Fundamentals of Nuclear Power Generation

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Module – 12
Waste Management & Economics
Lecture – 02
Disposal methodologies for HLW & IMV

Hello friends so, we are finally, at the last lecture of this particular course, where we were a discussing about the topic of Waste Management and Economics. So, this is the 12th week of the course and there is the second lecture on waste management. We already had one lecture, where you were introduced to some of the initial topics of waste management and today we shall we finishing off this by discussing a few more points waste to waste management.

Of course, this is a topic which is highly relevant to the nuclear industry and there are several newer technology, that is; coming up every day it is also strong field of research; but also quite expensive research, because it is not easy for an individual research or even for an institute to deal with nuclear waste or to do extensive research on nuclear waste unless, that is strong support from the government and corresponding nuclear agencies.

And therefore, the research that goes on with waste treatment or management of nuclear waste, is generally quite confidential in nature and every country has their own ways of managing the waste depending on their own policies and their own research observations, that is; why despite having quite descend volume of material on this waste management or despite this being quite active area of a newer findings, we have to restrict ourselves only to the fundamental concepts of waste management, and most major discoveries or most important type of definitions under this unit.

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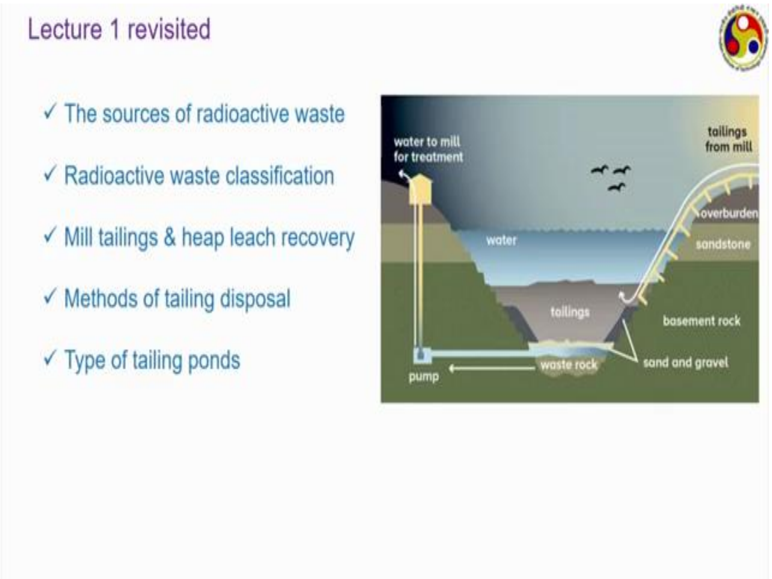

In the previous lecture, you were of course, introduced to the sources of radioactive waste we have seen that, it is not only the nuclear reactor which produces radioactive waste; rather we can have such kind of waste from several other sources; starting right from the point where nuclear material something like uranium is a harness from the mines, we have waste production. In fact, mines are the largest contributor from volume point of view for the radioactive waste. From the mines or from the subsequent milling process, we get the mill tailings which compress about 90 percent of the total volume of radioactive wastes.

Though, the corresponding radioactivity can be quite small; we can also radioactive waste production during several all the stages of the fuel cycle like, during the investment process the spent fuels which comes out of the reactor; during the reprocessing part or subsequent a downstream application, if any we can also radioactive waste production from medical fields, which is actually a growing contributor; in this particular segment when there are several other industries also which make use of radioactive nuclei and hence they also contribute towards the radioactive wastes.

We may have some kind of waste production from researcher as well, then we have to go for the classification, because the way we are going to dispose radioactive waste depends on the classification. Different countries have their own methods of classification, but we have selected the one that is suggested by IAEA, that is; International Atomic Energy

Agency who classifies radioactive west into 6 categories, starting from the exempt class which are, which are having in significant amount of radioactivity to the high level waste, which are the strongest contributor to the radioactivity volume point of view high level waste maybe just our 3 or 4 percent of the total volume.

But, can contribute above 95 percent of the total radioactivity and hence we need to be very very careful about their own disposal. Then we discussed about the mill tailings mill defer source of mill tailings were discussed just something, that is; quite relevant to that the heap leach recovery, which is another process of producing uranium, but it different method I should say, but then after the process is done, what is left there is quite similar to the mill tailings and, then we have discussed about the procedure of disposing the mill tailings. Under the there are several approaches that are attempted earlier to dispose the mill tailings.

But, also us we go on with time we gained a experience about how you should dispose; what are the methodologies are the principles that; we should follow from the while disposing the mill tailings. And also you got more information about, what are the possible hazards that we may have the mill tailings like, there can be read on emission to read on getting mixed with the soil and air and earth which can strongly contribute to the carcinogenicity in the human being. We can have arsenic; arsenic can have it is own radioactive decay or itself also is strongly carcinogenic in nature.

Then, we can have seepage of radioactive materials like, uranium and arsenic into the ground water and soils and there are several other kinds of liquids. And that is how you should be very careful about this despite having low level of radioactivity you should be very careful about this processing mill tailings.

And this diagram shows one of the proper mill tailing dams, that I used nowadays it is generally widely accepted that we have to go for underground disposal and also disposal underwater; there is a tailing should be under body of water, but that water also should be separated from the tailings by several layers of barrier. Then the such kind of tailing ponds again can have different kinds of classification like, we can have upstream tailing ponds downstream tailing ponds center tailing ponds depending upon how we are increasingly adding more likes each of them has their own advantages and disadvantages which we have discussed.

So, today we have to go for the discussion of different other kind of radioactive wastes, those high level or intermediate level particularly and then find a few possible methods of disposing those kind of radioactive wastes.

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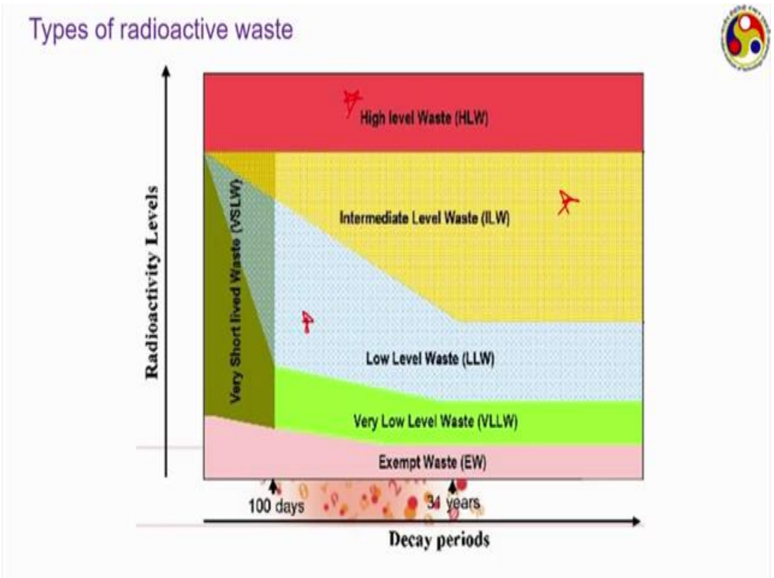

Now this is one diagram, which basically quantifiers all those radioactive wastes. Yesterday, itself we have seen that commonly you can have a 6 different kinds of radioactive waste as per the IIA guideline, where the first one is the exempt class and in this diagram we are quantifying them using their activity level and the decay period.

