Indian Institute of Technology Madras
Present

NPTEL
NATIONAL PROGRAMME ON TECHNOLOGY ENHANCED LEARNING

NUCLEAR REACTOR AND SAFETY
AN INTRODUCTORY COURSE
Module 06 Lecture 01
Safety Approach

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Good morning, everybody.

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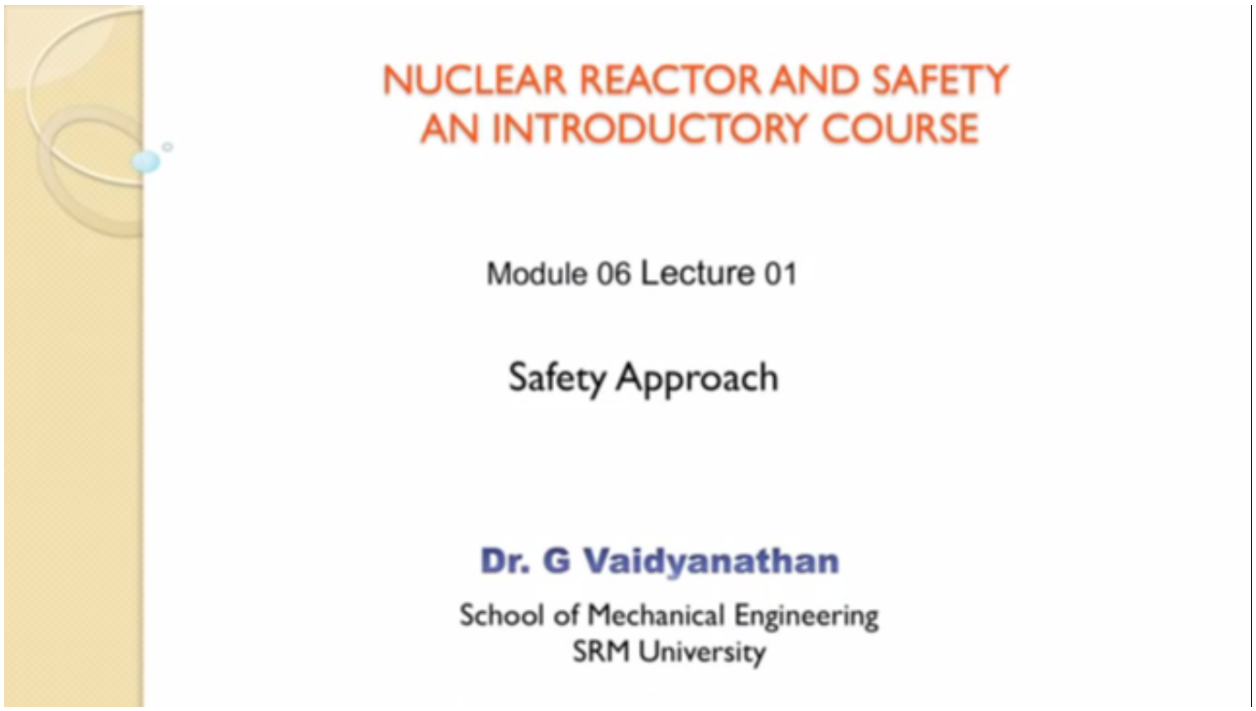

Today we move on to the lecture on safety approach. If you recall in the last lectures, two lectures, I had enunciated the different principles of safety which are followed right from the beginning of choosing the site, the design, the operation, I am sorry, the construction, then the commissioning, operation etc.

Now in this lecture, I will tell you how we really approach to satisfy those principles of safety.

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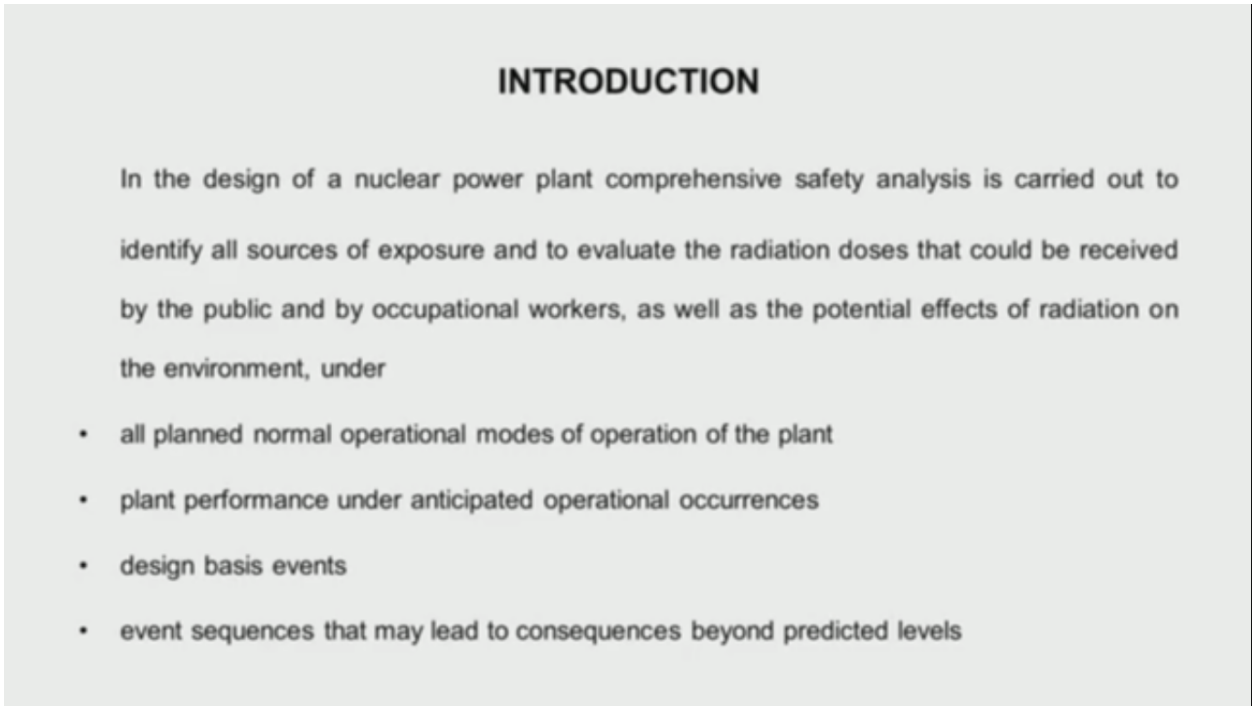

So, basically, we have to analyze the plant. We have to do a safety analysis of the plant so that we are able to identify what are all the types of events and what sort of exposures could the occupational workers or the environment get or the public get in case of each and every event so that we essentially know -- need to know what all states in which the plant will operate.

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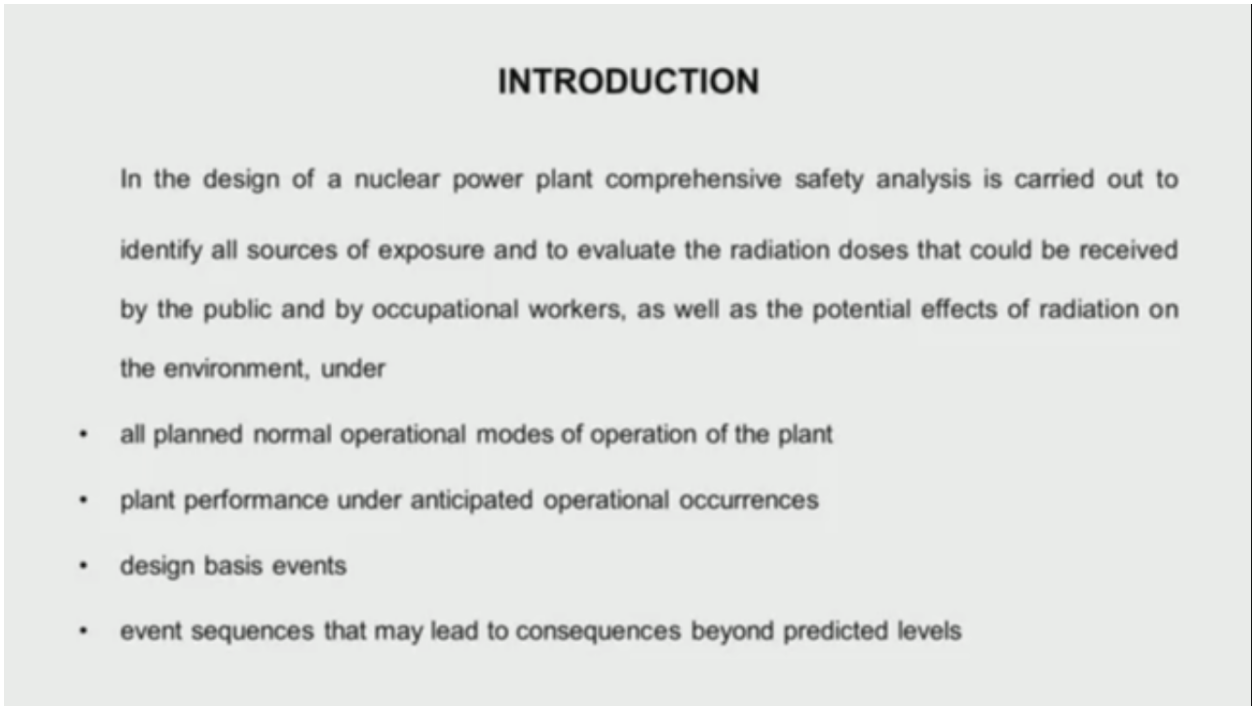

Yes, one could be a startup. Reactor is in a shutdown state. You make the reactor critical. Then go upon power. Then it comes down in power. This is a planned operation. Then let us say it is going to be shut down for some maintenance or it could be shut down for some replacing the fuel etc. All these are all planned.

Then you anticipate some occurrences in the plant. For example, everything is man-made. Nothing is infallible. For example, let us take a pump which is giving coolant to the reactor. Power might fail or the pump might get into a failure of its bearing. Anything would happen. So this is an anticipated operational occurrence, which we have to think.

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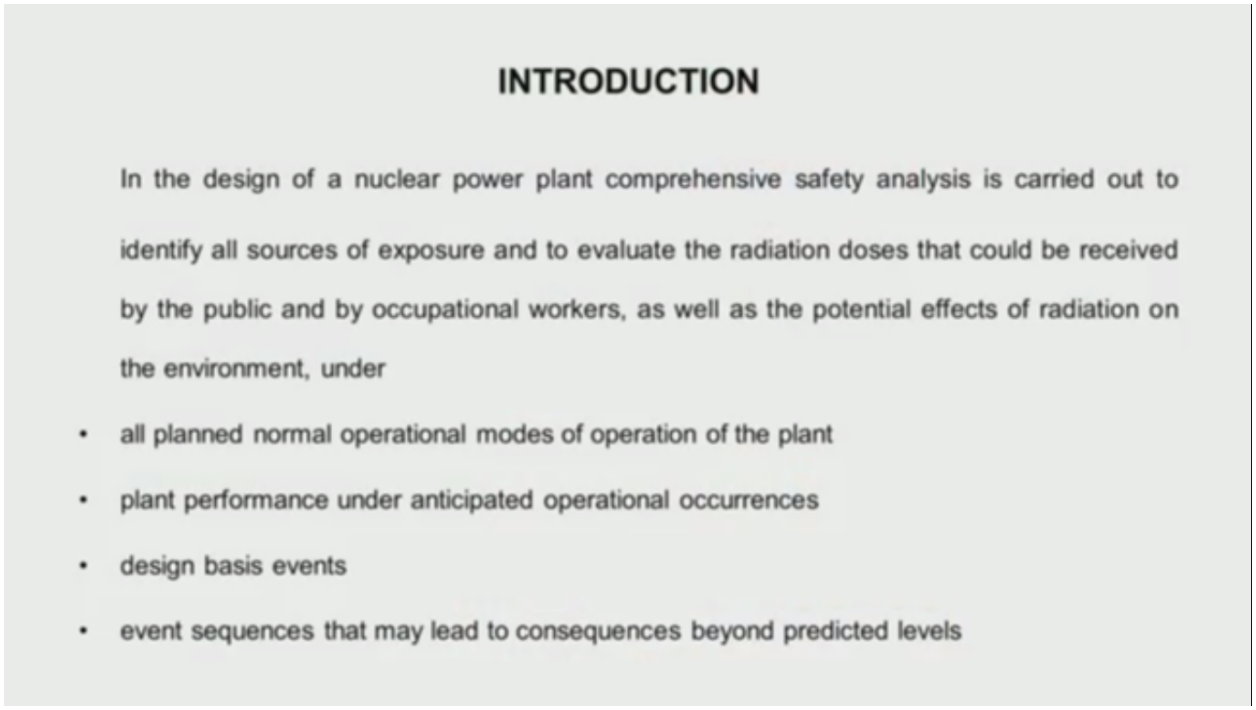

Then not only that, so once these events occur, there would be a chain of sequences of actions means the plant will go through a sequence of, you know, stages. We have to examine all those states -- stages and see really what can happen, whether the boundaries will be breached or etc. So we actually list out the normal operation and the different events, and as a whole this together we call as a design basis events.

And we also need to assess if some of the barriers have failed, then what sort of consequences it will have so that you are prepared for the consequences. So if you essentially look right from the beginning, safety, safety, safety, we always say, okay, if this fails, this is there, this is there. If that fails, another thing is there. And we also still, you know, assume a failure. That is because we know for the ultimate you need to provide surely some safety to the public.

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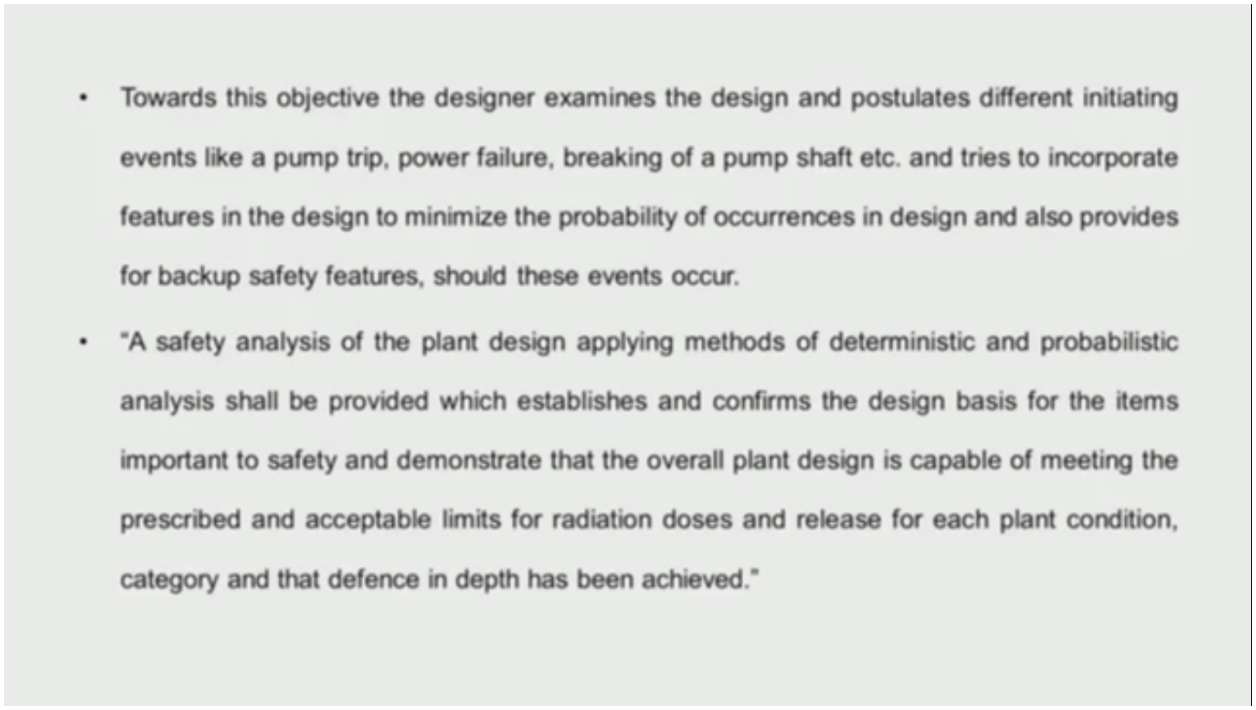

So what does the designer do in the design stage, for example? He postulates different events in the plant. One as I mentioned power -- pump trip. Other could be a pump failure, or it could be a shaft failure, or it could be a sudden trip of a turbine, or it could be any other event. So in order once he postulates that these events can take place, then he analyzes the plant how it responds, so that one is minimization of that event itself.

