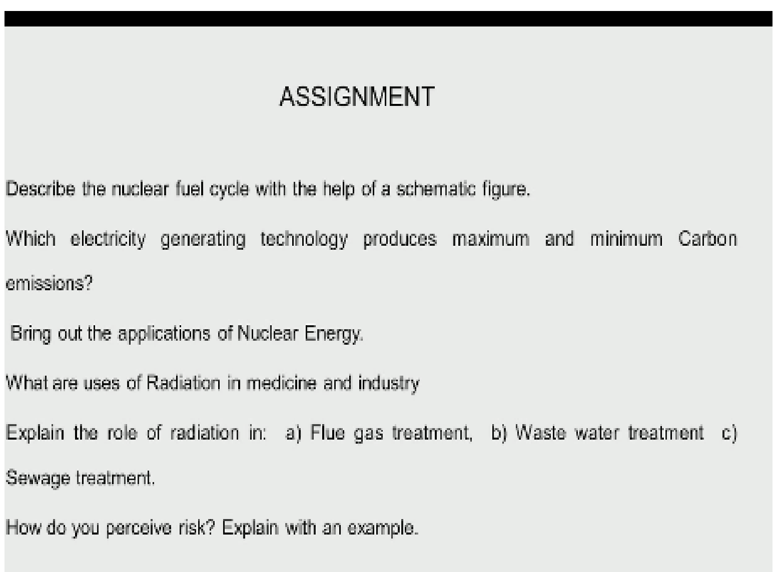

Maybe it would be of interest to have a small assignment on this which I think you should take it up very simple, what are the different electricity generating technologies? What are the different applications of nuclear energy? Besides power, I mentioned you so many other applications and what is its use of radiation in medicine and industry? And important how do we treat the flue gas by radiation and make it safe, there is sulfuric oxide and nitrous oxide, how it is absorbed and then you don't get it put it into the environment, the sewage treatment etcetera and last but not how you perceive risk.

Thank you for a patient listening. Now in my next lecture, I shall try to give you some insight into the structure of the atom. So that let us get back okay we talked about fission but how does fission happen and how that concept of the fission and hopefully with that background you would be in a better position to follow the further lectures**.**

Have a nice day. Thank you.

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