Exempt class refers to something receiving extremely low activity level; it is so low that we can just forget about the radioactive defect and dispose it like, we do the garbage disposal or any other invisible disposal. Then we have a very low level waste, that is again having a very short activity level and whatever radioactivity; they have generally they contain quite shortly radioisotopes, which can a lose its entire activity within a short period time maybe few days or weeks and after that. So, you basically need to contain this very low level waste only for a short period of a few weeks or maybe a couple of months and then it can be disposed just like the exam twist.

But they may have the low level waste, which this LLW and BLW are the largest contributor in the radioactive waste disposal technique, but we are those mill tailings the in (Refer Time: 07:52) fall under the get video of the VLW or LLW particularly. So, their disposal methods are also quite same and on this side; we have another thing something called a very shortly waste. These are again the radioactive waste, which are again extremely short life so, their activity level can be quite high, but general that spans over only a very short duration of time.

So, we generally do not need to bother about them after if you initial periods or activity, but the major concerns are related to this I LW and HLW both having significant effect of significant radiation effect I LW. While the half life can be quite large and also the radioactive level can be quite large, but the energy contribution that is a heat produced, because of their decay is generally insignificant. So, while we need to be very very careful about radiation protection, while dealing with I LWS we do not need to bother too much about energy removal or heat removal.

But, in case of HLW the radiation level is also the high and also the energy releases rate is also extremely high. And therefore, we have to provide the dual option of radiation protection plus cooling or heat removal. So, handling HLW is very very difficult I LW also needs to be handled properly. Another interesting thing, we can see here like if we follow a particular radioactive level or say a half life while you are moving in the upward direction with the increasing level of radioactivity, we are getting from EW level to the HLW level.

But, if we draw the same line horizontal line something from here again for a given activity level, as the decay period is increasing and moving from the very shortly isotopes to intermediate or in certain situations maybe high level isotopes as well. So, whenever you have a radioactive waste deal with first you have to identify exactly, where we stand from this chart point of view.

Whether, we are somewhere here or whether we are somewhere here or whether we are somewhere here. And according we have to decide our mode of disposal like, if you are dealing with low level waste, then we can dispose it only with a minimum amount of containment maybe quite short duration of time whether, whereas when he a dealing with a intermediate value as we have to provide strong radiation protection or a good amount of containment but, we generally do not need to provide any kind of cooling methodology or very small amount of cooling, but when you are dealing with the HLW radiation protection should be the strongest plus, we also have to provide abdicative amount of cooling, because it is going to reject large amount of heat, because of is radioactive decay and over a significant period over time as well.

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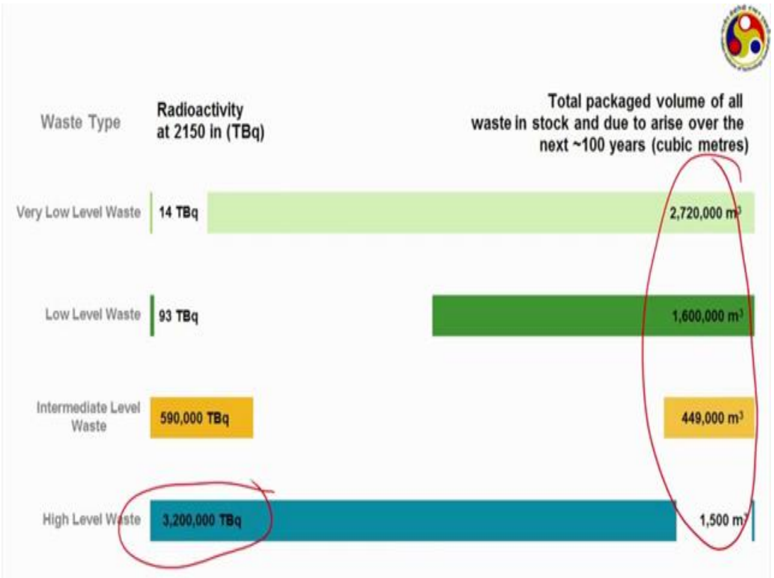

This is a some kind of projection which shows, what is the expected volume of radioactive waste in the year 2150; that is about 130 years from now.

So, that is very much a projection. So, we can said that as per this projection who in 2050, while the amount of very low level waste is will be something like this 2720 into 10 to the power 3 meter cube corresponding radioactivity will be only 14 terabecquerel. So, that is extremely small like if you think about the conversion between becquerel and curie; I hope you remember one, what is the definition of one curie that refers to the activity level of 1 gram of radio have to be 86 and t at is 3.78 (Refer Time: 11:57) is integration per second where as 1 bacquerel is just 1 disintegration per second. So, there is a very very small unit.

So, 1 terabacquerel is only of the order of 100 curies which is not which of course, is important to be important to isolate that amount of radiation from human being, but still that can be handled quite easily, but when you go to the low level waste; you can immediately see the expected volume of this low level waste is about 60 percent of very low level waste, but there is about 6 times increase 6 to 7 time increase in the corresponding activity level the; so, the while dealing with the storage or disposal methodologies while developing an a new disposal site we have to first decide what kind of material you are dealing with and if we have decided that is going to be for low level waste or very low level waste, then we have to provide very very large volumes.

But interesting a thing is that we may not have to store this waste material for a very long duration of time; maybe only for a short duration time we have to store them and once it loses this activity levels, then we can dispose it, but that is not true for the intermediate levels. Now first compare the expected volume, here it is less than one-third of the low level waste and less than 20 percent compared to the very high low level waste. But look at the change in the corresponding activity level it is a change of the order of 10 to the power 4 times, which is a substantial increase.

And finally, when we move to HLWs, then the increase is again about 6 times compare to ILWs; while the volume is reduced to a minimal digit. And now if we combine all these volumes this projections if you see that the total volume of a HLW what will have getting that is only very very small percentage just about 1 percent, but if even less than that of the total volumes of all this kind of radioactive wastes, but the radioactivity, that it is providing that itself is so, high that we can almost neglect everything else may not be the intermediate level waste, but we can easily neglect the effect of v a l LW and l LW and therefore, we may not have to provide large amount of storage for HLWs what that needs a very very strong amount of containment.

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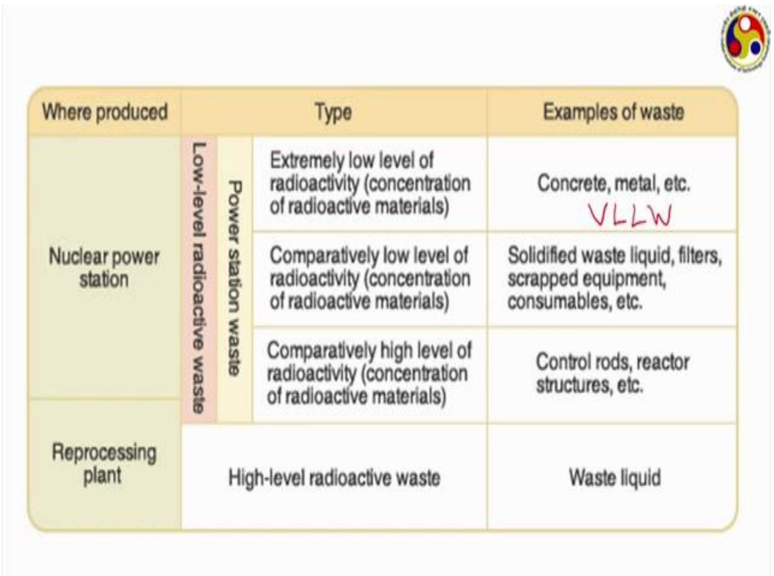

Now, from where we get which kind of active which kind of waste, now like if we always think that a nuclear power stations is the most common source. But if we think about that; now from the power stations we can get low level waste is the low level waste that we can actually from power station we get all different kinds of radioactive waste and from different parts of this we may get different kind of radioactive waste like; the structure of a nuclear power stations, the outside structures, the reactive building etcetera which are made of concrete or metals.