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- Towards this objective the designer examines the design and postulates different initiating events like a pump trip, power failure, breaking of a pump shaft etc. and tries to incorporate features in the design to minimize the probability of occurrences in design and also provides for backup safety features, should these events occur.
- "A safety analysis of the plant design applying methods of deterministic and probabilistic analysis shall be provided which establishes and confirms the design basis for the items important to safety and demonstrate that the overall plant design is capable of meeting the prescribed and acceptable limits for radiation doses and release for each plant condition, category and that defence in depth has been achieved."

Again, let us take the example of the pump -- pump trip. If the coolant pump trips, the reactor will not get the coolant and may need to be shut down. Yes, by shutting down, you have taken the reactor to a safe state, but then you have to remove the decay heat afterwards, so subsequent cooling also you have to think. So one way and every time you start up a reactor, you shut down, the plant availability is lost. So it is not good. So what he does? He puts two pumps. If one operates, if it tips, the other standby comes, so this way the trip of a pump that event need not be considered. Then that is what we call as the backup safety features.

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Then what are the safety analyses we do? We do two types of analysis. One is the deterministic and other is the probabilistic analysis, which gives us the design basis of the pond of the components which are important in determining the safety of the plant so that you can design in such a way that even if there is a radiation release, it is within -- within the acceptable level so that we are assured of safety within the boundaries.

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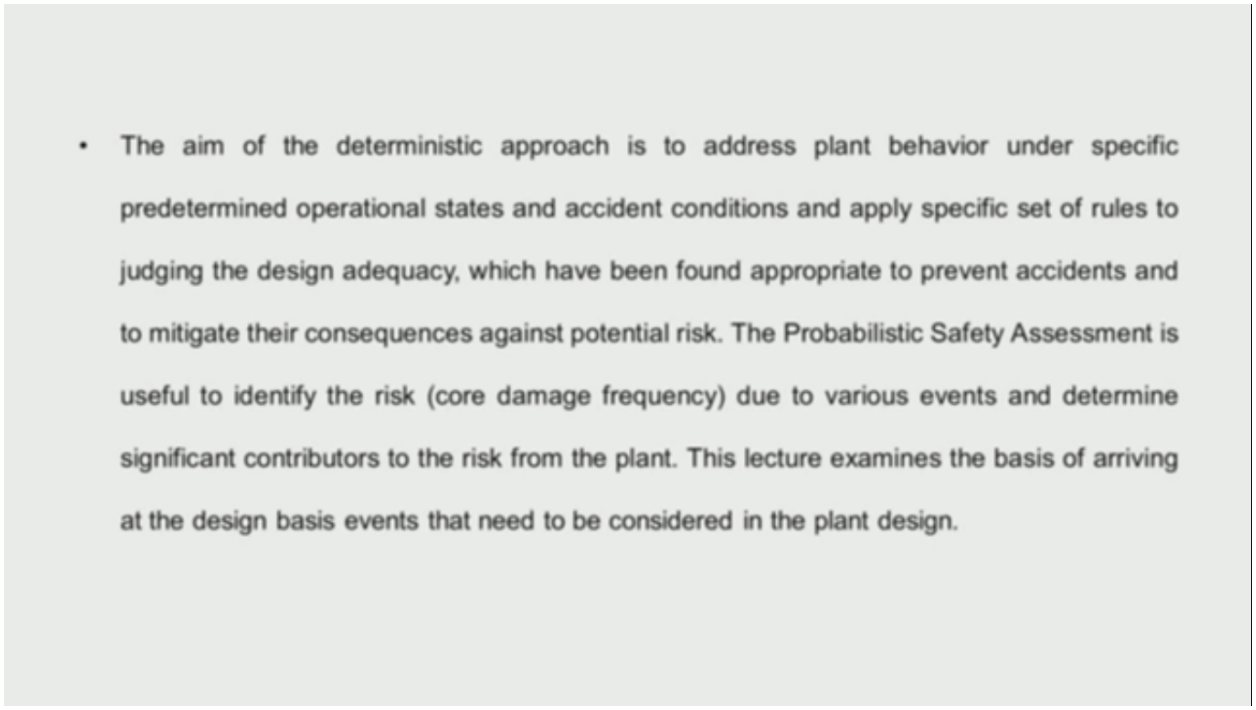

What is this deterministic approach? Deterministic approach is what, in a very simple way, what is the behavior of the plant under a specific operational state and the subsequent event. Then let us take you have a coolant pump failure. If the coolant pump fails, the core will be bereft of the cooling, so the temperatures will go up. If the temperatures go up, you need to shut down the plant. Let us say you don't shut down the plant. You -- the operation continues. Then the fuel will melt because the power is not removed. The clad may fail because of the high temperatures. The fuel will come out and then the activity will come to the coolant and subsequently, if coolant boundary fails, the activity will come out. So here this is just what is the event and how the event propagates.

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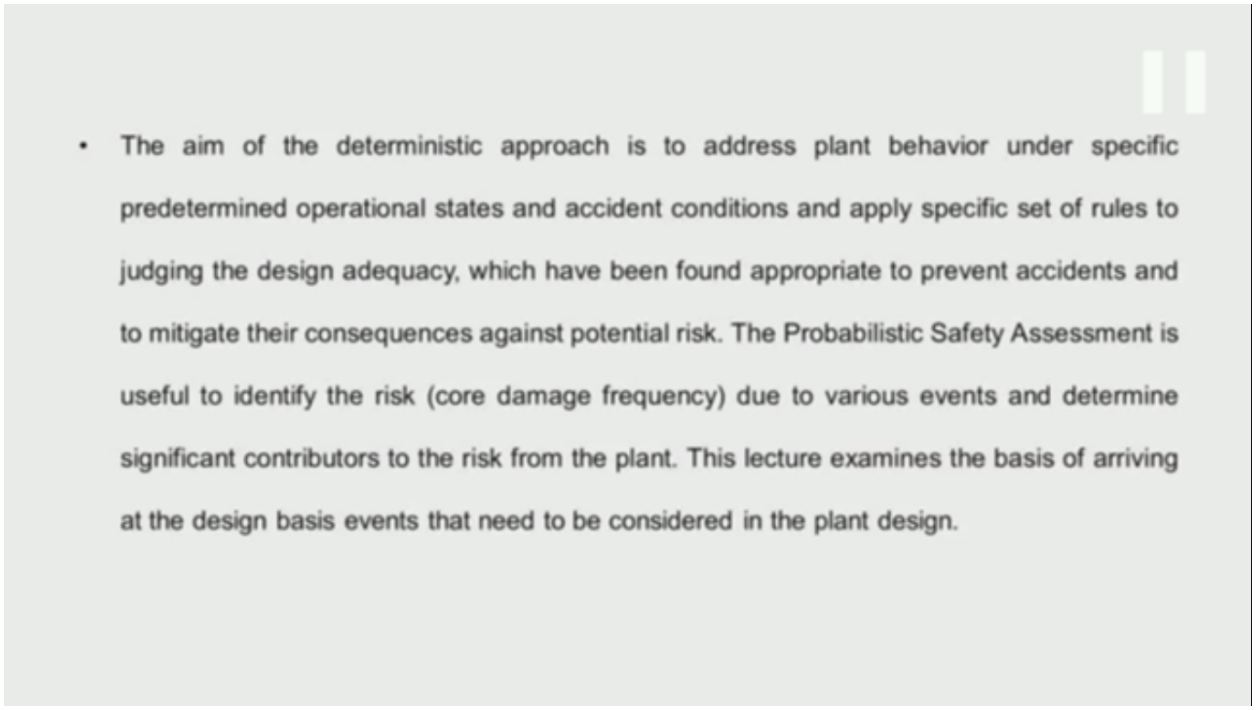

Now when we talk about probabilistic assessment, we will look at let us say again pump has tripped. What is the probability that my shut down will not happen? If I have a very reliable system, I can reduce the probability. For example, if I provide two shut down systems, I am assured. So then we need not consider that even that it will not occur and even if it occurs, the probability of that occurrence is so low. It may happen once in a while. Once in a while means maybe once in about in the plant lifetime, but then if it is going to happen once in a lifetime of the plant, maybe we could accept it with a higher level of consequence because the time -- number of times is less.

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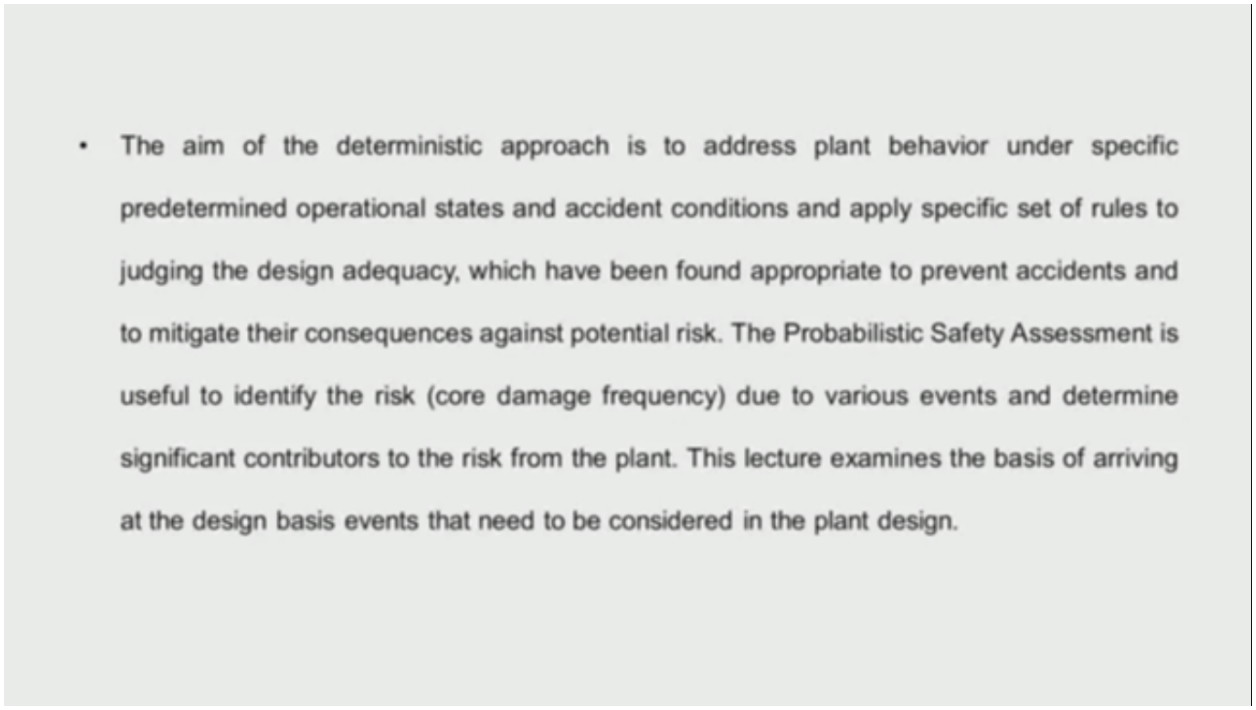

So, basically, here -- there in the deterministic, we just looked at the consequence. Here we look at the probability of occurrence and the consequences, so the net effect is what we see.

So in this lecture, we will examine the basics of arriving at the design basis events that need to be considered in the plant design.

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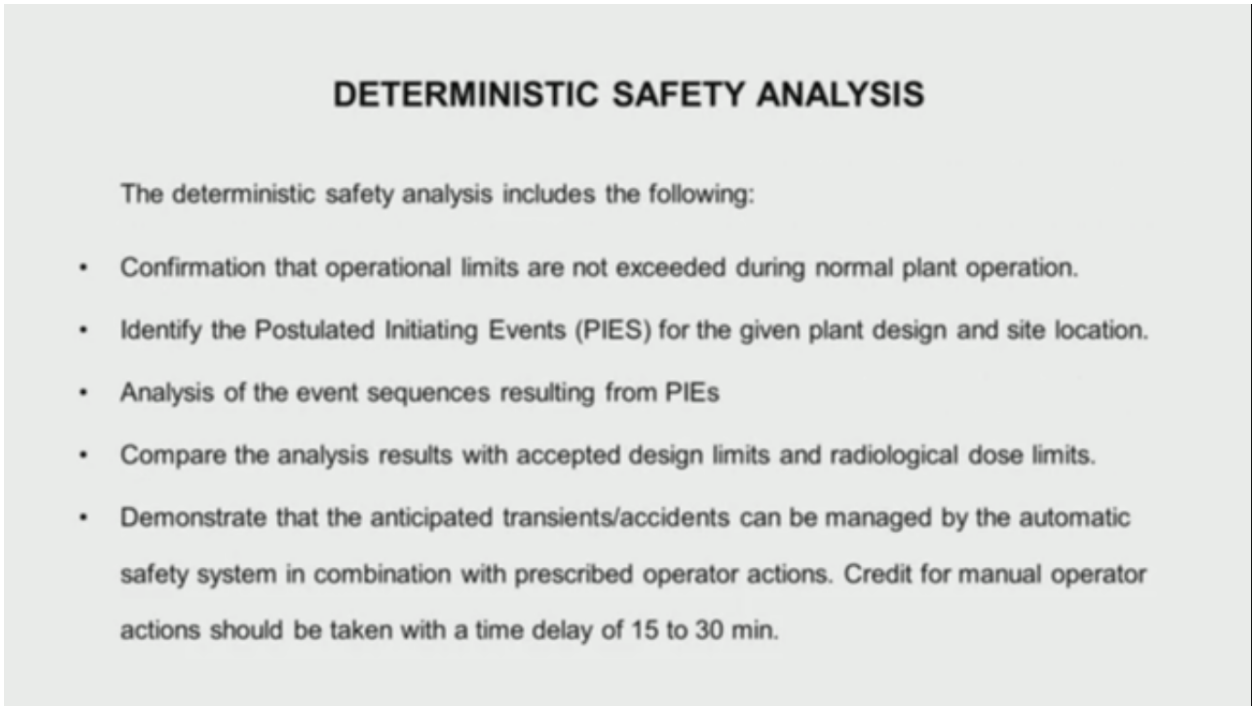

Now so what the deterministic safety analysis does? First, for a given event, whether the operation limits are exceeded or not, in case they are not exceeded, really you don't need to take any other safety action. Okay. Then as I mentioned, you identify different events or you postulate different initiating events for a given plant design and not only that, also with reference to the site where you are located. You may have something external happening, which is not from the plant, even occurring external.

