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NUCLEAR REACTOR AND SAFETY
AN INTRODUCTORY COURSE
Module 12 Lecture 01
Assessment of Radiological Consequences Of Incidents

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Good morning everybody. I have been talking practically safety and the way you see the subject material of the lectures is growing, you would realize that safety at every step is very important and we follow it in total, there is nothing like any relaxation on safety.

We talked about, so you see the depth to which we go. For example till now we were looking about shutdown, cool the reactor then contain, we said okay contain everything, we have got redundant, diverse and independent systems to take care of all this. Nevertheless we presume in all our situations, should all my engineered safety features fail, you might ask one question, why? When you feel the reliability is high. Yes, reliability is high, but then, should after everything is man-made we do have confidence in our designs, should something happen. So we should be able to take care of the radiological consequences. For example Fukushima, they had designed the reactor, the whole Fukushima plant, considering a tsunami of about 8 meters, but the tsunami had increased and that led to the submergence even of the diesel generators.

Of course there were other what you call some problems in the design, some problems in the way the operations were done, but nevertheless activity release was there, and mind you with all that activity release, today if somebody were to ask you okay how much would be the maximum activity that a person would have got, I can tell you in terms of something which you can understand you know, banana you take a banana it contains radioactive potassium-40 which is from the soil, suppose you consume one banana per day for 365 days, 1 year, how much activity you will get from the natural radiation is what you got in Fukushima, so but nevertheless so we, whenever we locate a plant everything we take these things into consideration that there will be a failure.

So in this lecture I will touch upon how we assess the radiological consequences in case of incidence. So what is it we need to demonstrate?

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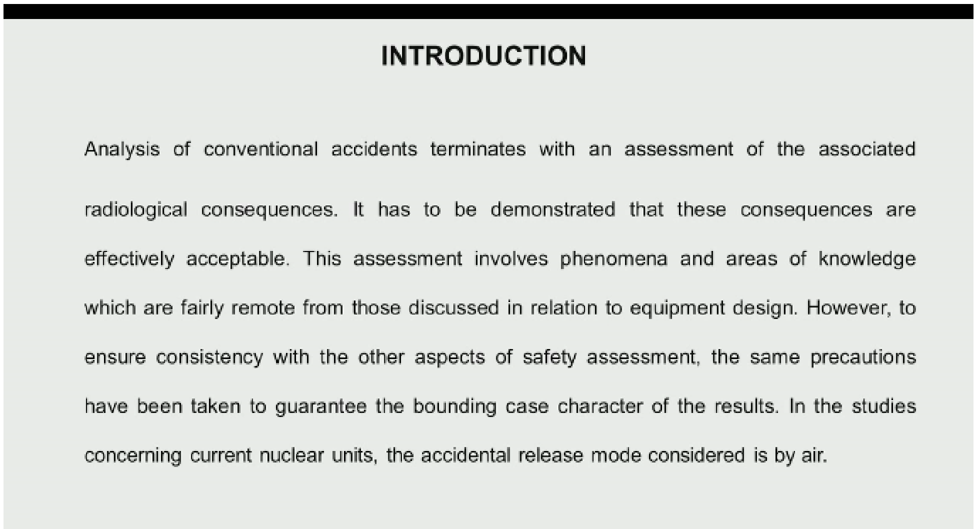

We need to demonstrate that should an accident happen, the consequences are what are going to happen are acceptable. Here what do you mean by consequence? We have put a limit on the maximum activity that can be received by a person of the, who is an occupational worker, we saw those limits in one of my few earlier lectures then we have a limit of a maximum in a single year for an occupational worker and averaged over 5 years that also we saw, then for the common public we had a limit of some 1 MilliSieverts, I was mentioning that we need to limit the amount of activity at to the, which is being, public would be exposed outside the exclusion zone.

So it is very much essential that we make an assessment of what could be the release of activity and how much could reach. So here if you recall we were talking about the stack release, how we decide the height of the stack in a nuclear power plant and then how it goes down, how we have models or the plumes etc. But now when we look at basically we look at the release which is coming through the root air route that is, let us say the containment has fallen, failed, the thing has come, the stack has no role it has come out, it is going round. So we need to find out how much of these activities coming now, that is what we call as the assessment of the consequences.

