Indian Institute of Technology Madras
Present

NPTEL
NATIONAL PROGRAMME ON TECHNOLOGY ENHANCED LEARNING

NUCLEAR REACTOR AND SAFETY
AN INTRODUCTORY COURSE
Module 15 Lecture 01
Passive Safety

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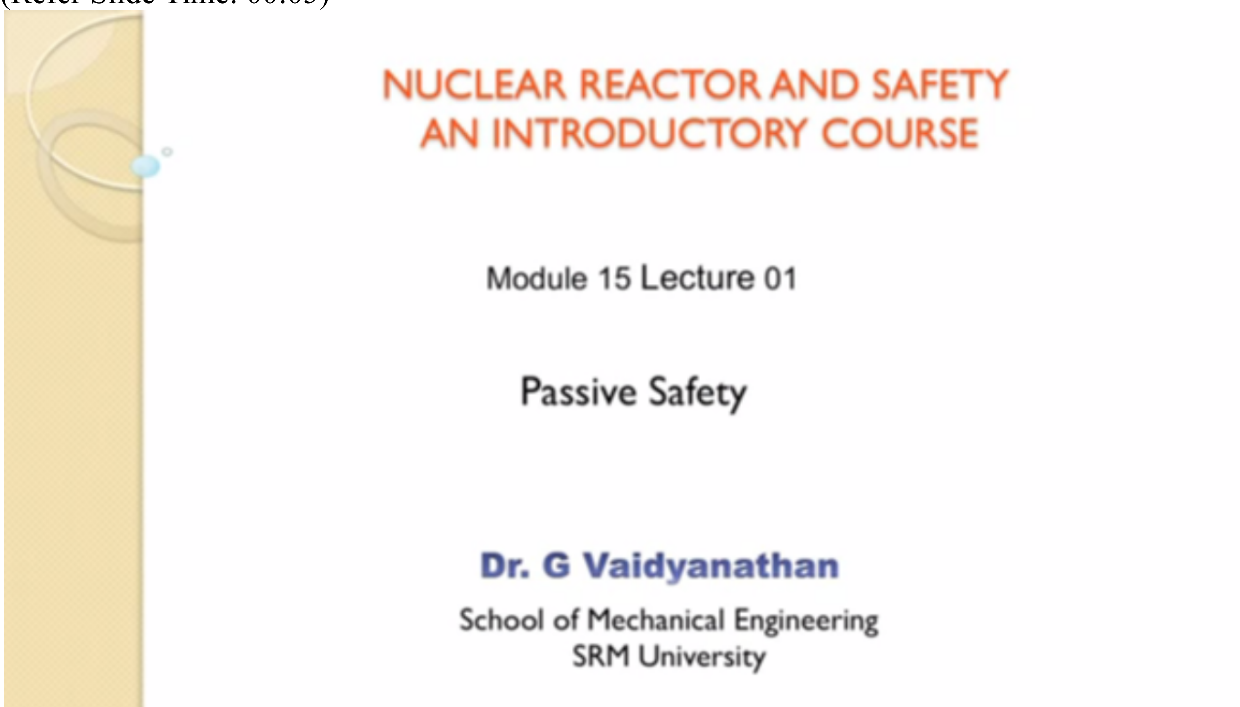

Good morning. In the last module, we covered the safety practices which are being followed in the nuclear power plants. Of course, with reference to most of the Indian nuclear power plants, I had given you lot of examples. Safety for a nuclear reactor per se means two things. First, you must be able to control the power of the reactor. Two, at all times during normal operation as well as shutdown, you must be able to remove the heat produced in the reactor.

One might ask why? Why heat should be removed after shutdown? Remember though the fission chain reaction stops once you have shut down the reactor by utilizing the control rods or any other shutdown system, still the fission products, which are produced during the fission chain reaction, they decay releasing different particles, gammas, alphas etc., and hence these get converted into heat. This heat, if not removed from the fuel, can result in fuel temperatures and the clad temperatures going high. So it is very essential to remove the decay heat. So that is why we say one, control the power; two, this decay heat removal.