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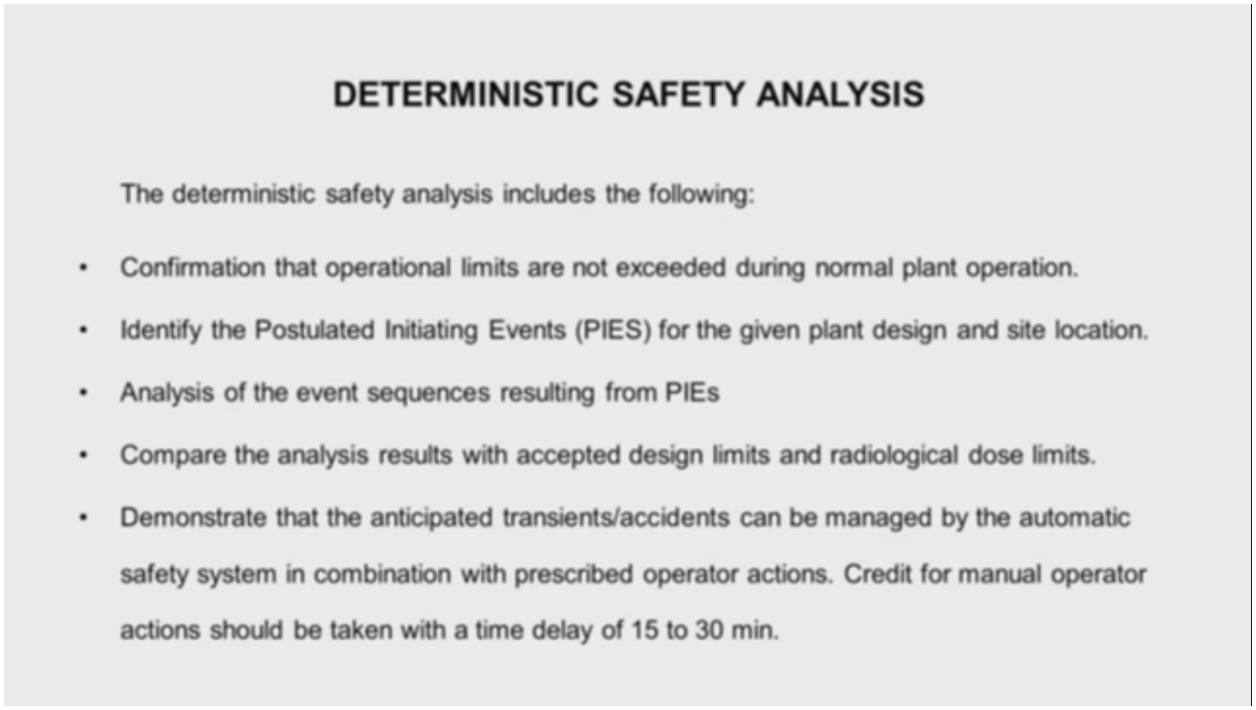

So you have to need where the location of the plant is there. Then you analyze what are the sequence of events, which is going to arise from the Postulated Initiating Events. Then whatever results of analysis you get, you have to compare with the limits, acceptable limits, if it is a temperature limit, in case there is a radioactive release, what is the radioactivity limit, you compare and satisfy yourself that the design and the design provisions you have made or your backups you are given here such that you are within the acceptable limits.

Then you would have provided automatic safety actions. So there is a need to demonstrate that the anticipated transients can be managed by these automatic safety systems, again, with maybe some operator actions, but not necessarily. Here again, I would like to reinforce one point that in nuclear reactor systems, we don't take credit for any manual action in the safety analysis for a period of about 15 to 30 minutes.

Normally, in the Canadian regulations about 15 minutes is stated, but the most of our designs, we don't consider for 30 minutes. So up to 30 minutes don't consider any operator. Operator will be there he will do something, but we do not take credit for that. So that way we are bit conservative. Here again, it is a human element involved. So we just cannot take, you know, what you call chances, but wherever till today you have seen the human beings things have been good. Humans, people have been able to act fast and take care and see to it that really the any event does not escalate into an accident.

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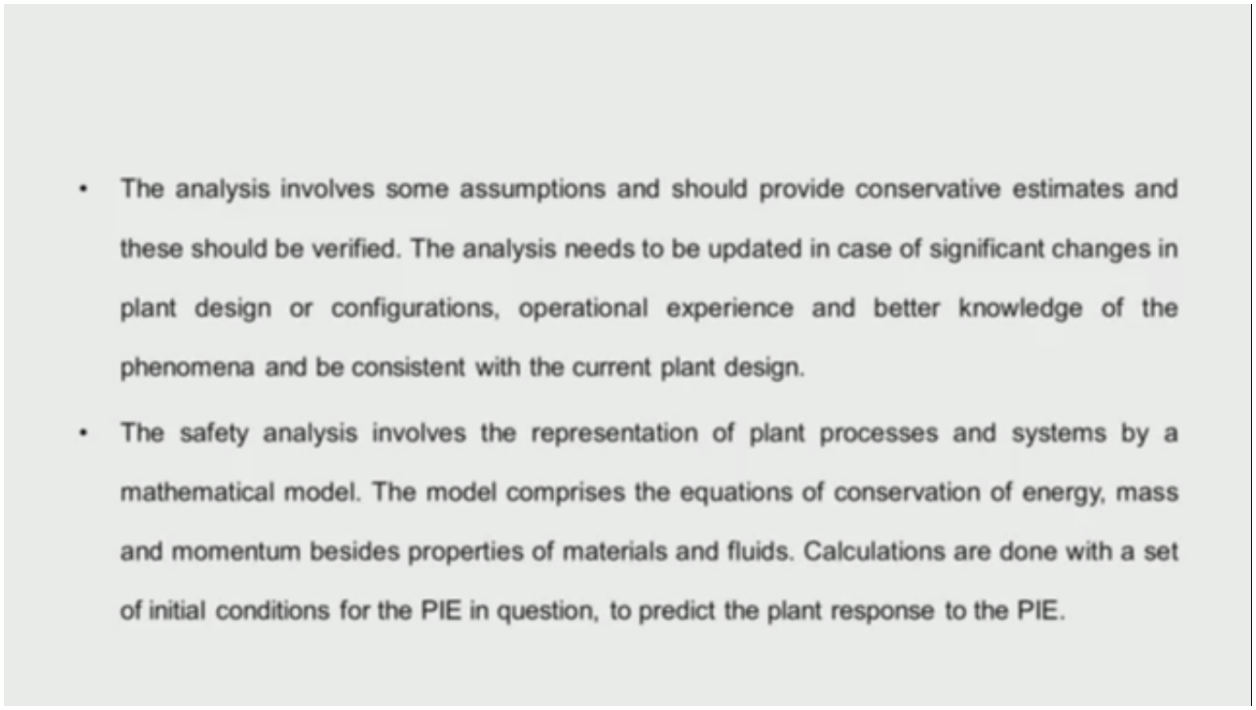

Now when you analyze the safety, you look at the behavior. You look at the process. Then you look at the behavior of the structures and how the material reacts to the pressure or the temperature. Now some phenomena may be one-dimensional. Some phenomena may be two-dimensional. It could have been two dimensionals and some things could be three-dimensional. So analysis, we need to be one-dimensional or two dimensional or three dimensional. But again, when you do an analysis, it involves certain assumptions.

So one is thing is very important, the assumptions which you make in the analysis should result in conservative estimates. For example, a result which you should get actually if it goes let us say from 500 degree centigrade to 540 degree centigrade, if your estimates say 550, it is good so that there is a safety margin. Of course, this should not be an undue safety margin because that is going to increase the cost of your safety. Then this estimates or this analysis has to be verified means you should be sure that the analysis is okay.

Let us say now you have designed a plant and you know when you do the design, you have to go after the design, you go to the regulatory authority to get clearance for the design. During this process of design review, in our country, this is generally done by the Project Design Safety Committee of the Atomic Energy Regulatory Board. So during this it is suggested no, you add this, you remove this, so like that lot of changes take place, and if there are significant changes or where things have really changed a lot, we need to reanalyze and see whether things are safe.

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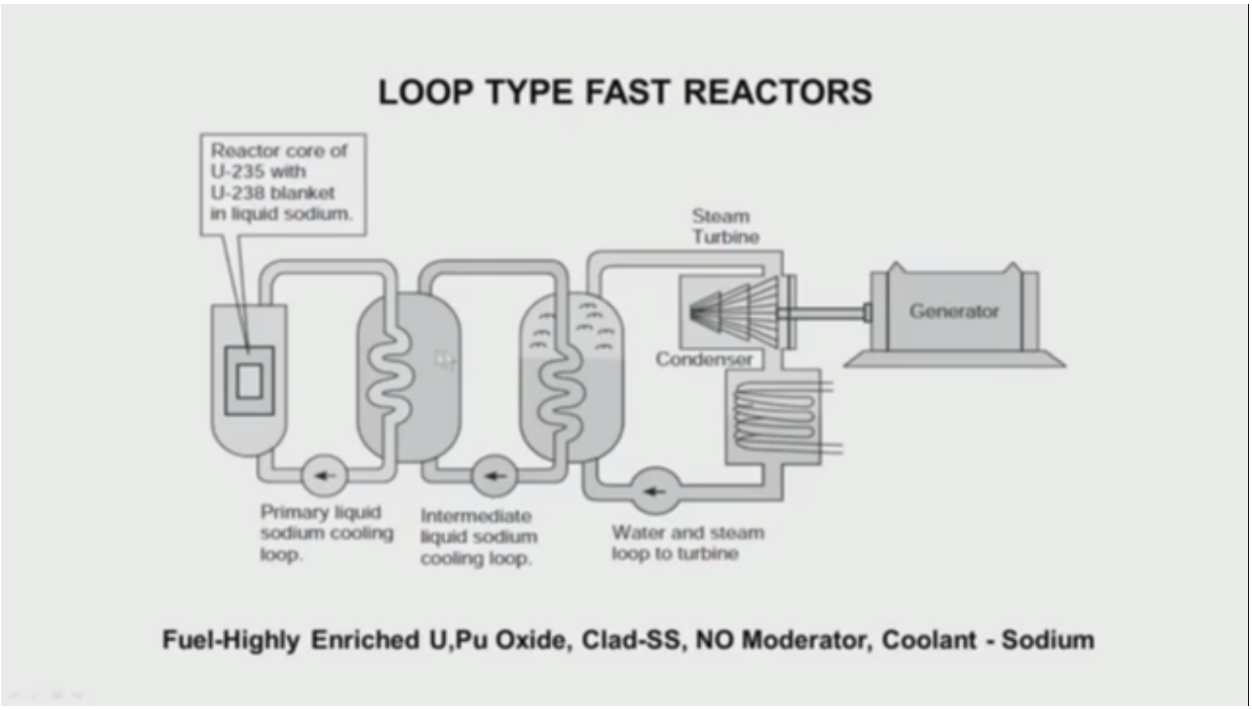

I will give you a very simple example. During the design of our Fast Breeder Test Reactor, as a designer, I had postulated different events and one event I postulated was seizure of a primary sodium pump. There are two pumps in parallel. So if there is a seizure of the primary sodium pump, the other pump would give flow to the core and reverse flow through the seized pump is reduced -- is nil because you have a non-return valve. It is a float type non-return valve which because of the pressure it will close so the flow will go to the core.

During the safety analysis, the question was asked. If the float valve gets stuck and it doesn't close, I was surprised. Arre! Non-return valve is meant to close. So what will happen? Some flow will go to the core. Some flow will bypass the core. So I had to do a reanalysis if the thing bypasses the core and we found the situation was comfortable. So here is what I am saying at every stage any change in the plant design or configuration is there. Then you also need to look at the operation experience of different countries based on which you can gain knowledge and you do the plant design such that it is in a safe manner.

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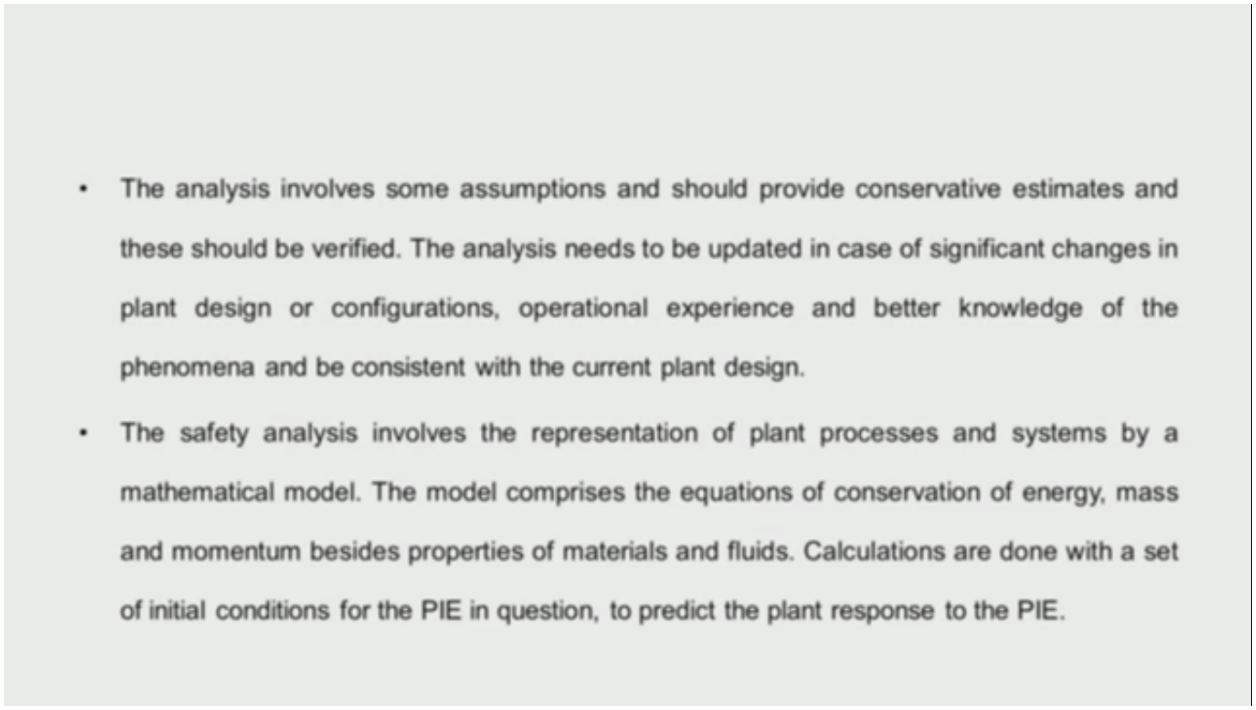

Now when you say a one-dimensional, two-dimensional and all, what does it really mean? Let us take the heat removal in the core. It involves basically the conservation laws. Heat is produced in the reactor. That heat has to be taken by the coolant and taken out to the heat exchanger, again heat, and in a steady state the energy which is released by the fuel is equal to the energy taken by the coolant. So it is an energy balance.

Then you take a capacity. Some mass is coming. Some mass is going. So, but in a particular volume, the mass is conserved. Then the pump is pumping the flow through the core and -- and a steady state operation whatever is the pressure developed -- pressure head developed by the pump will go to meet the pressure drop. So that is the momentum balance.

Then coming through the reactor portion proper reactor kinetics, basically, it will involve the neutronics equation, and then in all these cases we do calculations with a sudden initial conditions. Let us say we need to do analysis at highest power, lowest power, different initial conditions we have to do and predict the plant response.

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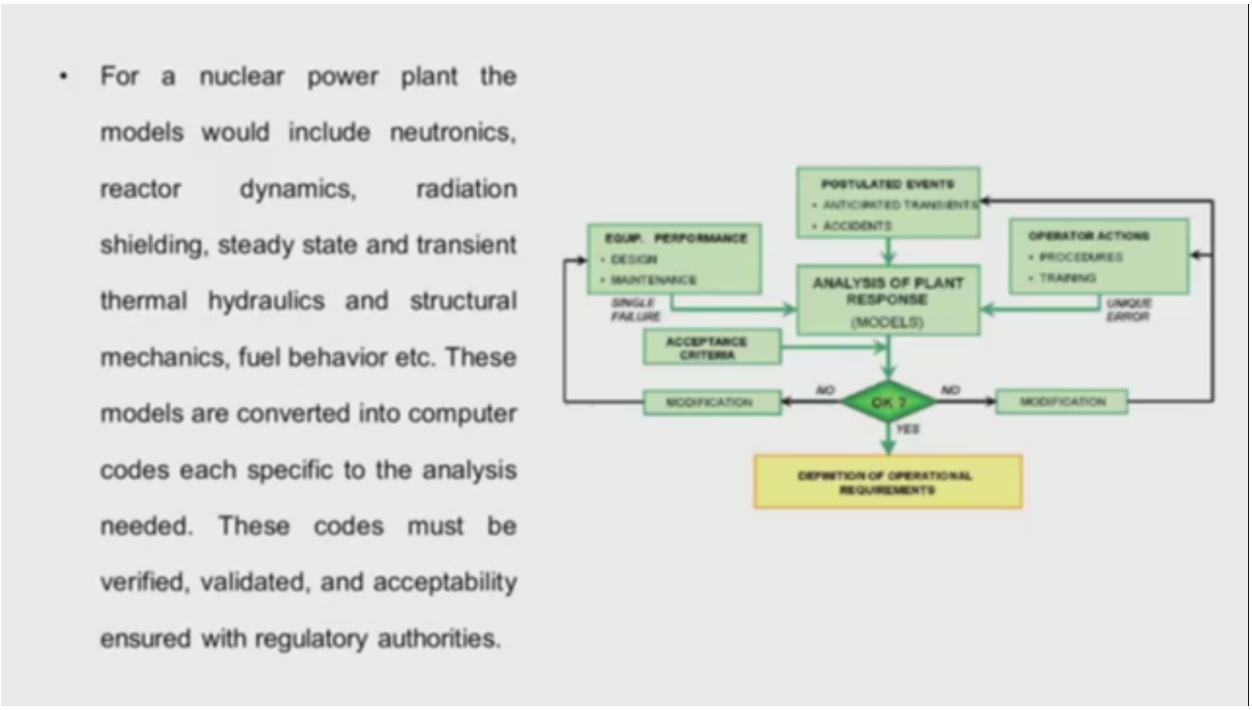

So here, basically, what you do? As I mentioned, you have the models for the neutronics, which is the kinetics to a change in the reactivity, how the neutronic power will change, so the reactor dynamics, steady state and transient, thermal hydraulics means the heat transfer and fluid flow, structural mechanics, how the structures would behave? And all these models are normally incorporated into a computer code one or two. For example, the thermal hydraulic codes give the temperature loads. The structural analysis codes takes this temperature loads along with the mechanical loads and tries to see whether the structure is safe for the given conditions.