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The relevant calculations comprise the following stages:

- quantity of radioactive products in the core or reactor systems
- release rate for these products during the accident considered
- possible modes of transfer and deposit in reactor systems
- modes of transfer and deposit in buildings
- leak rate from the facility considered to the outside atmosphere and, where applicable, filtering efficiency

So what we then need to know? We need to have an idea what is the amount of radioactive material which is present in the core. If the amount of radioactive material present in the core is less, you will surely have less amount of activity in case of a failure. This then takes us to another philosophy, we should have small reactors, so that activity release in case of an accident would be less, but then if you look any production unless it is a mass production your scale size cannot be less, and we have not come to your level where nuclear power plants could be mass-produced and I am sure if mass production is there, going for a smaller reactor would be good.

Moving on, then we need to know how much of this will get released, the whole thing may not get come out, some will get released. So what is the release rate, that is we need to know, then what are the ways or modes in which the activity gets transported. So we also need to know how this transfer is happening of the fuel particles, whether how much of the particles, fuel particles are going to be deposited the fission products are going to be deposited within the reactor system or how much may be deposited within the building. So then we also need to know if the containment has failed, what is the rate at which the leak would happen and come to the outside atmosphere. So we need to know all these to finally tell how much of activity, Becquerels of activity which reach the public.

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- environmental diffusion, transport and deposit conditions
- pathways to man
- conversion of the activity absorbed by exposure, inhalation or ingestion, expressed in becquerels, to doses expressed in sieverts.

So basically, then after coming to the atmosphere the diffusion in the environment is going to spread we had a look at that yesterday how it spreads, and then how it moves with the direction of the wind, then how it deposits, so all these studies then we need to know how this thing will go to the human being through what route, that we shall see shortly. Then of course based on this activity how much of activity has reached there, we need to calculate how much of it would be absorbed through the different routes, and go to the person, the human public person and how much effectively, whether how many Sieverts of he will be exposed to, because whatever is there is not going to get everything.

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Historical basis of Containment

Regulatory and public concerns about the use of nuclear reactors for power production focus on the potential for release of radioactive materials from the nuclear plant during normal operations or as the result of accidents. The early development of nuclear reactors involved relatively small amounts of fuel and, consequently, small inventories of radioactive materials. There was a great deal of uncertainty about the safe performance of the early developmental reactors. A safety strategy pursued during those pioneering development activities was to locate the reactors on large on lands well isolated from the public. In the case of accidental release of radioactivity, the radioactive material would be so diluted by the time it reached the site boundary that it would pose no significant threat to the public.

Now just to get back to Historical Basis of the Containment, nuclear reactors much before the civilian nuclear reactors were built, you know, lot of reactors have been built for defense purposes basically to produce plutonium, you must have heard about the Hanford reactor site in the USA, similarly there have been reactors in UK and USSR where reactors just for production of plutonium have been there.

So in that case the level of knowledge base was not though so much they were more interested in the, what you call not a good use of the nuclear energy at that time. They had relatively small amounts of fuel, not very much and they used to locate these reactors in places which are far away from the common man because it is all highly secretive. So what was happening, in case there was a release, accidental release, it would get diffused so it won't reach to, by the time it goes to the common public man it would have been very less. So they were all very well you know this thing. Of course based on those sort of measurements which these people had, they actually looked at the different, what you call measurement of activities and they actually made a thumb rule.

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For each reactor, a serious accident was postulated. The accident involved gross overheating or melting of the fuel, rupture of the reactor coolant system, and an uncontrolled release of radionuclides from the relatively conventional building that housed the reactor. Allowing for meteorological effects on the transport and dispersion of radionuclides, the Reactor Safeguards Committee of AEC, USA recommended that residents be excluded within a specified distance R of the reactor. The exclusion distance R depended on the reactor thermal power, P (kWt), according to the following rule of thumb:

- $R = 0.01 \sqrt{P}$ (kWt), where R is measured in miles, or
- $R = 0.016 \sqrt{P}$ (kWt), where R is measured in kilometers.

We will be surprised, it says the exclusion distance ray are from the reactor is a function of the Power P that is Thermal Power put in kilowatts square root of that into whole into point zero one, if it is distance is measured in miles you know in US. It is always miles. In other countries in the MKS system or the SI system kilometers, so it is .016, so there is only the conversion between the mile and the kilometer. So the reactor safeguards committee of atomic energy commission of USA postulated this as a rule of the thumbs. So that means based on the effects your meteorological effects and things like that they said if you do this it is okay.