They generally get only very very small amount of radioactivity which make it straight to the coolant or maybe coming, because of the ionization radiation, leaking out of the continent structure, the gamma radiations etcetera and so, these concrete structures or metal structures may become radioactive but the concern level of radioactivity will be will be extremely low.

Then as we move inside the solidified waste liquids solidified waste the liquids the filters scrapped equipment several consumer basically used in radioactivity they also are generally the level of LLW. So, the concrete or metal structure that we are getting there in the level of VLLW very low level waste and whatever radioactivity they get they may get of course, the concrete structure is going to stay with the nuclear power stations and we remove them only once they get damaged or only during the decommissioning of the plant.

So, when we are dismedeling on nuclear power plant, then this concrete structure gives separated, but the radioactivity level is so, low that only few days or weeks are contentment sufficient to remove entire amount of radioactive effect, but the solidifier wastes or the scrapped equipments are consequently is regularly get produced from the nuclear power station we have to provide some kind of continues treatment for them and they fall in the level LLW.

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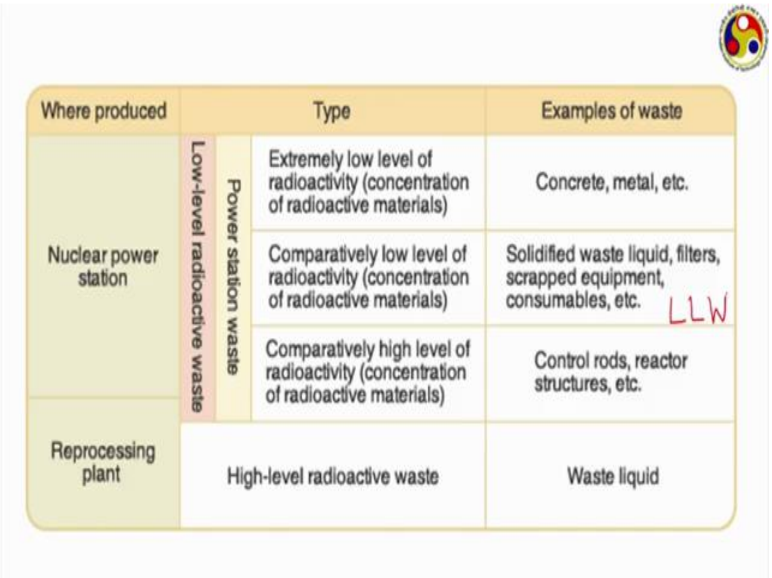

Where produced	Type			Examples of waste
Nuclear power station	Low-level radioactive waste	Power station waste	Extremely low level of radioactivity (concentration of radioactive materials)	Concrete, metal, etc.
			Comparatively low level of radioactivity (concentration of radioactive materials)	Solidified waste liquid, filters, scrapped equipment, consumables, etc. LLW
			Comparatively high level of radioactivity (concentration of radioactive materials)	Control rods, reactor structures, etc.
Reprocessing plant	High-level radioactive waste			Waste liquid

So, their radioactivity level is also low, they required some amount of the containment some periods of isolation. Isolation means we need to separate it out from the human beings are the in they are the living beings for a reasonable period of time and once that point in period is over again that can also be disposed of, but now comes some the structures, which are exact inside the reactor itself like, the control rods, like the reactor stainless steel body itself there directly exposed to the reactor nuclear fuel like a control rod material is absorbing strong large amount of neutrons.

And thereby they may become radioactive themselves, the reactor structure is also receiving the neutron bomb ointment, if that also receiving several other kinds of decay which goes on the decay of the fission products and corresponding all those beta and gamma emissions may lead to the ionizing radiation of the nuclears reactor structures and so, we will generally reach the level of ILWs Intermediate Level Radiation.

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Reprocessing plant	High-level radioactive waste			Waste liquid

So, for this structures we have to provide a much better amount of containment and we may have to store it for a few 100 years as well. And finally, the high level wastes interestingly from the nuclear power station, we may not get the high level waste, rather the major production site for high level wastes or the reprocessing plant the spent fuel is taken to the reprocessing plant.

And their input device applying other process fuels etcetera, we can convert the spent fuel into some usable product like we can separate of the uranium part from their and the corresponding uranium oxide can be sent back to the reactor we can also separate out uranium and plutonium and fabricate mox, that is a mixed oxide and that can also be used as a fuel and what is left after that entire process of reprocessing or refabrication we need to dispose it, and this generally are high level radioactive wastes which contains several heavy nuclei, which are which emits alpha radiation and also can have very very long half life’s.

So, we need to store them with the a maximum amount of containment and also for very very long period of time, which maybe if you 100 years. A particularly liquid waste that comes out of the reactors or from the reprocessing plant particularly are of major concern, because handling a solid fuel is much easier computer liquid fuel, because if there is any small crack in the containment structure liquid can leak out of this and leak to the spreading of radioactivity, where which is not true for the solid fuels.

So, while from the nuclear power plant we make it different levels of a starting from VLLW to ILW we generally get the HLWs produced from reprocessing plant. Also these are only the nuclear power station that we are talking about, but there can be other sources several medical equipments are contribute ILWs and HLWs the nuclear weapon program can have significant contribution to the HLWs also if there is any nuclear testing that happens the contaminated site of the corresponding site may get contaminated by the HLWs leaving all the neighboring areas to fornoriable.

Now, the principal and philosophy that we follow during disposal of nuclear waste should be very very clear to the operator and accordingly iia has sit out this philosophies.

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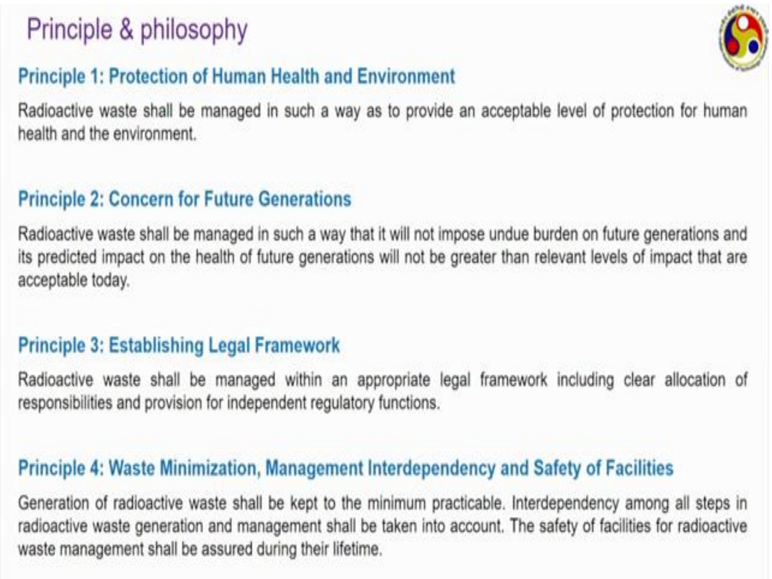

First is a protection of human health and environment means the radioactive waste shall we manages such the way has to provide an acceptable level of protection for human health and the environment under no situation the human health and the environment should we put on does a threat even a minor threat.

So, we have to remove every possible bit of radiation and a so, whatever waste is there we have to dispose that. Secondly, concern for future generations it is note that, at this moment we have disposed it with whatever we felt is the best one and say 20 years from now, it starts to create a huge massacre. We also have to keep an eye on the future, the waste shall we manage in such a way that it will not impose burden on future generations and its predicated impact on the health of future generation will not be greater than relevant levels of impact that are acceptable now a days.