Then these codes as I mentioned need to have been verified, validated and accepted by the regulatory authorities. This verification and validation many times if you are designing for the first time a system, you will not get a total data based on which you can verify or validate your code.

So here you have to do by parts. For example, let us take a heat exchanger. A heat exchanger is a heat exchanger whether it is whatever be the fluid. So only thing the properties change. So if suppose I have -- I need the model for a sodium to sodium heat exchanger, really making it and instrumenting it would be a quite a tough job, not that it is not possible. Nevertheless, I would -- I could construct many models in water and look at the heat exchange and I could validate my data, my code with that.

For example, we have a sodium to sodium exchanger in a fast reactor. We validated first against some water experiments, set of water experiments. We had the confidence. Then we also

validated it against some of the results, which were available in the literature based on other reactors. So, basically, what is the scheme?

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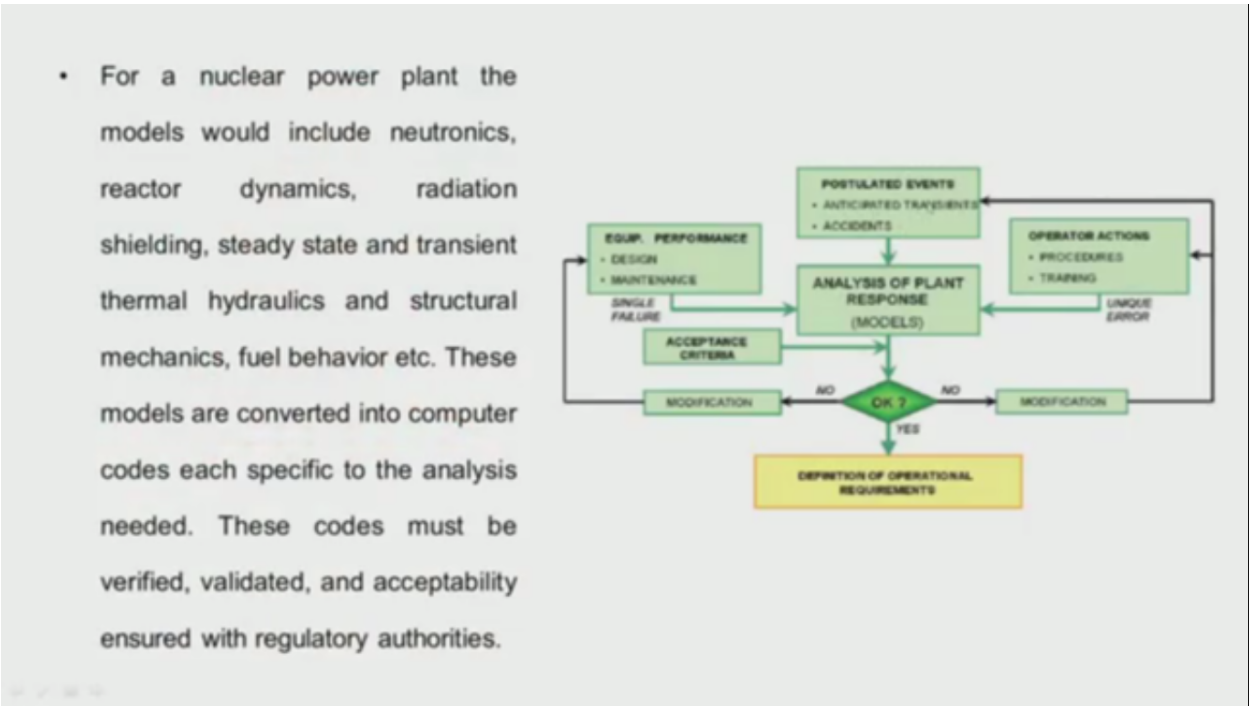

You postulate events and what sort of transients can come or what sort of accidents can occur and you analyze the response of the plant with these models or computer codes as I call. Then you see whether they are acceptable to you. The acceptance criteria does it meet? Okay. It meets. Okay. Then it is all right. You can tell what is the requirement, operational requirements. So it is okay. Okay. No, then you have to modify the things what one could be the operator response and other could be modify the design and see that in even in spite of a single failure, you must get the response acceptance. It must satisfy the acceptance criteria.

Here if you feel for some cases your automatic design or things cannot take care, you try to see whether operator action could be introduced by, without any error, by proper training and proper procedures. So this is how we go about analyzing the safety of a power plant and it is a very, very interesting portion wherein you get a real feel for what is going to happen in the reactor for each and every event.

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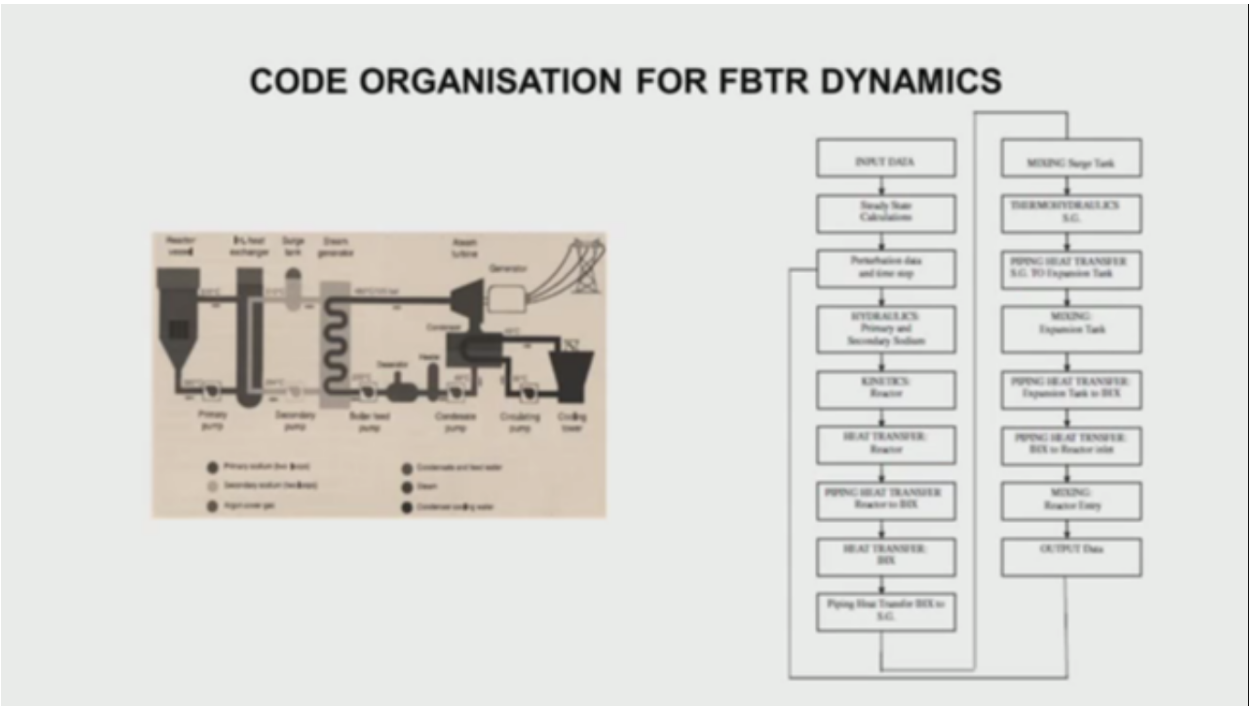

Just as an example, I would give the code organization for the Fast Breeder Test Reactor in which -- which was my area of work. You see here you have the main reactor. This is the core. The sodium pump pumps the sodium at about 380 degree centigrade. It comes out at 515 degree centigrade, exchanges heat with secondary sodium in a intermediate heat exchanger. Then this sodium is again pumped by the secondary sodium pump and it exchanges heat to water in a steam generator and this steam produced about 480 degree centigrade and 125 bars or 125 kg per centimeter square, drives a turbine and this is the steam water system.

Here you see a surge tank basically to take care of pressure transients in case of a leak of water into sodium. So here the code dynam which we had developed based on the input data, you do a steady-state calculation first so that what is the steady state condition. As I mentioned, you need to do the analysis for different conditions. Sometimes an event could be more harmful if done at a lower power whereas at the higher power, it may be safer. So you have to really not take chances. We have to do for the exact, you know, what you'll entire gamut of trees.

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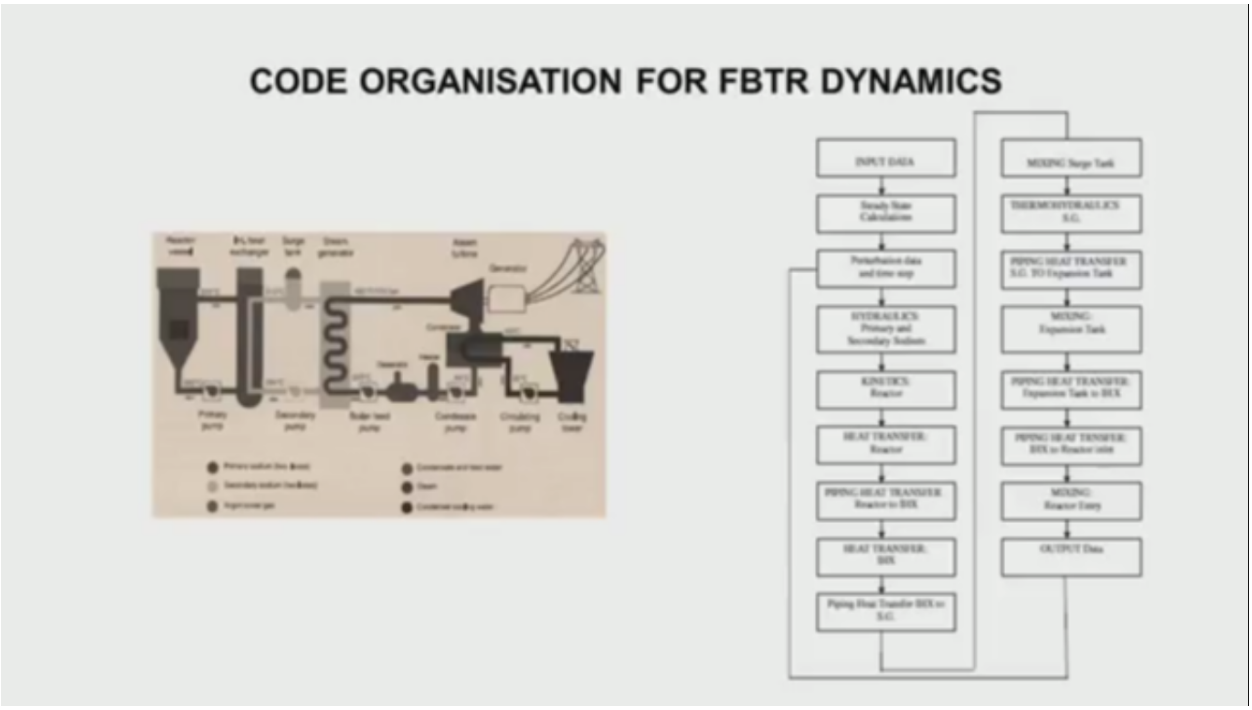

Then you talk -- talk about the event and then you first solve the hydraulics equations, then the reactor kinetics models you solve, then the heat transfer in the reactor, then the sodium going to the piping, you solve the piping heat transfer, then you come to the heat transfer in IHX, then again piping from heat transfer from IHX to a steam generator, then in the surge tank you have a process of mixing, then steam generator, thermal hydraulics you solve, then the piping heat transfer here from the IHX to the steam generator, steam generator to the IHX, then again IHX to reactor, and mixing at the reactor entry and then you get the data results. This is just to give you an idea in which how we do, and each and everything is a modular structure of the model, which we have validated independently and then integrated them to form an integrated model for the dynamics of the fast reactor, fast beta test reactor.

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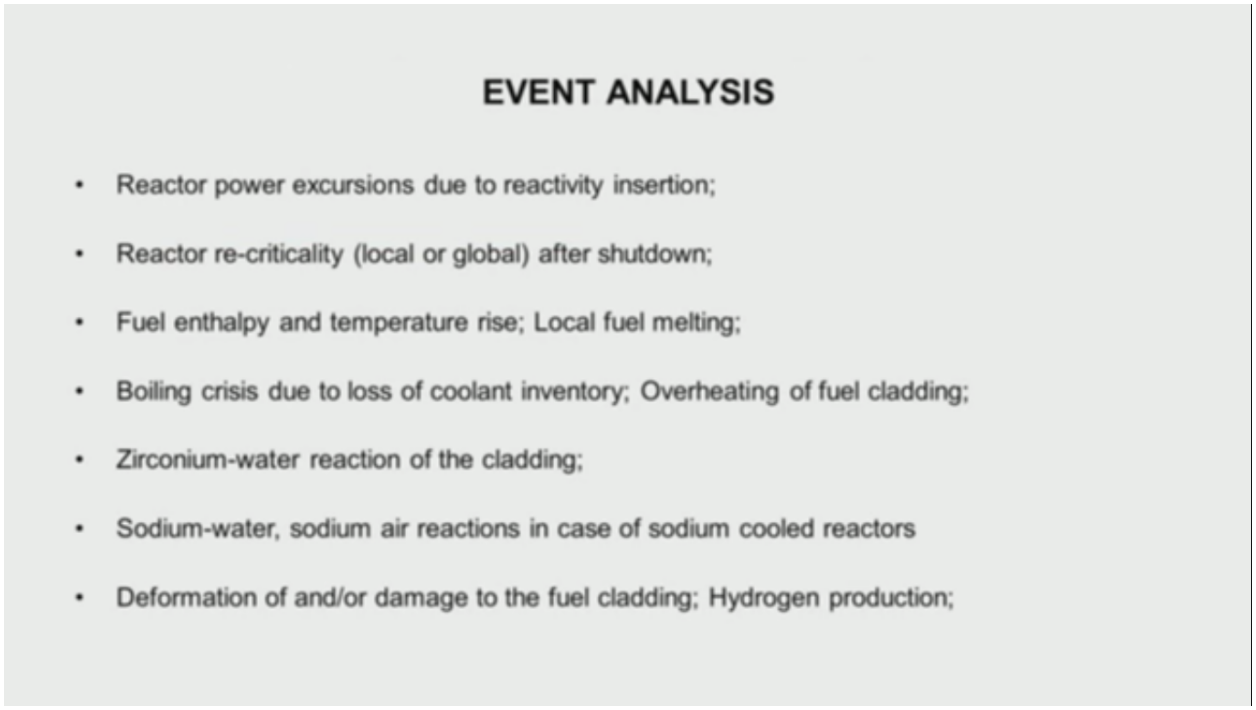

Now let us look what sort of events need to be analyzed. For example, let us take you move the control rod. When you move the control rod, there is a change in the neutron absorption. So when the neutron absorption changes, your neutron dynamics will come into picture. So how the reactor behaves? How the reactor power changes due to your reactivity insertion? And reactivity may also be inserted because of some temperature changes. Your control rod may not have moved. Your pump flow could have reduced because of the temperature increase. If the temperature increases, the density of the coolant comes down, the absorption of neutrons in the coolant comes down like that. So you have to look at the power changes, the reactivity effects finally, and then due to the -- or you could have some reactivity change due to entry of some moderating material. So all these things we need to assess.