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Outside the exclusion area, it was stipulated that the calculated radiation exposure should be less than 300 rem (which is roughly the threshold for a lethal dose), or evacuation should be possible. For a 50 MWt plant, the rule of thumb gives an exclusion distance of 1.73 miles (2.77 km). For a 3000 MWt plant like many being currently used to produce electricity, the rule of thumb would give an exclusion distance of 17.3 miles (27.8 km) In December 1953, the AEC invited private industry to submit proposals for the first "civilian" nuclear power plant. This plant, the Shippingport Atomic Power Station, (230 MWt, 60 MWe extendable to 100 MWe) which comprised pressurized water reactor (PWR), was owned by the government, but was designed and constructed by Westinghouse.

So if you just look up and outside that they said the calculated radiation exposure should be less than 300 rem, so in fact it is equivalent to a lethal dose for a thyroid.

So now then in case you are not able to satisfy then you must go for evacuation. This was the sort of a thumb rule which they made. If you take a 50 megawatt thermal plant this distance comes to about 2.7 or 2.8 kilometers, but if you take a 3000 megawatt thermal plant it comes to something like 28 or 29 kilometers. So if you look up the earlier plants which have been, the basically the defense plutonium producing reactors they were all, this distance away from the you know, places where thick populations were there.

So when the civilian nuclear program started in USA they wanted to set up a reactor at Shipping Port, it was a pressurized water reactor so they, it had a power of about 230 megawatt thermal, and 60 megawatt electrical, but depending on the core, they could increase the core size and go to about 100 megawatt electrical. Now this reactor was of course owned by the government but designed by and constructed by the Westinghouse.

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The PWR would not have met the 1950 rule of thumb criterion. The Shippingport, Pennsylvania site was about 420 acres (1.7 km^2) in area and about 20 miles (32 km) from Pittsburgh. Although remote, the site was in a region with more population than was characteristic of isolated government reservation sites. Therefore a containment building was provided for Shippingport. Further reactors were provided with containments, to take care of a hypothetical core disruptive accident and prevent release of radioactivity into the environment.

Now let us see what they did for this reactor. They went by the rule of thumb which has been given by the Reactor Safeguards Committee, so it's, they found that about 32 kilometers from the site you have Pittsburgh, but then many areas in between also had population, not very thick, but good population. So the government was wondering what they should do, whether they should put that in a different place they were not satisfied the, they have satisfy the criteria but still that you can't say null population, so what they did they decided that we will provide a containment. So that is how the containment structure started so that in case of an accident, the containment would take care, so this is just a historical aspect of how the containment came.

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Quantities of radioactive products involved

- Multiple fissioned fuels contain a more or less complete spectrum of possible radioactive products having an atomic number below that of uranium. Fission fragments fall into two broad groups: a light group having mass numbers between about 72 and 110, and a heavy group having mass numbers from about 125 to 160. The most probable mass numbers are 95 and 135. About 300 different fission fragment isotopes have been identified. The yield of the most probable isotopes is over 6%.

Now coming back to the Quantities of the radioactive products which are involved in the release, you have a spectrum of radioactive products, you have the fission fragments which have different mass numbers something varying between 72 and 110, also there is one side because you have two Fission products, other side from 125 to 160 mass numbers. Of course majority of the, or the major fraction yield is around 95 and 135 mass numbers. And there is a different fission fragments there are nearly about 300 Fission fragments, so which are there, so all these things need to be considered.

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From the point of view of safety, the characteristics that are of most concern are:

- Chemical volatility, because volatility promotes release in accidents;
- A strong chemical affinity for the human body, because such elements are easily taken up and remain in the body;
- A high energy gamma decay, because of the need to shield against such radiation; and/or
- A relatively long half-life, because of the persistence of contamination from such an element.

But then let us look what are the points of concern which should really decide our, you know calculations. Now what is the type of decay, whether it is a gamma decay, generally a gamma decay is important, so we need to shield against such radiations, that is one, and then we also see to the which nucleates are harmful for the human body, not all nucleates are bad for human body so which radioactive nucleates are harmful for the human body, that's what we call chemical affinity for the human body, for example you know iodine goes to thyroid like that. So every organ has got certain you know affinity for some of the species, and whether they are volatile any of the fission products are volatile, how they are and their relative half-life, of course half-life is a very important aspect because that tells you how long you are going to have the effect of the radiation.