Third principle is the establishing the legal frame work. The waste shall we manage with an appropriate legal framework, including clear a location of responsibilities and provision for independent regulatory functions and finally, the waste minimization management interdependency and safety of facilities.

As waste itself is very much hazardous so, you have to make every effort to ensure that the quantity of course, that your getting that is kept to a minimum possible and small waste produced from the facility small the effort required to manage that affect time required for is completely reactivity k is definitely much less. The interdependency amongst all steps in a radioactivity generation management shall be taken into account. The safety of facilitates for radioactive waste management shall be assured during the lifetime.

So, these are a few principles which the operator or agencies must follow while devising in method form radioactive waste disposal. Now methodologies for disposal there are four clear methodologies or four clear kinds of methodologies that are followed by different agencies.

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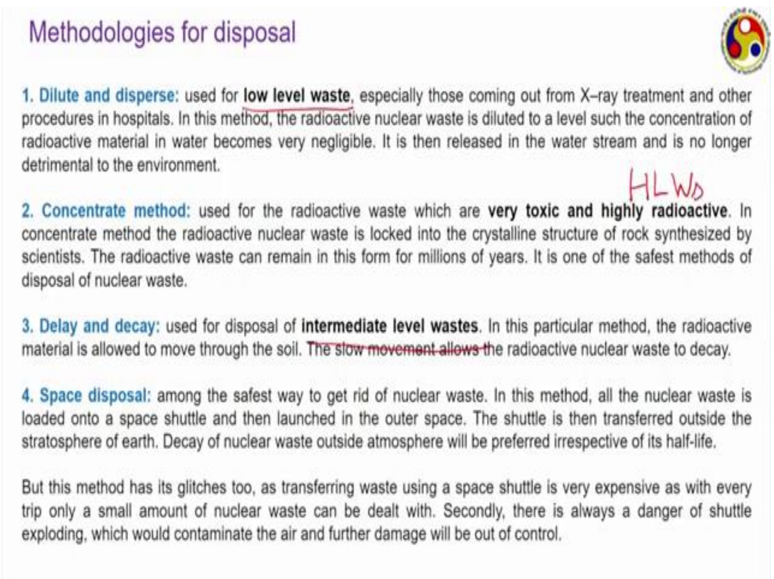

The first is dilute and disperse: it is particularly relevant to low level wastes, especially those coming out from the medical facilities like those we are gone from some kind of extra treatment or other procedure in the hospital.

So, the wastes that we get from such kind of low level wastes, their diluted to a level such that concentration of the relative material in water becomes negligible. So, we add this radioactive material to a huge volume of water too so as to reduce the concentration of radioactive material; to as to an acceptable limit and then that water stream can be released to the environment to some larger body of water and it is expected not to be any itrimental to the environment, but it is to only for the low level waste we cannot apply this for high level waste, because high level wastes not only have stronger level of radiovative activity but also a very large half life and so they will contain the radioactive effect for much longer.

Hence this method of dilute and disperse is limited only to the low level wastes. Then the concentrate method: it is the opposite instead of diluting the reactive waste here, we go for concentrating that into the smallest possible volume and this is something that is suitable for very toxic and highly radioactive wastes. In concentrate method the radioactive nuclear waste is locked into crystallized structure of rock synthesis by the scientists; or not only rock; we can have a few other kind of structures also we shall be staying shortly in the next few slides.

The radioactive waste can retain remain in this form for millions of years it is one of the safest method of disposal for nuclear waste provided we can make enough option of the radioactivity or radiation contentment and also cooling, that is the energy produced by the continuous radioactive decay of this wastes should be taken care of immediately. Then the delay and decay: that is used for disposal of intermediate level based.

In this particular method, the radioactive material is allowed to move through the soil. We know that their activity period is lesser compare to HLW so we allow them to move to the soil in the slow movement it decades and beyond a certain period of time it reaches some agreeable or acceptable level of radiation and so, can be allowed to mix with the soil freely.

And finally, a magazine technology the space disposal: It is probably the safest way to get rid of the nuclear waste, because we have infinite space available in the outside of biosphere and therefore, it is possible that we load the nuclear waste into space shuttle and then launch that into the outer space. Once the shuttle goes out of the stratosphere of the earth, then it is the mankind is completely safe or completely safe from the radioactive wastes of that particular shuttle radioactive decay of the material stored in that particular shuttle.

But it has its own issues as well, once it decays in the outer atmosphere we do not need to bother about that; whether if the half life is small or half life is large it does not matter, but during this transfer process. Firstly, space shuttle itself is very expensive and one shuttle can handle only a small quantity of nuclear waste, so large number of shutters will be required and secondly, there is always a danger of shuttle exploding, which would in fit happens at all then it will contaminate the neighboring neighborhood here and also for the damage will happen.

So, these are the principal methodologies which are followed during the disposal. The diluted dispose method is primary follow for the low level waste delay and details follow for the ILWs, whereas concentrate method is more suitable for the high level wastes and this is the chart shows the same thing like, when we are dealing with the high level waste, we need to be very careful and that is why the most common thing is to go for deep geological disposal at least at a depth of 500 meters.

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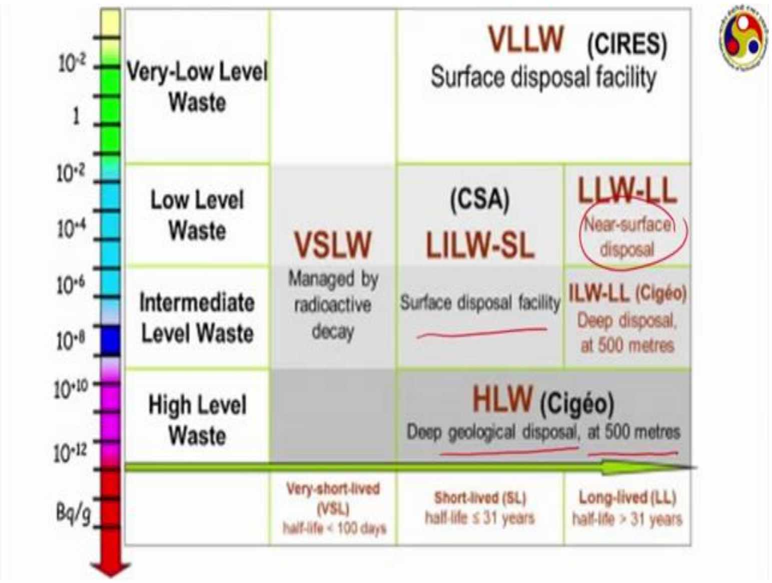

The intermediate level in wastes, surface disposal facilities can be there or we can also go for intermediate level disposal square similar to the HLWs deep disposal at 500 meters. For LLWs we can stick to near surface disposal that is any natural source like a mind feat or some natural tavern kind of thing can be allowed to store the low level wastes.

And for that very shortly go up generally doing to bother about the radio radioactive decay, because very short there radioactive decay period is quite short, their because heart half life is short so, they can decay a very very quickly and can lose it center hazardous effects within a few weeks or even within a few days. So, you do not need to bother about the disposal that much.