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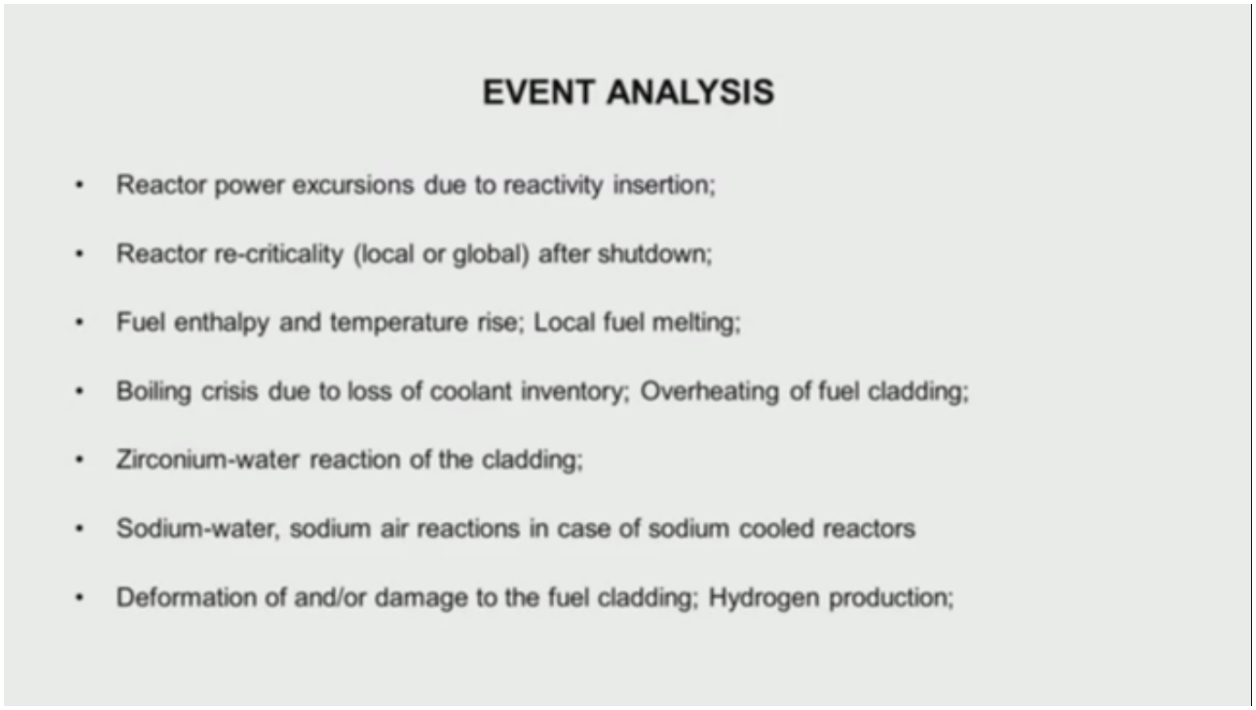

Then in some cases, basically, after an accident, we should see whether the reactor can become re-critical. The geometry of the arrangements of the, you know, the molten fuel everything should not again get into such a configuration that it again become re-critical. In fact, one of the defense in depth approaches in most of the reactors is when the core melts and falls to the bottom, we have a core catcher and which has got a slope towards the outside. That means if it falls on the core catcher, it will move away from so that it will not form a critical mass. So this is a very, very easiest way of doing things.

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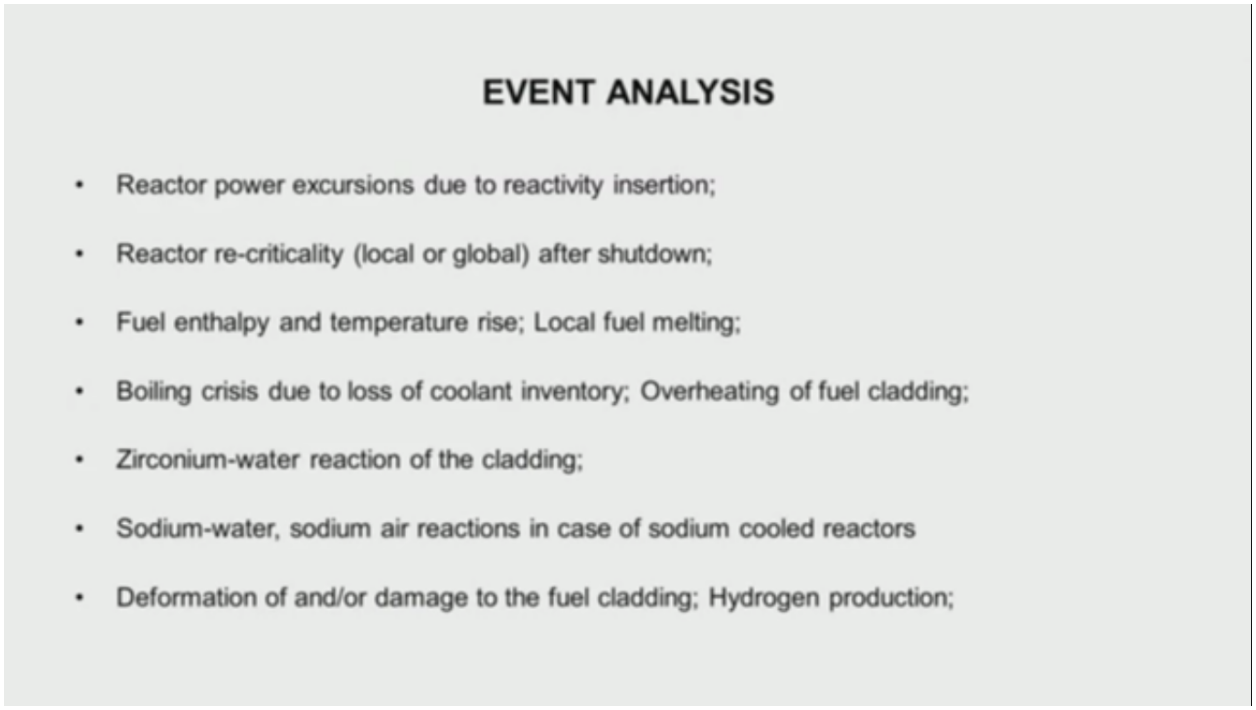

So as I mentioned how the fuel temperature will rise, is there going to be a local melting, there is going to be a bulk melting, if it is a water-cooled reactor, let us take a pressurized water reactor. You are not intended to boil the coolant in the core, but if the coolant flow is less or the coolant inventory is less, it can boil, and if it boils, your clad gets overheated. If the clad gets too much heat, it can fail and fission products can come out. Okay.

Then the other aspect in the case of light water reactors, you have Zirconium clad. Zirconium and water reacts more than 350 to 400 degree centigrade, producing Zirconium hydroxide and you know hydrogen, Zirconium hydride and hydrogen and this hydrogen will come out. Hydrogen also you have to be very careful.

If you look at a sodium heated reactor or sodium cooled reactor like a fast reactor, you see sodium is there along with water in the steam generator. Not side by side. There is a tube, but should a tube fail, you have a sodium water reaction. So this needs to be analyzed and these are very interesting analysis.

Then this hydrogen protection in the -- or helium production in the clad whether that can cause any bubbling of the thing or some sort of swelling of the fuel clad etc.

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- Major fuel melting and core degradation;
- Primary or secondary system pressurization;
- Pressure waves formed inside the reactor system; Pressurized thermal shock;
- Reactor vessel melt-through; Mechanical impact of the escaping coolant jet and the corresponding reaction forces on plant components and systems;
- Environmental impact of the escaping coolant on system and component qualification requirements (humidity, temperature and radiation);
- Direct coolant radioactivity releases due to containment bypass;
- Containment pressurization; Radioactivity releases from the containment;
- Containment base-mat melt-through.

Then coming to the pressure side, it should -- you have to see whether the pressurization is going to take place under any condition. Let us take a core melting and reaction with the water, whether anything can take place. If the system is going to get pressurized, you have to see whether the -- what is the pressure to which it would raise? And you have to design the vessel, the boundary of the -- has to be designed to withstand that pressure.

So basically, we are looking at how the process parameters will change so and so that in the design we can take care to avoid release of radioactivity.

Then pressure waves, which could be formed in the reactor system, whether is it there a possibility? In case of a sodium water reaction, you have a pressure wave in the secondary circuit. This pressure wave should not reach the reactor so we have the surge tank and the pump tank. So you take measures and design in such a way that these don't.

Now here if you take the surge tank alone, we have conducted experiments for different surge tank configurations so that which configuration gives the best pressure attenuation, that is the pressure surges are not transmitted to the other side, that we have done and validated our computer codes.

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- Containment base-mat melt-through.

Then the environmental effects. Of course, before the environmental effects, I forgot to tell about the in case let us say the boundary fails and the reactor vessel is breached, then there will be a melt through. So this once there is a break, the coolant will flow like a jet and you have to see what are going to be the forces on the outside containment, so these need to be analyzed as a part of the event analysis. Then the environmental impact, basically, the escaping coolant system, its temperature and pressure, what it will have, and any radiation what it will have.

Then in -- once it has come to the containment, we have to talk about the pressurization of the containment, the radiation activity release from the containment etc. So basically, this only gives you some idea on the reactor side. Like that we need to do an event analysis of different types of all systems so that all the plant healthiness is maintained.

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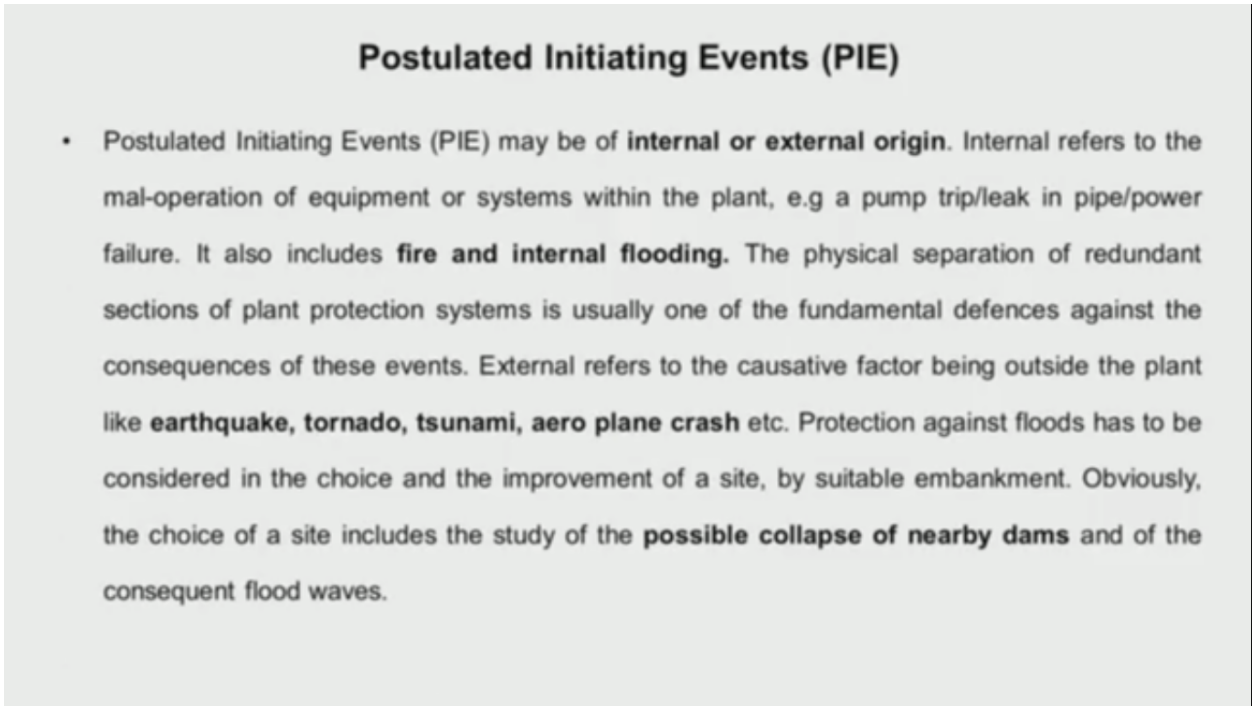

Now we talked about postulating some initiating events. These initiating events as I mentioned could be from within the plant like a pump trip, or a pump seizure, or a valve, sudden opening of a safety valve, so many things, but there could be something of an external origin also.

So now similarly fire. Fire, there could be an internal fire. There could be an internal flooding. Flooding need not be from outside. There could be a pipe break, one of the water pipes and whole thing could get flooded.

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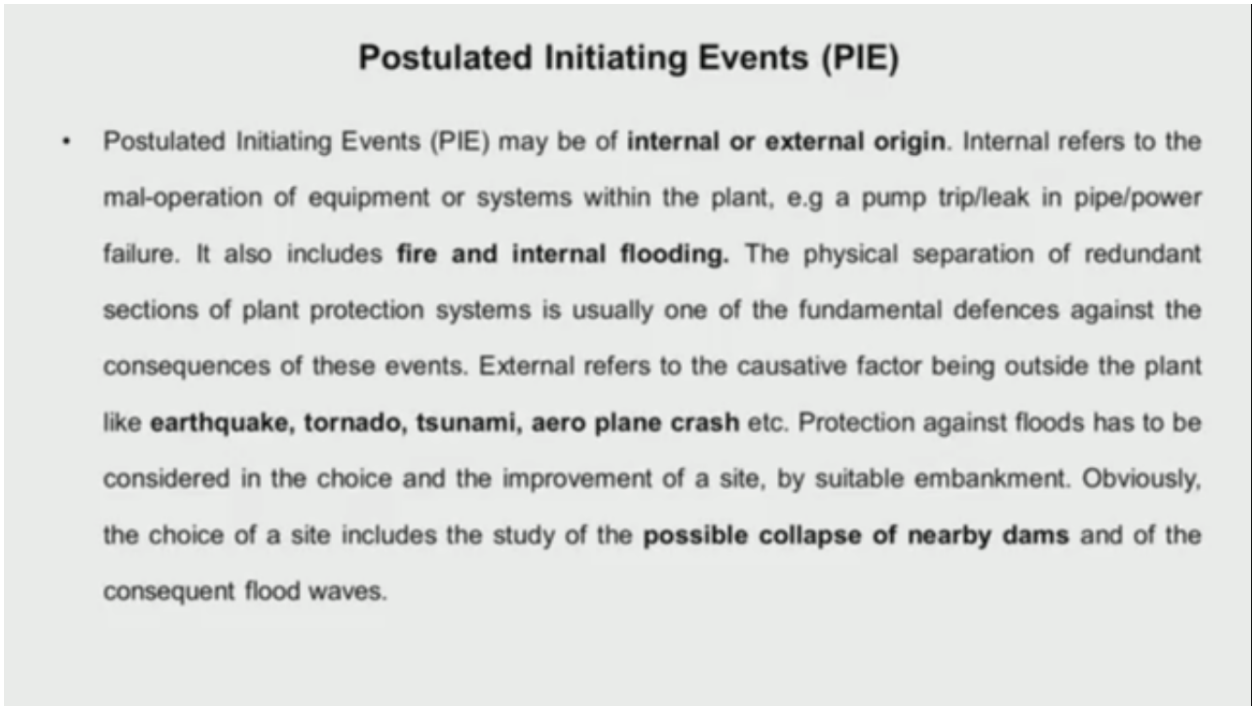

So how do we take care that this such -- such sort of events do not affect? We try to keep the components. We have provided redundant components in different compartments so that one of the flooding of one doesn't affect the other. Then coming to the external one is your earthquake. You remember the earthquake and tsunami we had in 2011 in Japan and of course, in India, we faced the earthquake and tsunami in 2004. Our southern coast was hit by a tsunami. Just few minutes before that there was an earthquake. So protection for this also need to be considered.