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Some of the isotopes of particular interest include krypton 85, strontium-90, iodine-131, and cesium-137. Table indicates the quantities of the main radioactive products to be found in a 900 Mwe PWR. These values and their relative importance would not be the same for a mixed oxide UO_2-PuO_2 fuel, thus containing plutonium from the outset or for significantly higher burn-ups. The term "core inventory" is often used to refer to the quantity of radioactive products in the core.

	Core 2 h after shutdown	Spent Fuel	Primary system	Gaseous Effluents
Rare Gases	10^7	10^6	$3*10^2$	$2*10^2$
Iodine	$2*10^7$	10^6	20	
Cesium	10^7	$2*10^4$		

Radioactive products, 900 Mwe PWR
UO2 Fuel 33000MWd/t.

Which are the important isotopes of interest radioactive isotopes, they are basically four, krypton-85, strontium-90, then iodine-131, and cesium 137. These are the four which are of maximum importance.

Now just to get an idea what is the quantity of these products, how they come down in case of a PWR Pressurized Water Reactor of 900 Megawatt Electrical, you can see this is the amount for, as I said 900, with a uranium oxide fuel, so what about the Rare Gases immediately after shutdown and finally what goes out in the gaseous effluence is only this much, iodine immediately how much is generated, how much is goes to the primary system, is this much and how much cesium, how much? So if you look up that if you have all these things are a function of the burn up of the fuel, that is why we said for a 33000 megawatt days per ton burn up, that means effectively so many megawatt days or so many energy per ton of fuel. So this term core inventory is what we call as the quantity of the radioactive products which are in the core. So this is what we look up and you see how the thing changes as a function of the different areas.

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Neutron activation of structural materials

- Most commonly used structural materials will absorb neutrons to some extent, and will, therefore, become radioactive. Materials used in the reactor core itself are selected to have as low an absorption level as possible in the interest of good neutron economy. However, some activation will occur, even in low absorption materials such as Zircaloy used for fuel pin cladding. In addition, leakage neutrons will activate material in the reactor vessel and in-vessel structures. For example, neutron absorption in nickel-bearing alloys will produce cobalt-60, which decays with a high energy gamma, and is, therefore, a shielding problem. Corrosion products of activated structural material, carried through the coolant system, also contribute to the need for shielding of the coolant system to protect plant workers.

Not only this we need to consider that you have lot of structural materials, you have zirconium, which are the important, we have said zirconium you know is not a good absorber, you have selected it, so that we can have a good neutron economy in the light water reactors, so but nevertheless it will absorb some neutrons, it will get activated.

Now in fact if you have a nickel based alloy, it will produce cobalt-60, and which is a gamma emitter and it will decay, emitting gammas. So then you get into a shielding problem also for the occupational workers. So one thing you remember, we try to avoid nickel or at least minimize nickel in the materials which we use for the nuclear reactors, then what else? We need to look at the corrosion products, because as water is there it is corroding, this corroding product also get activated, it is not the fuel alone, fuel is there, fission products are there, then you have got your structural material which are active, then you have got the corrosion products which are active, so all these are, it goes to the coolant system and you have got to shield the plant workers, the occupational workers from this, so you see you have a large job in hand.

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Neutrons may be absorbed in various other materials to produce radio-nuclides of interest in safety.

- Tritium production from neutron absorption in deuterium -important in heavy water reactors.
- Formation of nitrogen-16 from oxygen in the water -a shielding concern because of the high energy gamma emitted as nitrogen-16 decays.
- Formation of argon-41 from argon-40 in air dissolved in the coolant-also a shielding concern because of a high-energy gamma.

The radioactive products in the primary coolant are due to activation of corrosion products and possible fission product leakage through the fuel clad. In this case, accumulation is limited by the periodic renewal of part of the water and by purification.

Then not only this, Neutron absorption may create some new radio-nuclides. For example in this heavy water reactors deuterium absorbing a neutron gets converted to tritium. Tritium is not good so in fact tritium activity in the pressure heavy water reactors is one matter issue which needs to be dealt with very carefully. Then we have formation of nitrogen-16 based on the radiation of oxygen in the water, radiolysis of water you get nitrogen-16. Here again it is a gamma emitter, so it is again a concern and as it decays it is going to emit a lot of gamma rays. Then argon-41 it is a, this problem is also there in fast reactors where argon is used. The argon-40 gets converted to argon-41, that argon you may ask from where it comes in the light water reactors it comes in the air which contains a little amount of argon-40 and here again it is a high-energy gamma emitter we need to be careful, we need to take care of that activity.