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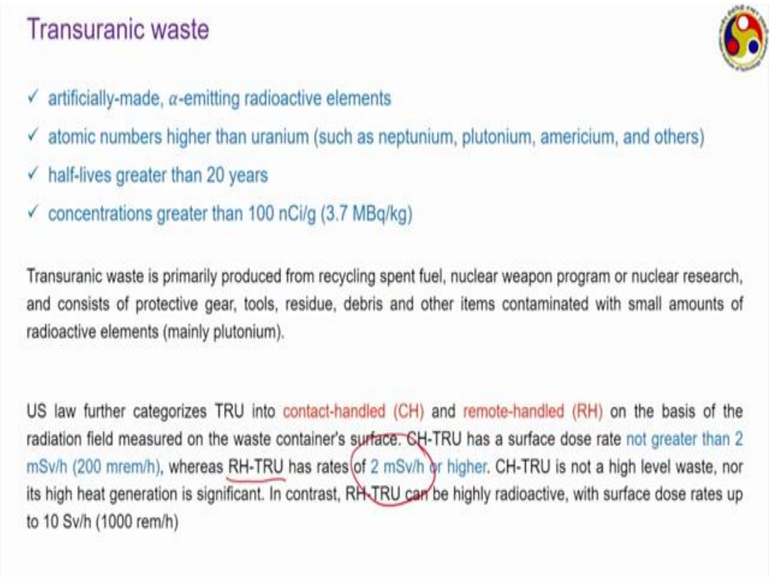

Now, let me introduce another new term of course so far we are introduced to all this trans that is a very low VSLW, LLW, HLW, ILWs etcetera and also I have miss this VLLW very low level waste, they hardly have any kind of radioactivity effect and that is why we can discuss them like the normal garbage.

So, they can go for surface disposal, but all this 6 kinds of convey that we have followed their even by iiea th, but there is another very commonly used on that is transuranic waste which is generally use only by united states. Transuranic waste refers to the wastes, which are artificial and also heavy nucleus and heavy alpha emitting nucleus. The atomic numbers of the principle element should be greater than that of uranium...

So, the term transuranic uranium default reports for something having atomic number higher than uranium, such as neptunium, plutonium, American, and others curium can be another example and because they are heavy their atomic number is greater than 80s so they are most likening to go for alpha emission and also we have to remember that, uranium is the heaviest natural naturally found isotope. Anyone having atomic number higher than uranium and that is from neptunian onwards 93 atomic number they are all artificially produced.

So, it has to be something that is heavy and artificially produced; then half life greater than 20 years, if half life is less then we can go for very short life storage; if half life is less we do not need to bother that much about them, but is half life is more than you have to store them properly and final the concentration should be greater than 100 into 10 to the power minus 9 cube the power gram of 3.7 mega Becquerel per kg.

So, just having 1 or 2 isotopes will also not do the solution, just having a few small nuclear, which does not keep that amount of concentration will not guarantee something to be called transuranic. All this four conditions needs to be satisfied. Transuranic waste is primarily produced from the recycling process, and the nuclear weapon program and also nuclear research.

The nuclear weapon program is the biggest contributed to the transuranic wastes. They are several countries who have very strong nuclear weapon program and that is why; they produce good amount of transuranic waste, while the term itself is recognized only united states there are other countries also which get similar level of waste. Transuranic wastes essential is a high level wastes that is why other countries do not use this term rather such kind of waste materials are directly categorized as HLW, but this is one term specifically used by US, practically related to the nuclear weapon program of corresponding research.

And materials which are associated with such kind of equipments like protective gears, tools, residue debris and other items that are contaminated with very small amount of radioactive element particularly plutonium all are transuranic. US law further categories this transuranic waste into 2 categories: one is the contact-handled was CH, other is the remote-handled RH.

On the basis of the radiation field measure on the waste container's surface. The contact on the handled one as a surface dose rate not greater the 2 m milli Sevels sevais per hour for 200 million per hour, but we are talking about the remote-handled there the surface dose level is much much high it is in the range of I think I have a mistake here it is not m it is just 2 sevais per hour...

So, it is at a level oh ok, sorry; actually here we are talking about the transuranic waste, which is having a dose rate of greater than 2 million is per or awareness for in case of CH it is less than 2 millions per hour so the values are correctly written but practically this RH-TRU, that is remote-handled transuranic waste can have radiation dose value which is much much higher than basically in the range of 5 to 10 seasons per hour.

So, they are a definitely high level wastes. The contact-handled one that is CH-TRU is not the high level waste noisy generation is significant therefore, it can be treated as a Il s ILU or ILW or sometimes even as LLW, but in case of RH-TRU it can be highly reactive with surface dose rates can be in their can reach in the level of 5 to 10 sevais per hour or 1000 range per hour...

Therefore the handling of transuranic waste is also of extreme importance....

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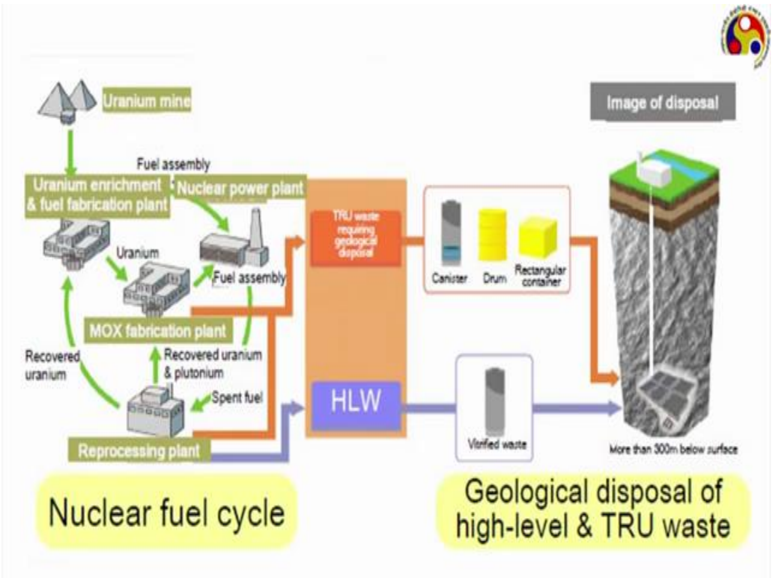

This is one typical example of production of TRU from the uranium mine whatever ore we get that goes to the enrichment and fuel fabrication process in and fo[r] after the fuel fabrication is done this is the part from here we get the mill tailings. Now after the full fabrication is done this fuel assembly goes to the pow[er] nuclear power plant from the power plant after the operation is completed for one cycle is this goes to the fuel assemblies and then it comes us the spent fuel in the recovery of everybody MOX fabrication plant and the recovery uraniums directly feedback to the enrichment process.

Now, the production of HLW as mentioned earlier is most likely to be from this reprocessing and replenishment unit. Whereas, the TRU there they can also get reduced from this particular component, but they can also get reduced from the MOX fabrication plant. So, HLW is primarily coming out of the reprocessing unit, but I repeat the TRU's can get produce and reprocessing unit or being a MOX fabrication as well; that is why they are strong amount of plutonium presents them.

Now, how to get back to the reactor or I should say how to the waste that you are getting HLW or TRU. Now how should we dispose them a small scheme is shown here first we have to convert that you canister then put that into drum those drums will be put into the rectangular container and then it is going to get to the disposal facilities.