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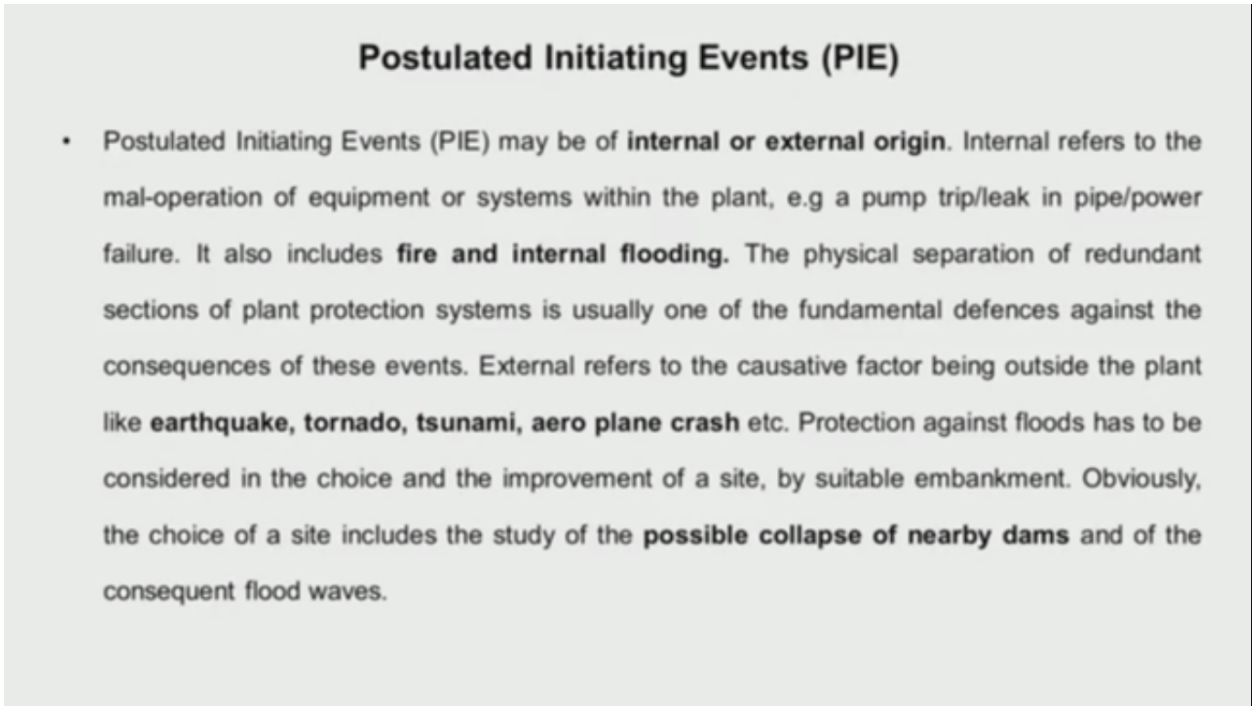

Then let us say you are taking -- your plant is located somewhere near a hydroelectric project, so there would be a damn. You have to consider possible failure of the dam and flooding of the plant.

Again, if you have a river, many times, you know, rivers have floods. These floods may cause havoc to your plant if you don't have bunds and also many times it is not the bunds. Many times water may enter through those discharge things from -- for which you have provided. They itself could become an input. So you have to safeguard your plant against all such events.

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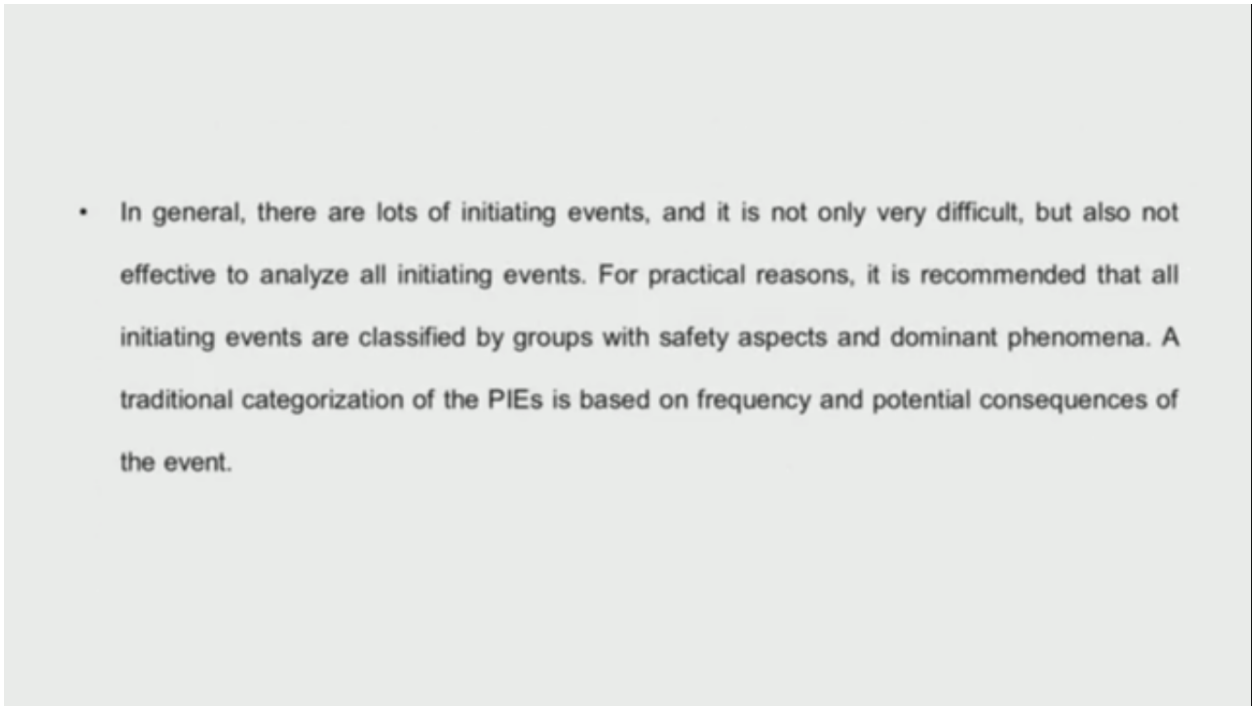

So if you look up, there are a lot of initiating events, but it is very difficult to look on -- go on looking at different types of events. So we actually try to group the events of similar type, and out of that take the one which can have the dominant effects, and try to analyze them so that for every group the maximum consequences are possible, that event alone you analyze, and then we follow it for the next rest of the events.

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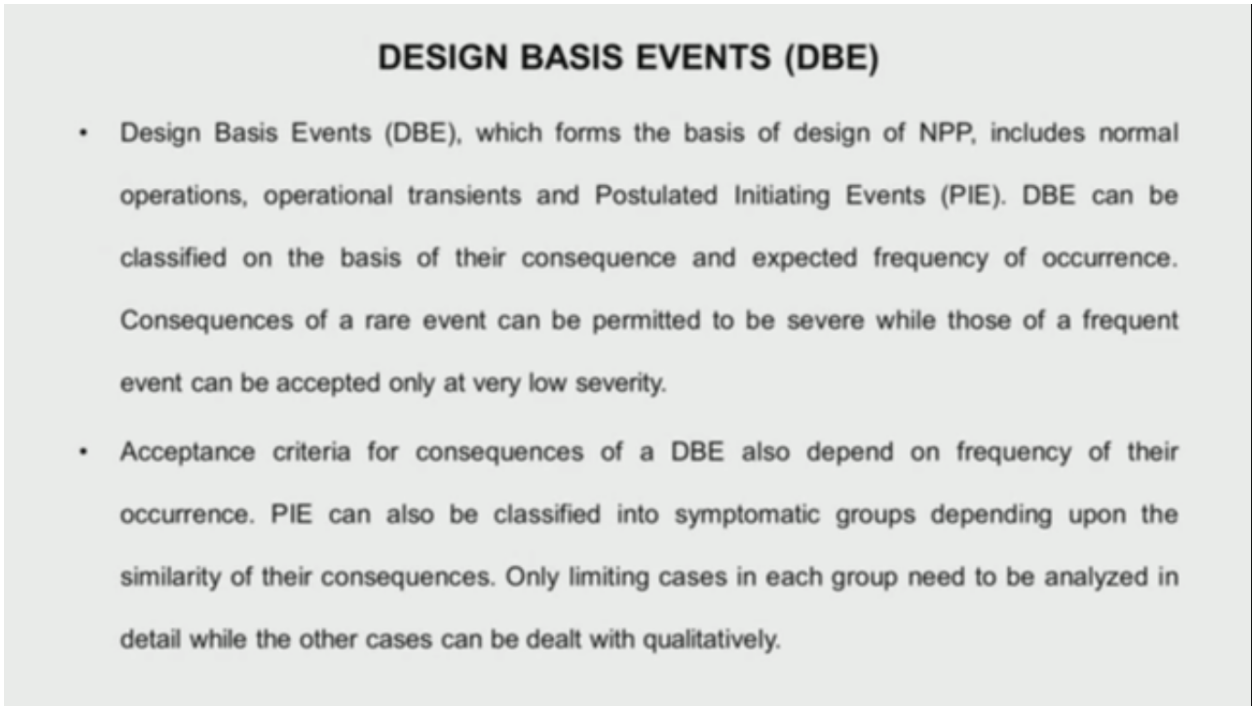

So then we come what is a design basis events? These are the events based on which -- which have been analyzed and based on which your plant is found to be safe. So these design basis events are the events which include normal operations, startup, shutdown, fuel handling, then operational transients. Let us say there is a frequency change in the grid. It will affect. There could be a trip of a pump. There could be a dip in the voltage and coming back. All sorts of operation transients and all the postulated initiating events, which you have thought about, all these together form the design basis events.

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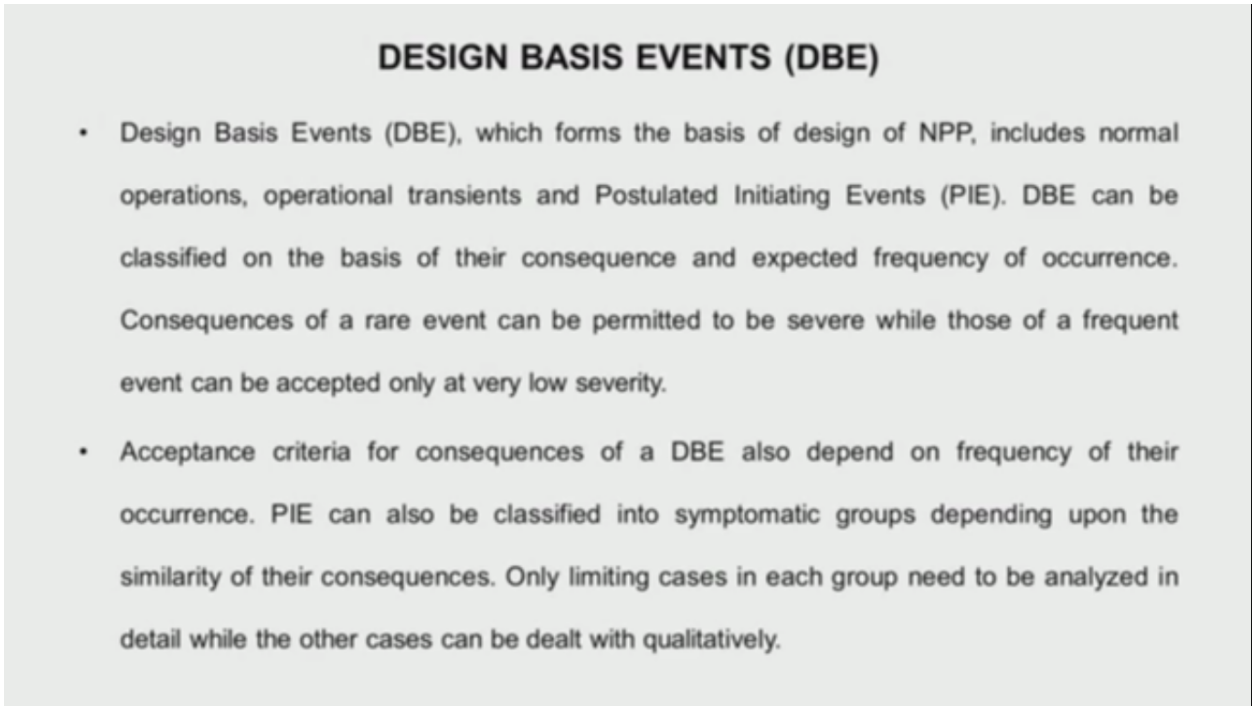

Now as I mentioned, we need to classify the design basis events based on certain criteria. So what we do? We have two things. One is the consequence and not only that and the expected frequency of occurrence. So this expected frequency of occurrence is a very important issue. Suppose there is an event which happens once every year. You really have to see that the consequences of that event are not severe whereas a equal -- a situation which can going to happen one in some what you call 1,000 years, there you can allow for a higher consequence.

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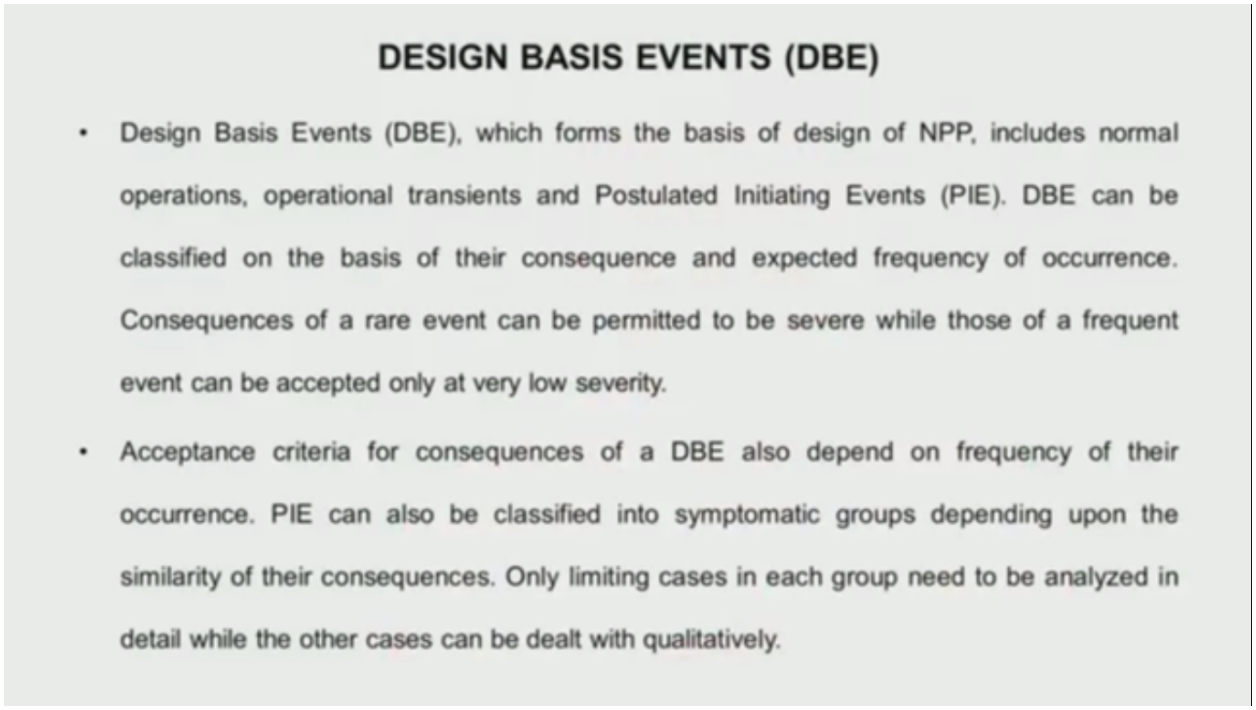

So our acceptance criteria, again, is again dependent upon the frequency of the occurrence of that event. So we classify all these events into different groups and we analyze only the limiting cases means which in event in a group causes the maximum damage to the plant.