So the radioactive products in the primary coolant are to summarize the activation corrosion products, the possible fission products that come out of the clad and how much of accumulation, because they don’t get if suppose the coolant flow was there they would get transported to somewhere, so it will get into other systems also, so how much is there, everywhere, all this sort of idea is needed for to assess.

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Release rates

- The characteristic release rate for each fission product is a particularly important factor. Light water reactor fuel is made of a type of ceramic which is both difficult to melt and relatively impermeable, enclosed in leak-tight clad, from which fission products cannot easily escape. The release rates of the various elements depend to a considerable extent on their physiochemical nature and the temperature of the fuel pellets. Certain substances, notably some iodines and noble gases, manage to migrate in small quantities from the fuel to the clad-pellet gap under normal operating conditions.

Then let us come to the Release Rate. How much is getting released? You remember, when we talked about the different barriers, multiple barriers, we told that the fuel itself is a barrier, because fuel holds, it has got a capacity to hold the fission gases and fission products inside. So that is the first barrier, of course the second is the clad through which it cannot really escape, if the clad is intact. Then how the release from the fuel take place, it depends on the temperature the fuel, if the temperature of the fuel is high, the release of the gases may be faster, otherwise it may be able to contain, then some of the gases would surely pass from the fuel to the clad gap during the normal operating conditions, again depending on the temperatures, so all these things given the release rate of the fission gases.

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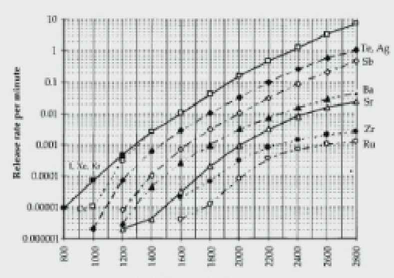
- Extensive release generally only occurs when the fuel pellets have melted, which does not happen in design basis accidents, where the clad temperature is limited to 1200 ^{0}C, that of the pellets being only slightly higher. Radioactive substances located at the onset of the accident in the primary coolant water, the structural materials or the gaseous effluent tanks could escape far more easily.



Now if you look up, really only when the fission, only when the fuel has molten, everything will come out. The fuel is not molten everything will not come out. So we generally normally limit the maximum clad temperature to 1200 centigrade in most of the light water reactors. Here you see a graph the pellet temperature versus the release rate. And this topmost graph is the release per minute of Iodine, Xenon, and Krypton.

Next is of course tellurium then antimony, barium, than comes here strontium, ruthenium, zirconium. If you see that as a temperature increases this increases and at the temperatures where we are crossing the release rate is very less fractions .0001, so it is very essential that we consider these things when we make the assessment.

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Transfer and deposit in reactor systems

- When clad failure occurs under accident conditions, the radioactive products emitted at high temperature enter the primary cooling system as steam. Some of them will settle on the walls of the system, but this is not the case for the noble gases. The steam cools and may condense forming aerosols, which may also settle on the system walls, depending on thermal hydraulic conditions. In addition, there is the possibility that deposited material may return to circulation, but this also depends on subsequent thermal hydraulic conditions. These phenomena are only taken into account in the event of direct discharge to the atmosphere, as is the case with a steam generator tube break for example. All other cases where the release path is through the containment are consequently rather overestimated.

Now we mentioned at the beginning of this lecture, we need to consider how the clad has failed and how the radioactive products are, will now enter into the primary cooling system, then since it is there, it will form, steam is there, it will form steam. Now this steam will be going, carrying the products, steam will condense on the walls of the containment building and it will fall down, then some of the material which has come out may be circulating in the coolant because you have still continued to cool using the emergency cooling system or the emergency water system, so something might be still going ahead something may get deposited.

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Transfer and deposit in buildings

- When they reach the buildings, all radioactive products are in aerosol form, except the noble gases. They generally stay there for a few hours to several days. High density aerosols tend to agglomerate. Soluble aerosols will be entrained by steam close to condensation or spray water, thereby gradually reducing their concentration in the atmosphere. This happens with the iodine soluble aerosol, cesium iodine, which can on the other hand; undergo radiolysis in the sump water to produce the gaseous iodine I2. In the other cases, the aerosols settle more slowly, by sedimentation, steam condensation on walls (diffusiophoresis) or due to a thermal gradient between the vector gas and the walls (thermophoresis). These phenomena, the impact of which on release rates is highly significant, are imperfectly known and are currently the subject of research.