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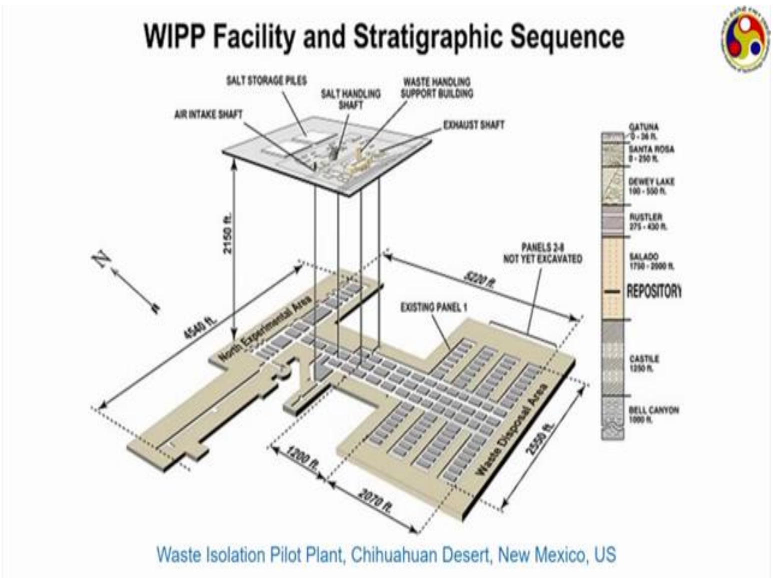

The waste isolation pilot plant of new Mexico United States is an examples of kind of; I do not want to go to the details of this, but this WIPP is the most regarded facility for disposal of both LLWs and ILWs and also the transuranic waste it has different segments some part hand is TRU's some part handles ILU's.

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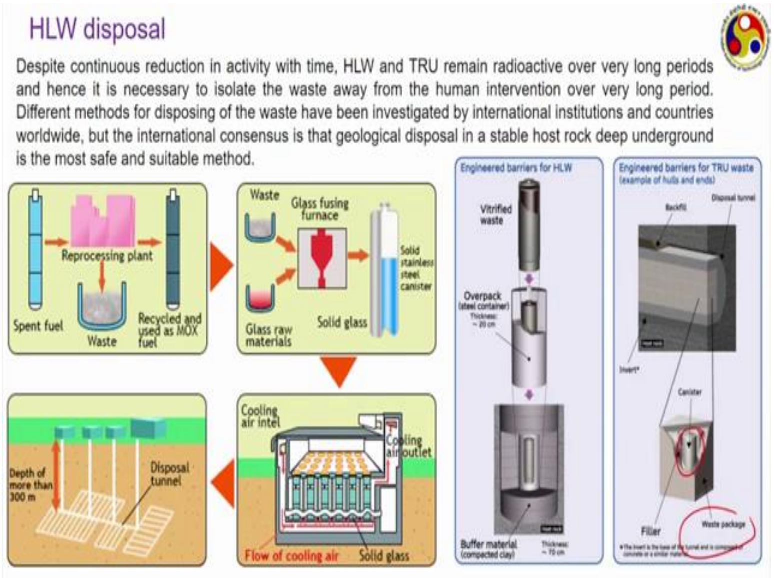

Now, the HLW disposal despite continuous reduction in activity with time HLW and TRU remain radioactive the over very very long period. HLW as I have already mentioned have very long half life and therefore, as the radioactivity decreases asymptotically, still you will be strongly radioactive even say a few 100 years, since the point is first dispose.

And therefore, it is necessary to isolate this waste from him you intelligent for very very long duration of time. Different methods of disposing this was investigated by the international institutions and countries and which is the common consensus that I have to go for zoological disposition, in a stable host rock keep on deep underground.

So, this is the flow chart this from the reprocessing plant, we are getting this HLWs and the recycled which also during the MOX fabrication part we make it HLWs for those are general TRU's. So, the wastes that we get those wastes finally, comes in the form of liquid and to that we had some kind of glass fabricating materials. So, that we get through glass using furnace we are able to produce solid glass or you able to convert this waste material into solid glass and this glasses are covered or enclosed by stainless steel canister.

So, the material converted into solid glass form is covered first by solid stainless steel canisters. Next, this canisters were put into a proper structure, where each of these solid glass element are covered ok. Let me show another picture here, this is the vitrified waste. Vitrified refers to the waste converted to the glass form and then it goes to the steel container look at here the thickness of the steel container can be as much as 20 centimeter.

So, it is it is quite thick 20 centimeter we are talking about and now this steel container actually in between the steel container and this vitrified glass we may have some kind of buffer material also, which is the compact it clay or I should say outside the steel containe,r first we have the vitrifiers in the form of glass, then cover the steel container, which is covered by buffer martial which is compacted clay.

And now this entire structure is arranged let in a matrix like this which is a continuous receiving continuous supply on cooling water and maybe sometimes cooling year as well and thus finally, this entire facility this entire block that is displaced to a depth of this diagram for 300 meter, but generally for HLWs and TRU's we go to a depth of more than 500 meters.

Look at this is the steel canister and then it is will covered by the waste package on you decide with and the in between portion its filled with some kind of filler.

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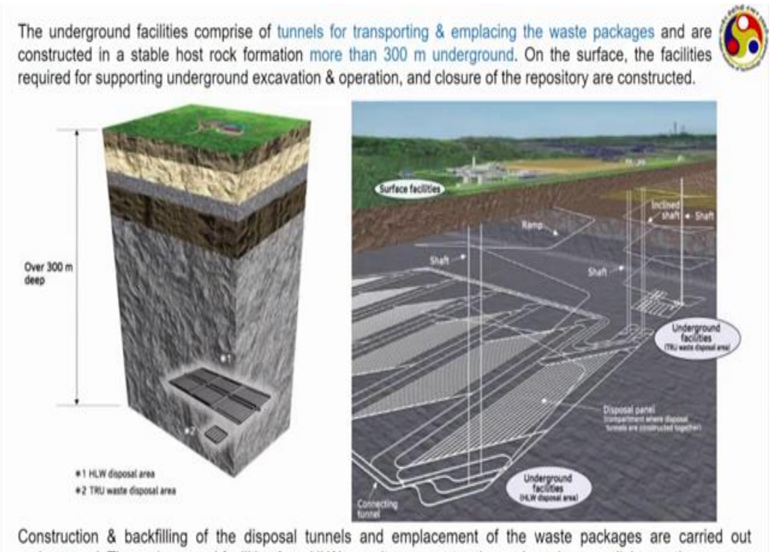

This underground facilities that we are talking about they have their own buildings like their tunnels for transporting and placing this waste packages and their constructed in a stable host formation more than 300 to 500 meter underground and the facilities required for supporting underground excavation operation and closer of the repository are also constructed. Is a typical cite this is an incline sheft from where the underground or all this waste packages are put in the underground tunnels.

The underground facilities this is the ground level from the ground level we are going downwards. This is the portions, where we have all the channels or tunnels I should say where this waste packages are disposed with proper supply of cooling material. Look at this over we are going to a depth of something like 300 meter, this is a location where HLW's are disposed and at the similar depth TRU's are also disposed. Generally the TRU's are smaller in volume, because here we are referring to only the isotopes feature heavier than uranium but HLW can contain several other isotopes as well.

And this all this construction facilities, they are carried out underground means we have to construct the tunnels, then we have to fill up the tunnels using this waste packages and then we have to that filled the tunnels this everything needs to be done underground and all these processes are all these operations should be properly paralyzer or should be properly synchronized so that as soon as we have one tunnel ready we can filled that up with waste packages and immediately we can backfield that tunnel and we can start operating on another tunnel. So, proper synchronization is absolutely essential otherwise there will be chances of some kind of radioactive decay or leakage.