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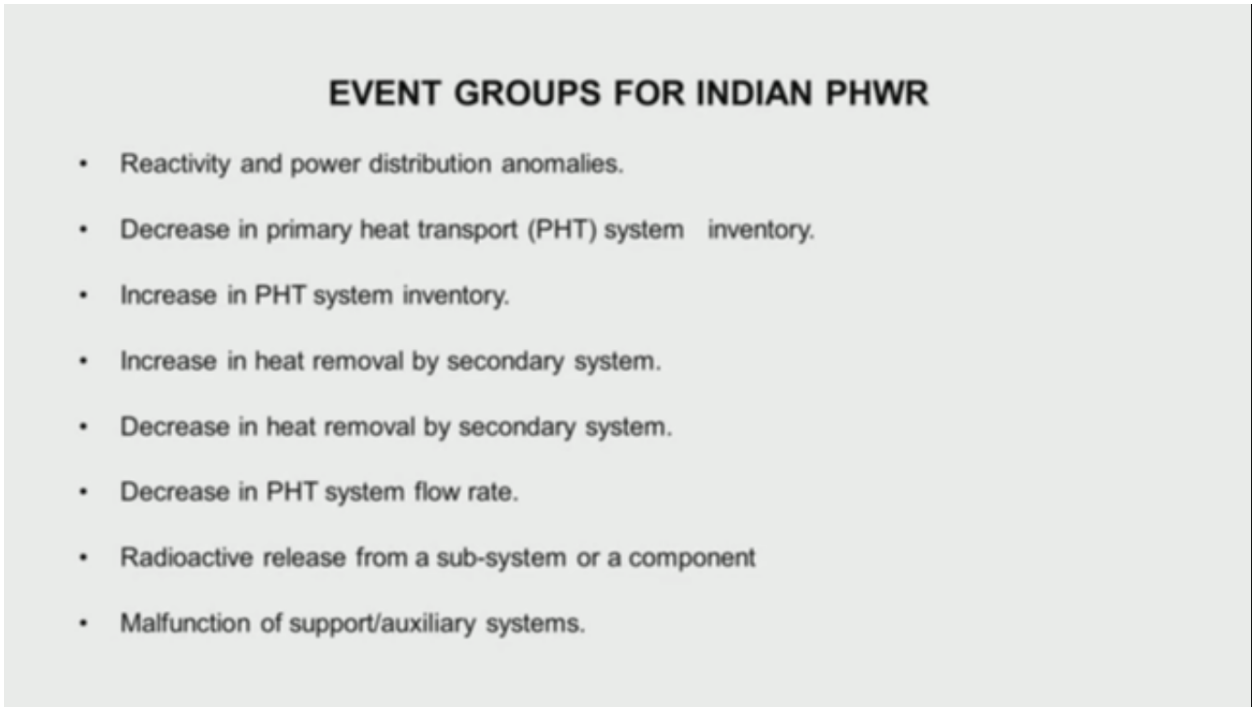

So we group -- we can group them for the Indian pressurized water reactors, we have events because of reactivity and power distribution anomalies, decrease in primary heat transport inventory, increase means let us say the inventory has gone up because of increased flow, sudden speeding of a pump resulting in increased heat removal or a decrease because of a trip, decrease in the flow rate or radioactivity release from a component, malfunction of an auxiliary system, all sorts of event groups are there.

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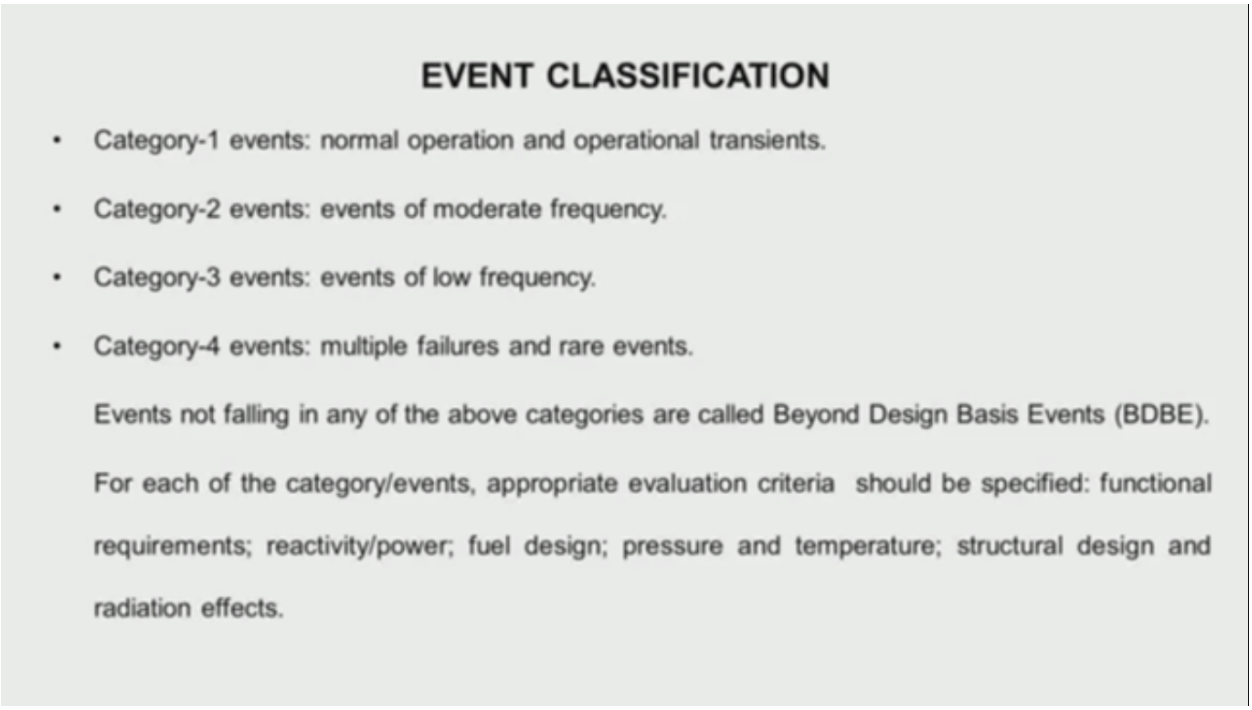

So we classify all these events. First, category-1 we call includes normal operation and operational transients. Normal operation again means startup, shutdown, fuel handling, then the operational transients. Then category-2 consists of events, which are of moderate frequency, may be occurring with a good amount maybe one per year. We will see in the next slide. Then category-3 still lower frequency and category-4 where you have multiple failures. All the times we are only talk about single failure. Here it could be a multiple failure. Only then only it can cause event and multiple failure happening itself is a -- of a very low chance or low frequency. So that is there.

Events which are not coming in all these categories, we classify them as beyond design basis accidents or beyond design basis events and for each and every category of events, we have evaluation criteria. That means we have the acceptance criteria.

For example, let us take the clad for category-2 events in a fast reactor, I say the clad should not cross steady state. It should be only 700 and for a category-2 it should not cross 800 degree centigrade. For a category-3 event, I would allow a higher temperature. So like that for the fuel

temperatures under no condition, it should cross the melting point. So all such requirements, specifications we -- our acceptance criteria we have to see and then evaluate the plan design.

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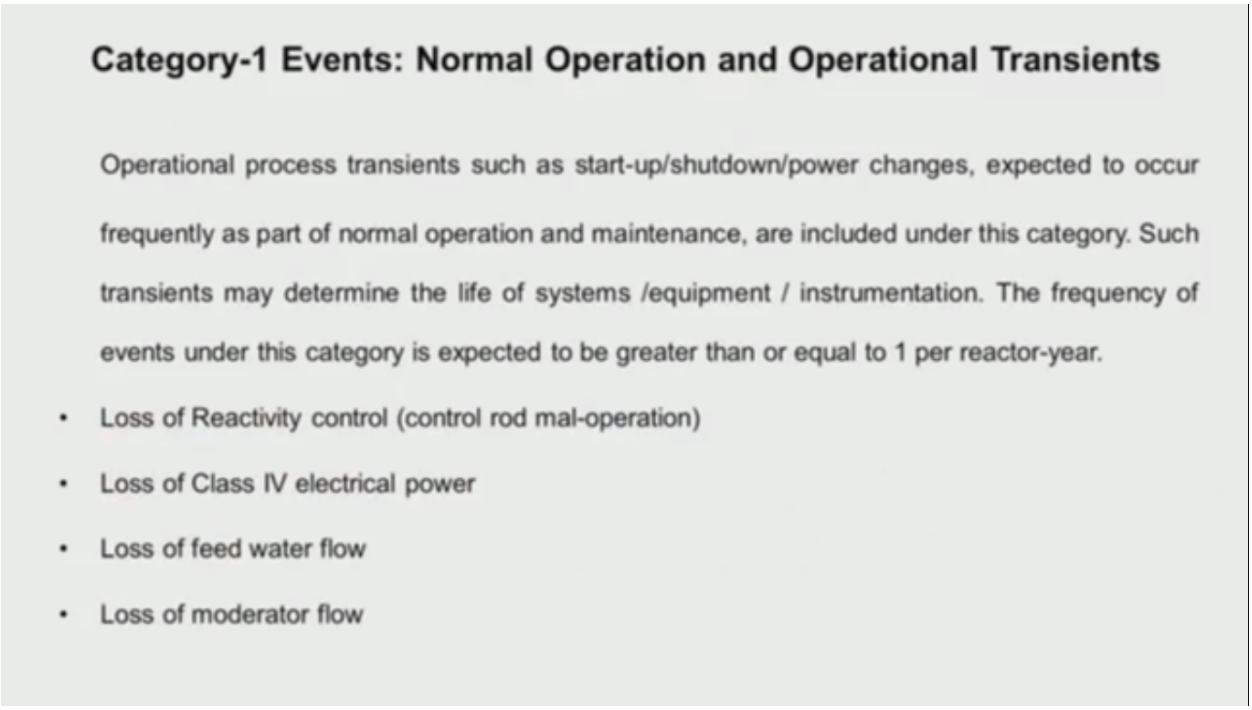

We will now go further into the events, class-1 events for our pressurized heavy water reactors. We saw that it has got a startup and shutdown. Then the power changes I mentioned which can happen because of any movement of the control rods to adjust the power etc. Then loss of reactivity control. Suppose when you are trying to operate the control rod, and you have to move it by a certain distance, it moved more than that. What will happen? Then loss of feed water flow and loss of moderator flow. In our PHWR, the moderator system is different from our flow coolant system. So there are two pumps, so each pump independently could fail and flow could reduce.

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- The behaviour of the plant and its systems/equipment/ instrumentation should be analysed to prove that design limits are not exceeded. Adequate margins should be provided to meet requirements of applicable design codes. The number of DBE during the lifetime of the reactor should be conservatively estimated for use in design of the NPP. The frequency of events may be estimated based on the operating experiences of NPP.

So we need to analyze the -- all these events and the number of such events you normally get based on operational experience of previous plants.

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Category-2 Events: Events of Moderate Frequency

Events of moderate frequency (~ 1 to 10^{-2}) per reactor-year are included in this category.

- Feeder Pipe Break
- Pressure tube failure
- Service water system failure
- Uncontrolled withdrawal of one bank of shut-off rods in primary shutdown system or draining of one bank of liquid poison tubes in secondary shutdown system.
- Feed water system malfunctions that result in increase/decrease in Feed water temperature.

Category-2, we talked about events of moderate frequency something like 1 to 10 raised to minus 2 per reactor-year. Here we consider a feeder pipe break or a pressure tube failure in the reactor or something like a service water system failure. Service water system is one which provides cooling for all exchangers in the auxiliary systems. Then we do consider uncontrolled withdrawal of shut off rods, one shut off rod or one bank of shut off roads because maybe there was a, what you call, malfunctioning or the operator did a mistake. So in each shut down system, we try to take. So here it is something which can happen not necessarily, but it can happen. So we consider that in a event of moderate frequency. Then any malfunctions which result in feed water flow decrease or increase.

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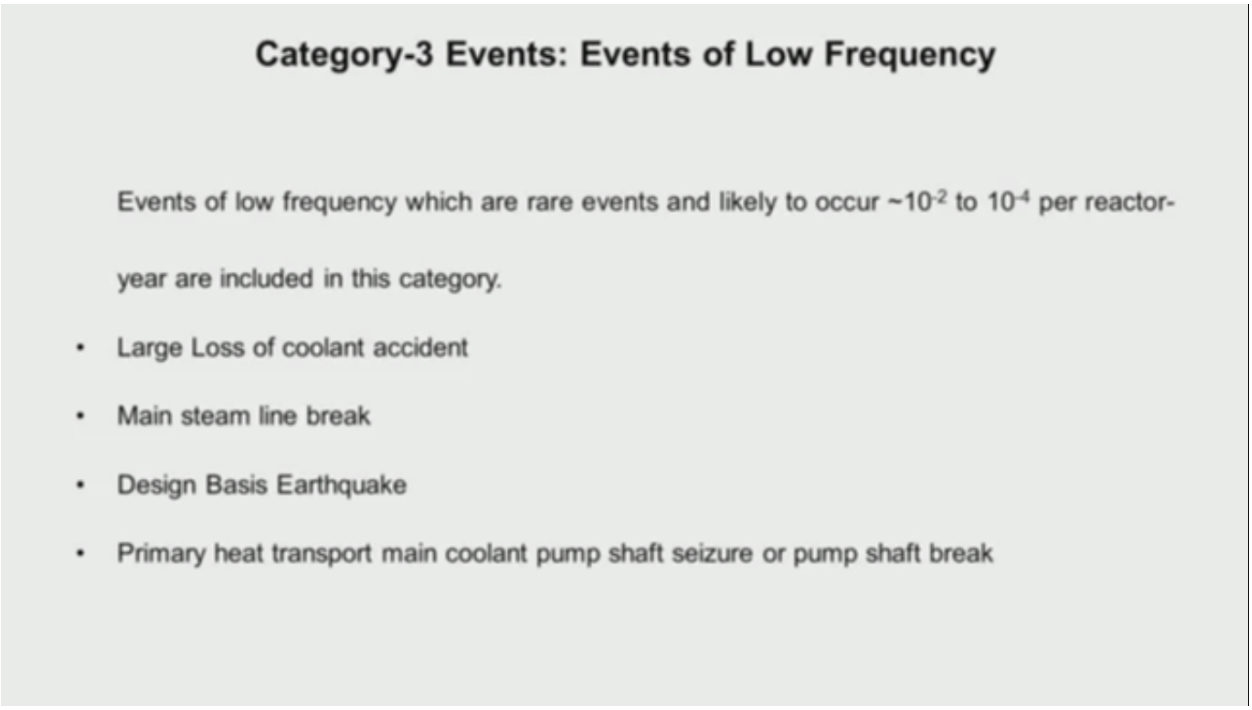

Then the Category-3 events. Here we talk about a frequency of 10 raised to minus 2 to minus 4 per reactor-year. You could have a loss of coolant accident. You could have a main steam line break or a design basis earthquake. Earthquakes also don't happen. We choose a site where the earthquakes are minimal and the frequency is not that. So it is a very low frequency event or a shaft seizure or a break, all such things we consider in the category-3 events.

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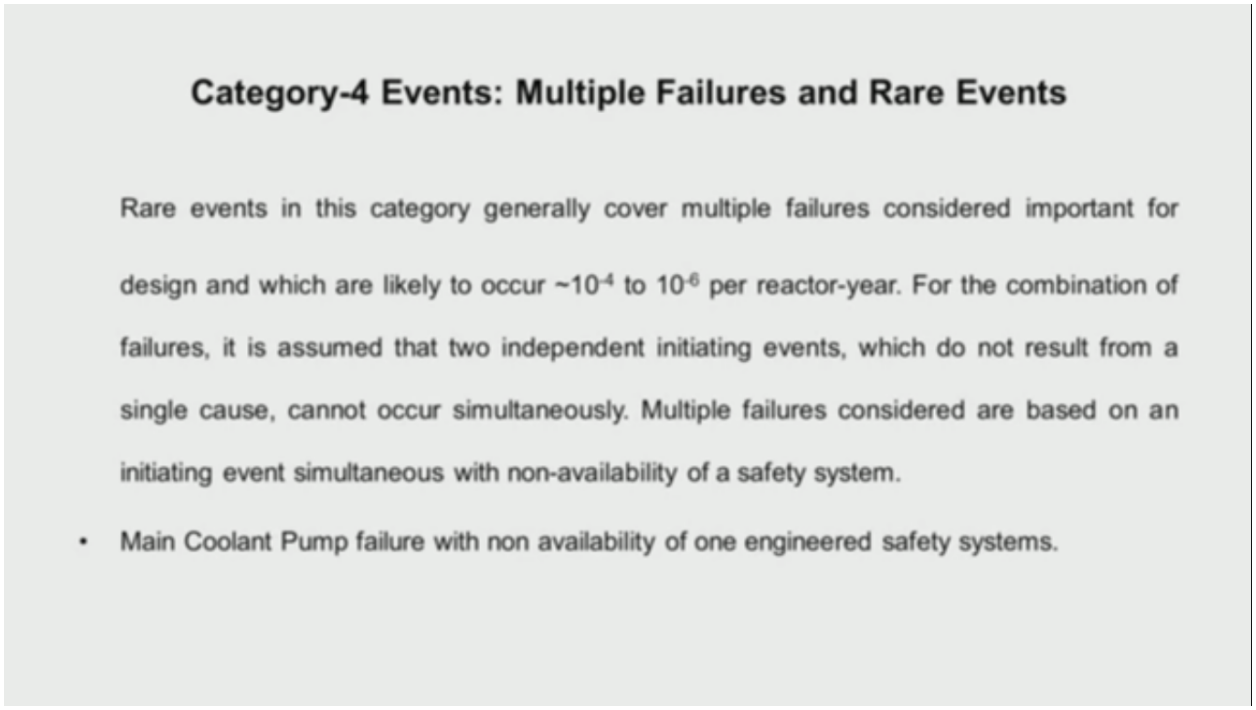

As I mentioned for the category-4, we talk about multiple failures, very rare events, 10 raised to minus 4 to minus 6 per reactor-year or a combination of failures. One example could be main coolant pump failure and along with unavailability of the other safety systems. So it could be a lot of postulates, a very -- they are very rare events.