So we need to know how such things will take place and we should not overestimate the amount of, so even though if we have a core inventory all of that is not coming out into the public environment.

Now, in the buildings if it is an aerosol form they could be gaseous form then some of the aerosols may be soluble, some may not be, so if it is soluble, for example iodine soluble aerosol now cesium iodine can happen, then it can undergo radiolysis finally produce iodine or these aerosols may move along with the steam condensed on the walls, so there is and how these moves within the containment, is a function of your temperature, there could be a diffusion, there could be a thermal diffusion, all sorts of, it is a very complex phenomena which is taking place. So all these need to be considered when we talk about the, how much will come out, then from the containment building to the atmosphere.

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Leak rate to the outside atmosphere and filtering provisions

- The radioactivity leak rate to the outside atmosphere depends on any overpressure in the building induced by the accident and on the building leak rate and any ventilation and filter systems. Building leak rates and filter system efficiency must be determined with circumspection and periodically checked. Consideration must also be given to the risk of direct leakage to the atmosphere bypassing any filter systems and thereby reducing their overall efficiency.

Now we do have filters, ventilation system and filters, so some of the radioactive material would be caught up in this filter system and depending on their efficiency of the filter system you will still get only less in the environment. So we have to see under this condition whether the filter system is getting bypassed or not, so we have to look at all the scenarios of this, so that we are able to estimate reasonably well.

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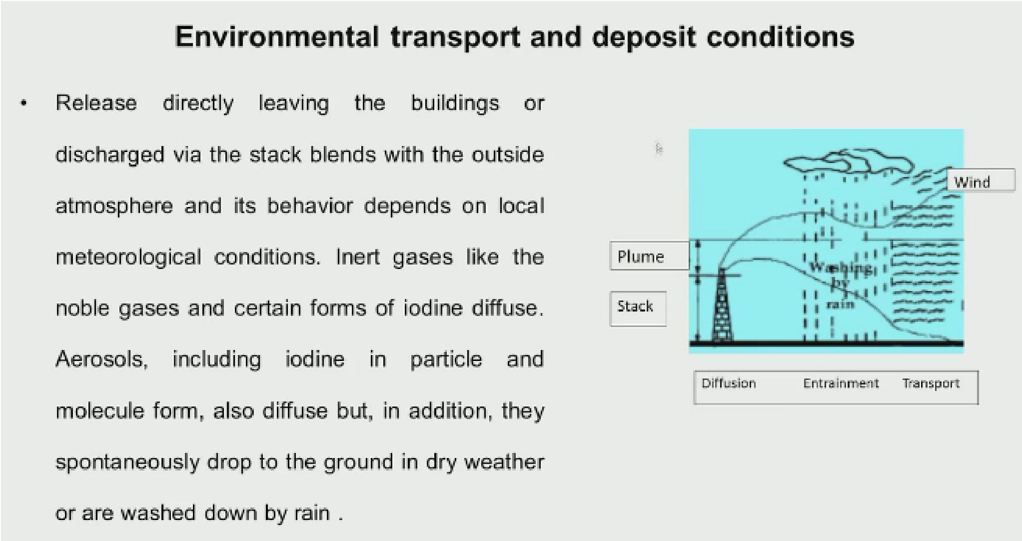

Now coming to the environment, as I said we discharged via the stack, anyway will continue and its behavior will depend upon the local conditions, the plume, then you have the rain. So here it is basically a process of diffusion, if rain is there it is a process of entrainment, and if the wind is there it gets transported. So all these things need to be understood, so here is where the modeling helps, the weather model which is based on the local conditions then and their current conditions we should be able to predict which direction things will go and how much of, which area will get affected. Now some of them could be washed by rain, so in that case this area would get affected, so if there is no rain it may go still further.

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Calculations of Radioactive release

- The formulae for the calculation of the dilution and deposition of radioactive materials release from a reactor, includes a term that describes the magnitude and the duration of radioactive material release from the reactor. This term, became known as the "source term." It has come to include a description of the physical and chemical forms of the released materials as well as the magnitude and duration of the release.
- The source term focuses on the radioactive noble gases, typically xenon and krypton, and radioactive iodine. One hundred percent of the noble gases are assumed to be released. Only 50% of the iodine is taken to be released from reactor fuel. Of this, only half is taken to be available for release from the plant. The released radioactive iodine is 91 % gaseous I, 5% iodine-bearing particulate, and 4% a gaseous organic iodine compound.