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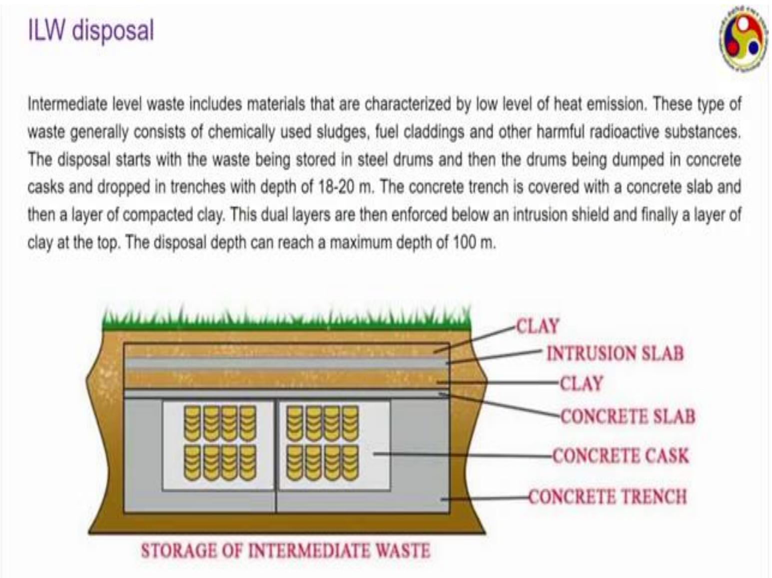

ILW disposal is so much easier, because ILWs while the radiation level is still significant there is we do not have to provide any cooling option. And therefore, this I LW material can first be converted to general in the form of chemicals largest or rather this I LW material that will get the general in the form of chemical used largest of cladding materials of the fuel and certain other substances.

So, the first this way of this is waste materials are converted or tech into steam drums this are the steam not steaminess steel drums solid metal drums and this drums are then dumped into concrete casks. So, this white portion, that is shown here this portion refers to a this concrete casks, then this concrete casks are put inside a concrete range, and then that range is covered with layer of compacted clay this entire facility is then put at the depth of attlee about 100 meters or so,.

So, ILW we can disposal upto a death of 100 meters not for HLWs or TRU's you have to be use to a level of at least 300 preferably 500 meters, and you can understand the corresponding level of effort required to each and underground depth of 500 meters and also it is not that once we have we have gone to the depth and put them dispose the material, the everything is done we can completely filled up rather we need to keep an option so that we can go back there and you can continuously observe what is happening there.

So, these are the primary classifications based upon the activity level and based on different kinds of classifications we have also seen some of the methods of disposing radioactive waste, but there are a few other classifications for the purpose of completeness, I am providing them like sometimes we also classified radioactive waste defense and nondefense the terms of self expiries as the defense which refers to the waste produced into military activities the weapon program and corresponding research reactors; whereas the non defense is primarily contributed by the medical and the power production facilities.

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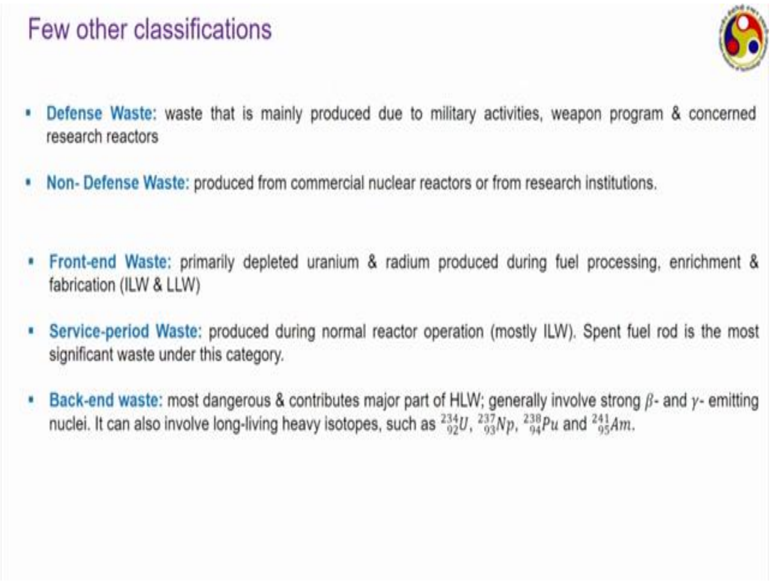

Based upon the time when they are produced we can also have front end waste front end refers to the initial part of the fuel cycle, these are produced during the fuel processing and enrichment and fabrication parts, which are primarily the depleted uranium and radium and falls under the category of ILWs and LLWs, then you have the service period wastes which involves the spent fuel rods. There also generally in the intermediate level, because spent fuel rods generally have very small amount of fuel left at the end of I am say 1 year or something like of operation.

And finally, the back end waste which is of major concerned, because at the back end during the reprocessing part we get the long living heavy isotopes such as uranium 234, neptunium 237, plutonium 238, American 241 all of them are strongly radioactive and also have quite long half life; and their strong beta and gamma these are heavy isotopes which go for alpha emission we also gets several other isotopes which are lighter, but have strong beta and gamma emissions.

So, this backend waste which primary constitutes the HLWs are a something that needs to be properly disposed, and the generally the HLW disposal methods are the ones that are applied to them.

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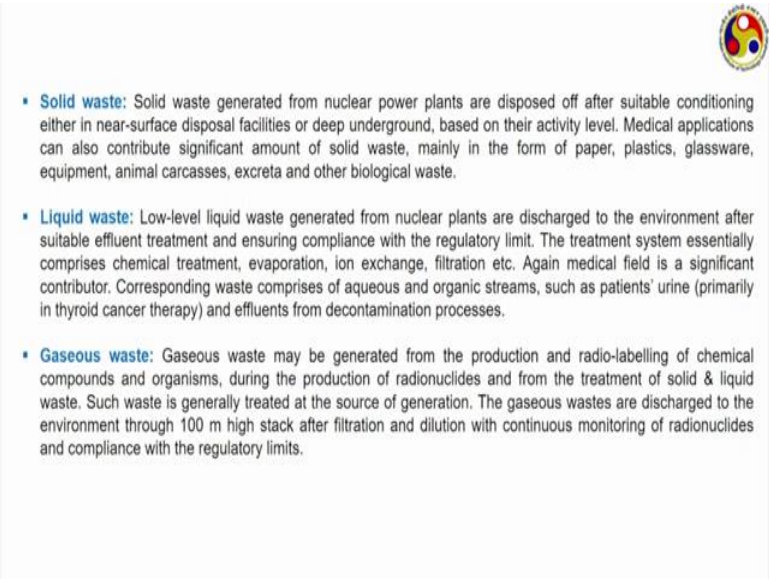

Depending on the physical state also you can have a classification live can have solid waste solid waste disposed there easiest to dispose I should say generally like, we have shown recently the HLWs are vitrified to convert to glass from solid glass.

So, solid waste disposal are much easier after suitable conditioning depending upon the activity level the either go to the near surface disposal, like in case of LLWs or over 100 meter depth for ILW there maybe the at the level of 500 meter depth in case of HLWs. Medical applications can also contribute significantly towards the solid waste like a papers, plastic, glass, ware equipment animal carcasses etcetera and other biological waste that all can come from the solid waste category.

Liquid waste is something the handling that is much more difficult. Generally the liquid level or low level wastes that is; if they are radioactive level is low we can directly discharge it to the environment after a few days of containment or suitable effluent treatment ah, but if their activity level is high their much more complicated to handled the treatment system, this appellant treatment essentially in compressors chemical treatment evaporation ion exchange filtration etcetera like one prob diagram you have seen during the previous lecture without going to the detail of that.

Medical field is again a suitable significant contributor the liquid wastes, it comprises both aqueous and organ stream such as the patients urine and other kind of fluid patients which are getting some kind of radioactive treatment like the thyroid cancer therapy etcetera. They are excretion can contribute to liquid wastes, and also the effluents from the decontamination process can contribute the liquid wastes the containment system for liquid waste despised low level of activity should be very strong, because a small leak in the structure and the waste can come out and spread radioactivity directly to the environment.