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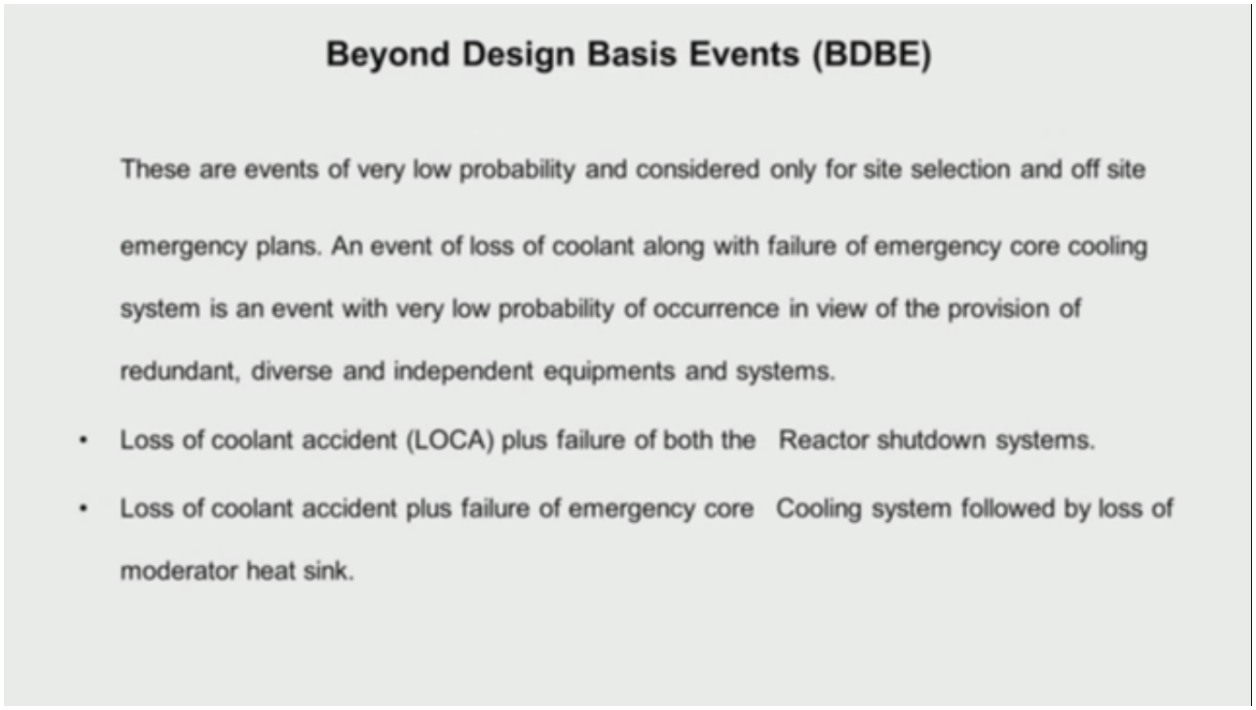

And as I said events which are not covered in the design basis, they are the beyond design basis events. Here their probability is very, very low. For example, loss of coolant accident and failure of both the reactor shutdown systems. We have two shut down systems in a heavy water reactor. So both fail or loss of coolant and the failure of the emergency core cooling. All such events are called as beyond design basis events.

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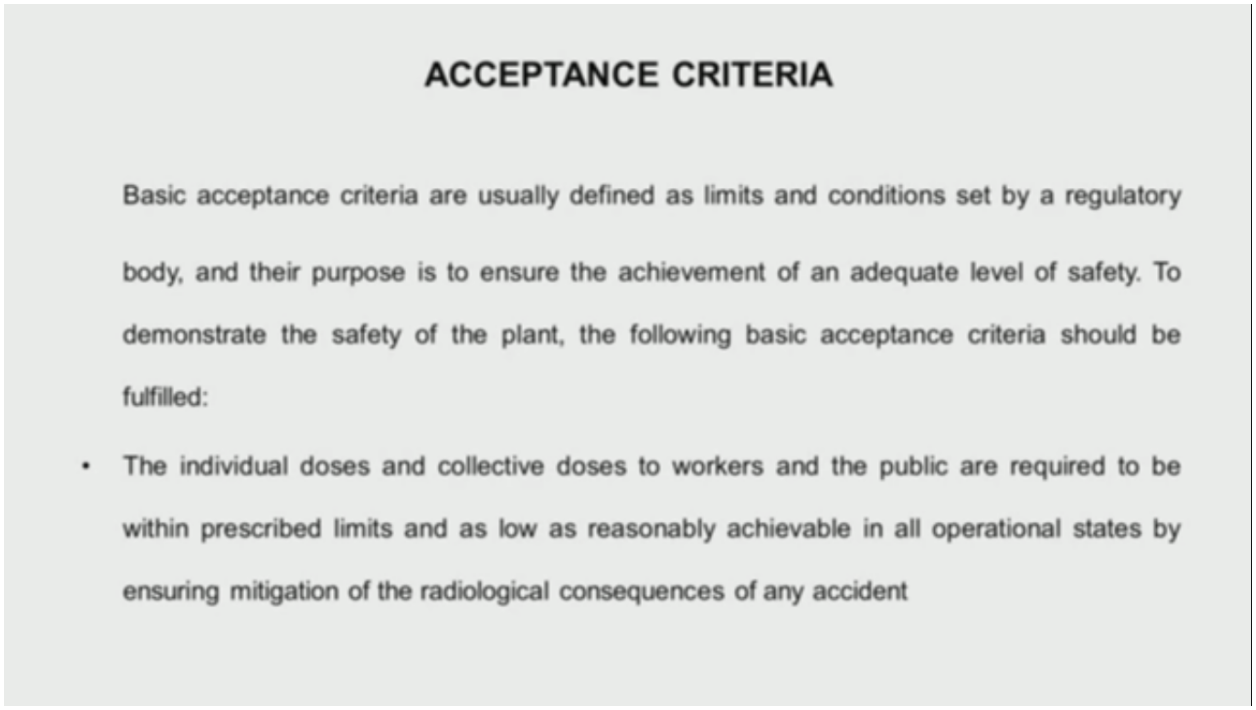

Now for the beyond design basis events, we only look at the case of the release of activity, how to mitigate the consequences. How to -- now everything has happened. Now we have to mitigate. I have to see that the -- so that is where your on-site emergency and offsite emergency things which I mentioned come for the analysis.

Acceptance criteria, we need to define the acceptance criteria for each and every class of events. One is the individual dose, the collective dose that should be within the prescribed limits, and as I mentioned earlier, you may not -- you need not go to the limit. It should be as low as reasonably achievable so that the consequences, if any, are minimal.

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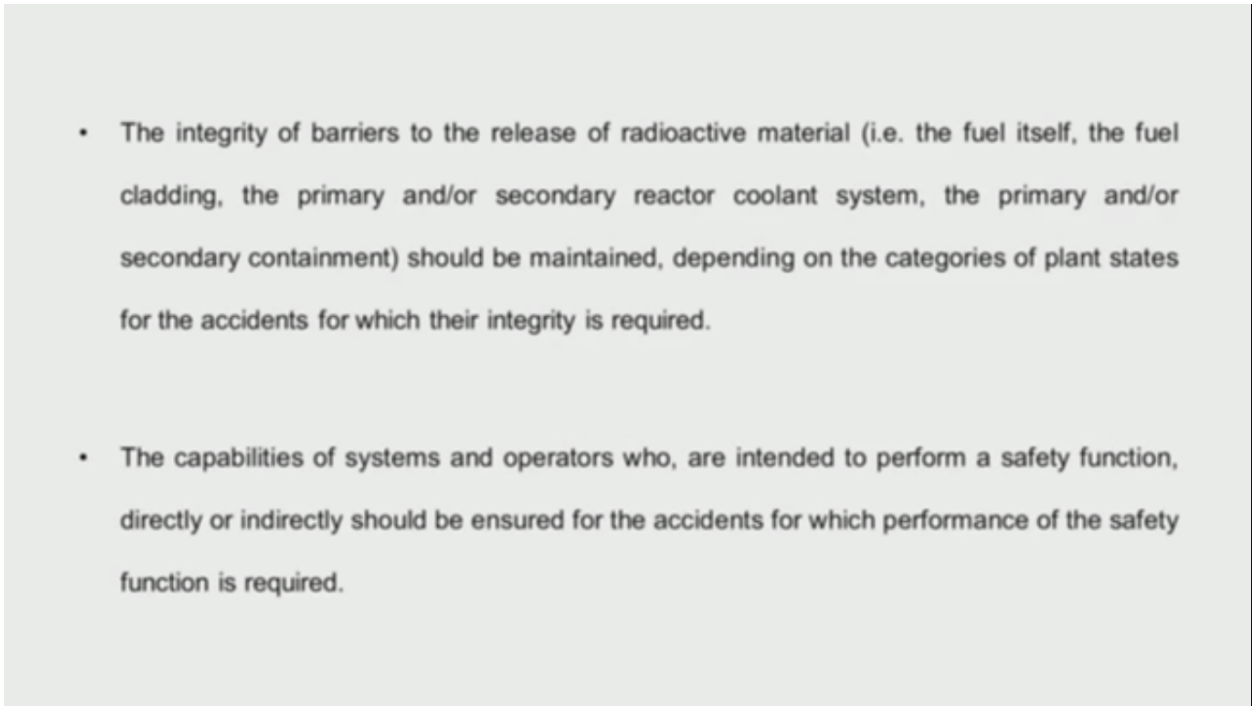

So the integrity of the barriers which release the fuel outside like your fuel itself, the cladding, the coolant system boundaries, these need to be maintained and under different conditions of the plant events, it should be seen that they really are intact and the -- not only the systems, the operators also need to be trained very well so that they can perform their safety functions.

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- Acceptance criteria should be set in terms of the variable or variables that directly govern the physical processes that challenge the integrity of a barrier. Nevertheless, it is a common engineering practice to make use of surrogate variables. Examples of surrogate variables are: The peak cladding temperature is calculated based on the channel inlet and outlet temperatures and considering the uncertainties in all properties of fuel, clad and coolant (referred to as hot spot factors). The coolant in the PWR is not expected to reach boiling. Compliance with the single failure criterion should be evaluated for each safety system in the plant, where practicable. A single failure is one which results in the loss of capability of a component to perform its intended safety function, and any consequential failure(s) which result from it.

Now acceptance criteria, we may not be able to set up an acceptance criteria directly of the measure because all variables are not measured. So we use a surrogate variable. For example, you can't measure the temperature of the fuel, very difficult. You can't put an instrumentation to measure the temperature of the fuel. So we really have to come to the fuel from the coolant temperature.

Similarly, clad temperature you cannot measure directly. So you have to estimate the clad temperature based on your coolant temperature. Coolant temperature is one you can measure outside the fuel and then from that based on your models, and here we talk about hotspot factors means we will calculate considering the normal conductivity properties or normal other thermal properties to get the fuel temperature, but the properties themselves would be having variations. The fuel composition could be having variations.

So we know that from the data available we know how this can vary and we try to predict the maximum temperature, which can occur, and that we refer to as the hotspot factor. We multiply by the whatever we get by the hotspot factor and look at that temperature, and that temperature should not cross the limits. Again, all these events analysis we consider besides the postulated initiating event, we -- a single failure in the whole chain we consider so that under that condition our plant needs to be safe.

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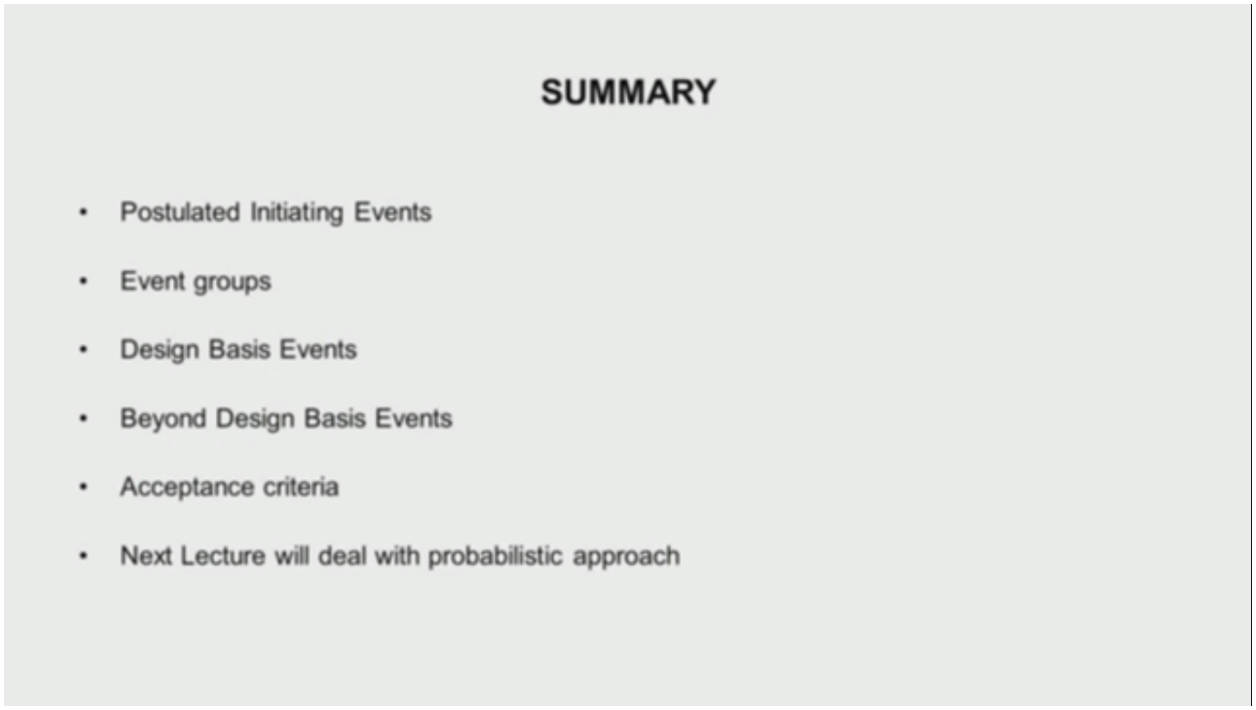

In summary, in this lecture, I have covered what are the postulated initiating events. We talked about grouping the events so that we need to analyze only the topmost one event which has got a maximum of that group so that all the things need not be analyzed and other things could be qualitatively, you know, discussed. Then the design basis events, then the beyond design basis events. Basically, design basis events are taken care in the design -- your design is protected against such events whereas where you are not able to protect, something has happened multiple failures, you have to look at mitigating the consequences and protecting the public. So then the acceptance criteria we talked.

Now in the next lecture, we will look at what is the probabilistic approach. Thank you for your patient listening.

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