So now we're having seen all this complex processes people have brought out that some formulas for calculation of this whole dilution and deposition considering all that a value which tells you how much of activity is being coming to the public or coming out of the containment like that, they call this as Source Terms.

So what the Source Terms tells? It is the radioactive noble glasses like xenon and krypton and also our radioactive iodine and we assume that whatever is released 100% of these gases are coming, they are coming but only 50% of the idea of this is taken to be, for the release out of the fuel because the fuel itself has got the capacity to hold. Then again out of this only released from the plant we take another 50% of this and the released iodine is practically gaseous in about 91% form and about 5% is in a particulate form. So these things are based on studies which have been conducted on fuel assessment has been made of the iodine content and how much of iodine is coming and a very conservative estimate have been made for the calculations.

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Source Term Estimation

- Source Term (ST) is a way to describe how much material needs to be modeled for airborne transport in atmospheric dispersion modeling. The process of determining source term is based on experimental data and is selected as a balance between realism and conservatism. The phrase "source term" can be confusing. The full equation actually provides the "respirable source term for a release to the external environment". There are other "source terms", for example, "airborne source term" can capture the amount of both respirable and non-respirable material released to the environment and subject to deposition. Airborne source term is often used to calculate the impact of released material deposited on the ground near the event site.
- Source Term = (MAR) (DR) (ARF) (RF) (LPF)

So this source term we have to estimate for our plant, so as I mentioned it needs the modeling for the, airborne transport of the materials it talks about the dispersion, so all these models need to be validated and we do have such validated models so that we get a realistic.

Now the source term equation is something like this, there are five terms and this contains materials which are as I mentioned whether some of them may not go into the human system so because of respiration breathing something may go in, something may not go in, so all these factors we call as respirable fraction and non-respirable fraction and all these things. Now we will look into each one of these terms what they mean.

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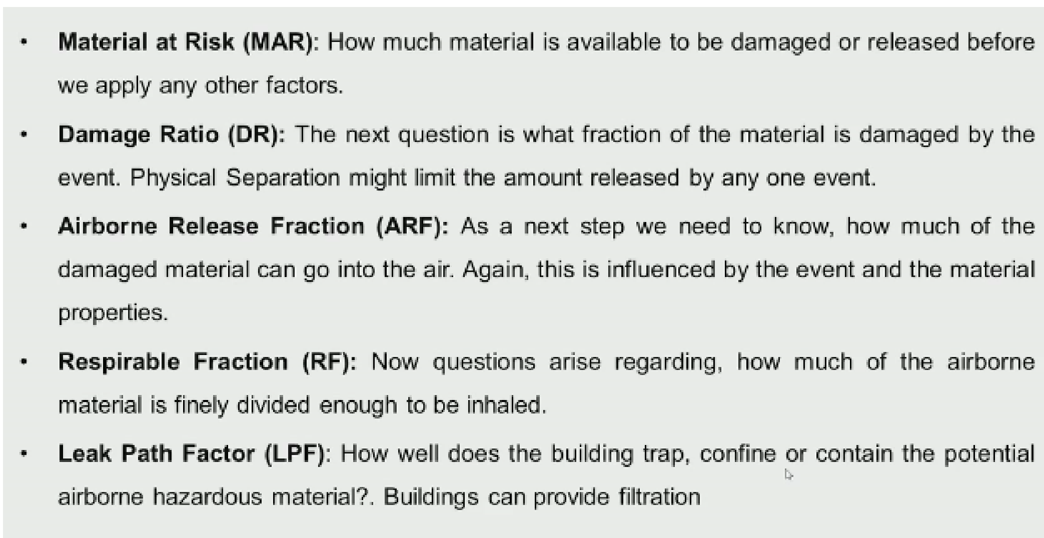

MAR is the material at risk, so we will say how much material is available to be damaged basically it is the inventory in the core, how much material is to be available, okay. Now we apply the factors.

Next one is the Damage Ratio. All the fuel elements may not be damaged only some fuel may be damaged, so we need to consider how much is the percentage damaged very peripheral core may not be, so we have to see if there are one or two fuel bundles only melt, in fact some of the studies have been done in different countries to see what happens when one fuel melts, one fuel assembly melts, they have found that this can maximum go to about 6 or 7 sub-assemblies, even though this is there, still we assume that the some times that the core, more than half of the core melts, but here this factor needs to be kept in mind.