Finally, is a gaseous waste they are generally created or produced during the production and radio labeling of chemical compounds and organisms. During the production of radionuclides and also doing the treatment of the solid and liquid wastes; generally this wastes are treated the source of generation and allowed to discharge to the environment through very tolled stack something having 100 meter height or like that after filtration and dilution with continuous monitoring radio nucleus and of course, it has to compliance the environmental regulation limits as well

So, these are the classification based upon the physical nature, but again all of them can be classified as HLWs or ILWs or LLWs and primarily all the disposal methodologies follow that IIEA classification the which is based upon the activity level.

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These are a few common disposal sites of the world from US from France, Spain, Argentina, Australia every country of their own disposal sites this is another from.

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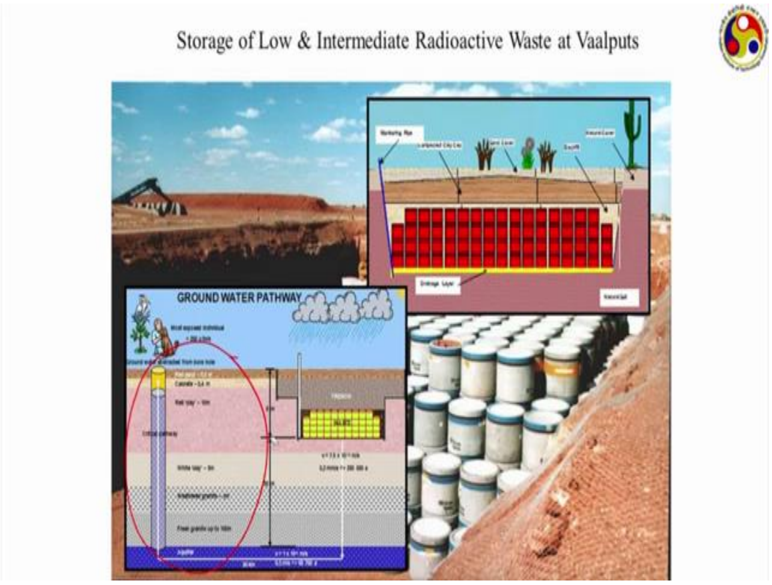

South Africa a very common cites you can see from this diagram the different levels of protections, that they have provided different layers of protection that they have provided to get the radioactive material on in underground location and to stock any kind of radiation effects.

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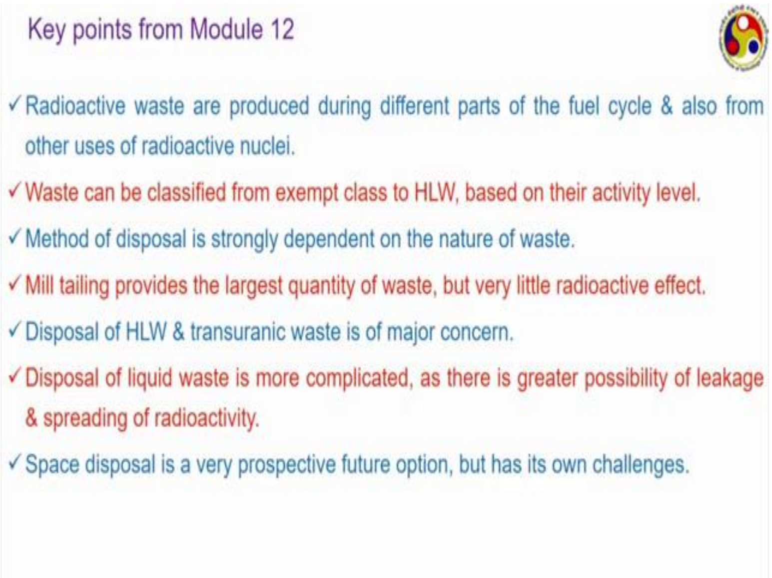

So, that brings us to us the end of this particular module 12 here we have learned from discussed about the radioactive wastes. We have seen that the waste can get produced during different parts of the fuel cycle not only from the reactor, but also from the milling process as well enrichment process refinishing and reprocessing part and also several other industries can contribute to the radioactive waste fluid. Wastes can be classified from exempt to class to HLW based on their activity level and their disposal methodology strongly dependent on the classification.

Mill tailing which generally falls under low level of very low level wastes ah, but their largest in quantity can contribute of the 90 percent it is volume, but radioactive waste is very small less than 5 percent or maybe in the 5 to 10 percent range disposal of HLW and transuranic waste is of major concern the volume is very less can be just about 3 percent of the total waste volume, but can contribute about 95 percent of the total radioactive wastes.

And therefore, we have to provide extreme conditions for extreme care for their disposal like several layers of protection underground depth of 300 to 500 meters and also very well the cooling options and also very very long period over, which this is maintained. Disposal of liquid waste is more complicated as there is a greater possibility of leakage and spreading of radioactivity and space disposal is a very prospective future option.

But has its own challenges because their can be political issues as well and also the this after the spacecraft has start been launched it is not fully in control of the operator, if there is an extent happens then the radioactivity will be directly spread to the environment. So, we have to think this or you have to very very careful about applying this space disposal there is the end of our module 12 and at the same time it is the end of this particular MOOCS course on fundamentals of nuclear power generation.

It was it is I do not know how to express, but it was an association for 12 weeks during which we have discussed about several things. I have received several messages from you discussing which contains your queries some of the messages where praising the course, some of the messages which mentioned about the problem that you are having I tried to address those issues like, your having major issues about solving numerical problems. I have tried to address that by providing the solutions hopefully you are in a much better position.

Now to tackle relevant numerical problems while some of the topics we have discussed quite extensively like the fundamentals of nuclear reactions, the neutron moderation technologies, neutron diffusion, neutron nucleus interactions several other places also I have restricted myself those more practical in nature, like the fusion technology, the breading reactions, radiation protection, the waste management, here all these are very practical methods and their several other things I could have included; but this being only the first course on nuclear engineering I have restricted myself if any of you are interested about any of those topics you can go to the internet and search for materials there are infinite resources available to learned. And also while this course ends here if any of you are interested about in interested to know any relevant topics you can always contact me my contact details are available on the IIT Guwahati website.

So, you can always get in touch with me and let me know and a please give your feedback is at the end of the course; what you have at all learned from the course, where there you have gained at all in from gained anything from the course or not please let me know, because actually this was a new experience to me as well. This is for the first time I had this experience of teaching in empty room in front of the cameras and monitors, but no student in fronts.

So, I am not able to have direct eye contact with you not able to interact directly with you which is quite boring to me. I will also I personally do not like too much or this slide or presentation mode of teaching; I am evict in the old mode go to the blackboard and do everything there and that is why a while I was very much excited while preparing the slides put my best effort to decide what to put in the slides, how to organize the slides.

But during the lectures quite often I lost my energy you may have simply it using during some of the lectures also because I felt bored just start talking in front of cameras, but hopefully I was able to get across some of the fundamental ideas, and if even some of you have understood, if you aspects of nuclear power generation I would think that is the successes for me this course. Again another final request please give your feedbacks, you can give the feedback on the course web page.

You can also write personate to me above regarding what is your own observation about this particular course, because that will help me in similar kind of future endeavors as well. So, that is it for now we name it in future in some other platform maybe in another MOOCS course or maybe some of you may come to IIT Guwahati as a future student; if or maybe somewhere else just accidently, if that happens please let me know I shall be very happy to and also if you need any kind of help; academic help that is anytime in future. Please let me know I shall try my best to help you out so.

Thanks a lot for the final time.