The next is I'd call ARF that is Airborne Release Fraction that means how much of this will get into the atmospheric route, if it does not get into the atmospheric route it cannot travel to the public, to the environment, so that is the next one factor fraction we have to put. Then Respirable

Fraction so how much of it this is in such a form fine aerosol form in which it can go in, if it is in a very colloidal form it may not go in, only aerosol form will go when the person inhales, so this factor also you consider.

Then Leak Path Factor, Leak Path Factor means how well, see everything in the building is not coming out. How well the building itself is able to trap, has it got, it has a potential to trap how much the building itself traps, so how much is the leakage from the reactor, so that is what is the Leak Path Factor.

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Margins of Safety

- Often each factor chosen is conservative and has some safety margin (sometimes very large) built in to accommodate uncertainty. If all five factors a margin of safety ranging from 110% to 100:1, then you can easily end up with very exaggerated source term. It is not uncommon to see very large margins of safety in each source term factor.

So with all of these factors you calculate the source term. And of course we do apply some safety margins with all these five factors we apply is something like 110% safety margin, of course if you look at all this lot of variation is there in the source term factors considered by different countries, but nevertheless this is on the conservative side and you are assured that things are not bad and this we are looking if we look at the Fukushima or the Chernobyl accidents where in the, there was no containment, Fukushima the containment failed, the people who died maximum in the case of Fukushima were because of the tsunami, the death was due to tsunami, hardly few deaths due to radiation, intense radiation.

And talking about the genetic effects I will remind you what I mentioned in my lectures, few lectures behind, I mentioned that they have analyzed the effect of the radiation of which was given to the Hiroshima, Nagasaki in the bombings and how they're survivors who have had a very good amount of radiation they have been followed up, there few next generations have been followed up and it appears that if at all I can attribute, I could attribute some two cancers of the total number of cancers that have happened in the last 60 years in Hiroshima or Nagasaki to the atomic bomb, so it is not but nevertheless where we have uncertainty we try to keep as low as possible, alara principle. So that is what we do in our design.

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SUMMARY

- In spite of various defence mechanisms and barriers nuclear power plants are located in such a way that the radioactive release to the environment, in case of containment failure should be mitigated. In this direction, one needs to assess the amount of radioactive materials that would reach the environment. This lecture has given the basis of arriving at based on the depositions and dilutions at different stages of the accident. The amount of such material called as the source term is used in the estimation of dispersal into the environment based on the existing weather conditions and wind directions.

So I would like to now summarize my this talk in spite of the various defense mechanisms multiple barriers still we assume that the radioactive release is that to the environment, and that means we assume a containment failure, but should a containment failure happen we should mitigate to the consequences, so we need to assess the radioactive materials which will come out of the fuel? Which will come to the coolant? Which will come out of the coolant, into the reactor vessel? Which will out of the coolant reactor building? How much of it will come to the outside atmosphere? How the air plume will move? How the wind direction will affect? How the rain will affect? And all sorts of things have to be studied, many of them have been modeled, individual models have been developed and validated based on separate experiments and how much of can become an aerosol, because that is what will finally going to cause you, if it's other things is not going to cause a problem to you. So we estimate the source term and that is what we use for assessing the consequences of a radiological event.

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I can list a large number of literature, in fact large number of literature is available of the different countries, most of them refer to the US Nuclear Regulatory Commission. This is the first one calculation of distance factors of power test, 1962 is one of the oldest thing wherein you can find out maybe the formula which I gave for defining the exclusion zone. Then what sort of assumptions are used, one thing I can tell you here you see everything is documented, nothing is just, and one of the important things is the Wash 1400 report which was there, it is called as the Assessment of Accident Risk in US Commercial Nuclear Plants, this has given as a lot of deep studies into the modeling.

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And a comparison of the different countries basically German, France, Germany, France and USA have been given by the Sandia report, and this is a German Risk Study directed conducted and again this is an NRC report. So you can find out lot of these things in literature, but what I can tell you with all these factors put in even though there may be different source terms all the source terms are still highly conservative and can assure you that they are not going to cause any harm.

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ASSIGNMENTS

- Trace the historical basis of containment for nuclear reactors.
- What do you understand by neutron activation of materials? Why this needs to be considered in the assessment of radioactivity release during an accident?
- What do you understand by "Source Term"? Give the basis of arriving at the source term to the environment.
- Compare the source terms used by different countries for the assment of radiological consequences.

Now even though it is a subjective matter, I would still like you to look at these questions and deep into that and improve your understanding of the subject for yourself. Thank you.

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