Now we have seen in the previous modules how the decay heat and the -- has been removed -- is being removed by different means in different reactors and how the reactor is being shut down. Reactor is generally shut down by the use of control rods and heat removal is basically through providing a coolant, which can remove the heat directly from the reactor or indirectly through heat exchangers. The means of decay heat removal is a function of which system is available.

Now there is a feeling that if we minimize the number of active safety systems, wouldn't it be better? So that is what is called as Passive Safety.

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Now in this module, we will cover the passive safety with reference to the different types of nuclear power plants. So let us get into what is passive safety.

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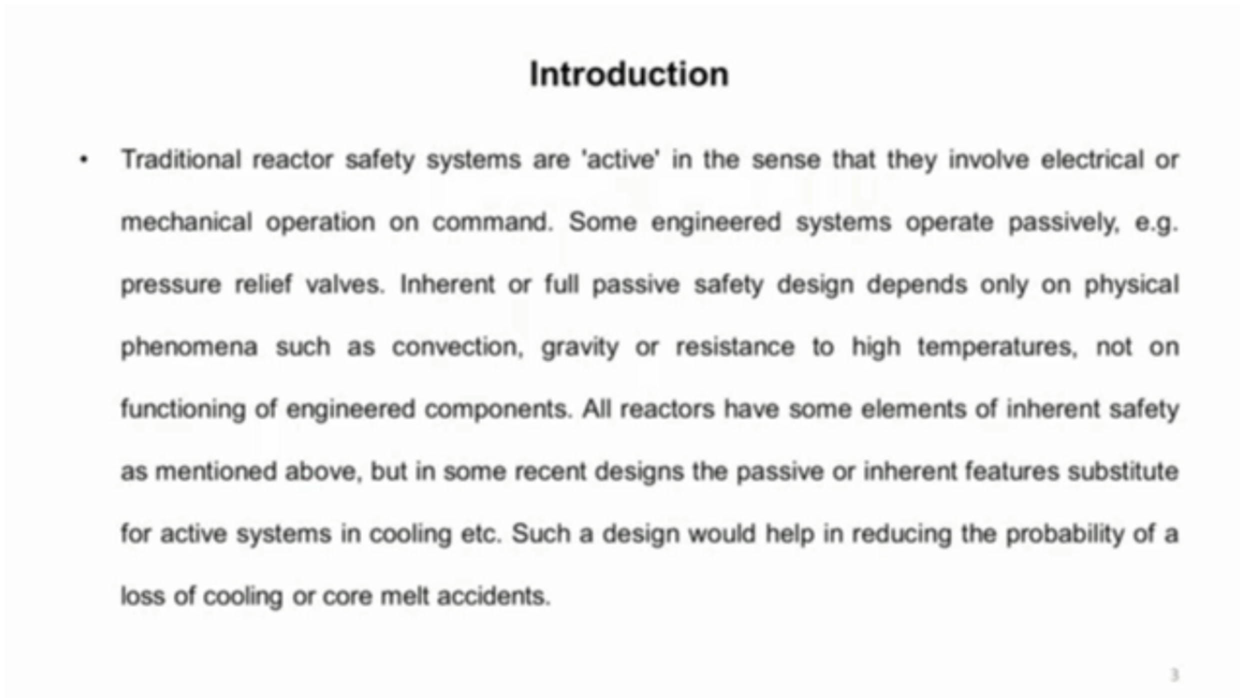

Now when we say passive, the other one is active, as you have in English the active voice and the passive voice. So in active means it involves either electrical or mechanical compounds, which get actuated and give command to a particular system. Now if you take a safety relief valve, which is provided on many boilers, the moment the pressure rises beyond the setting, it opens the pressure is sufficient to compress the spring and open. So this is a passive way of releasing the pressure.

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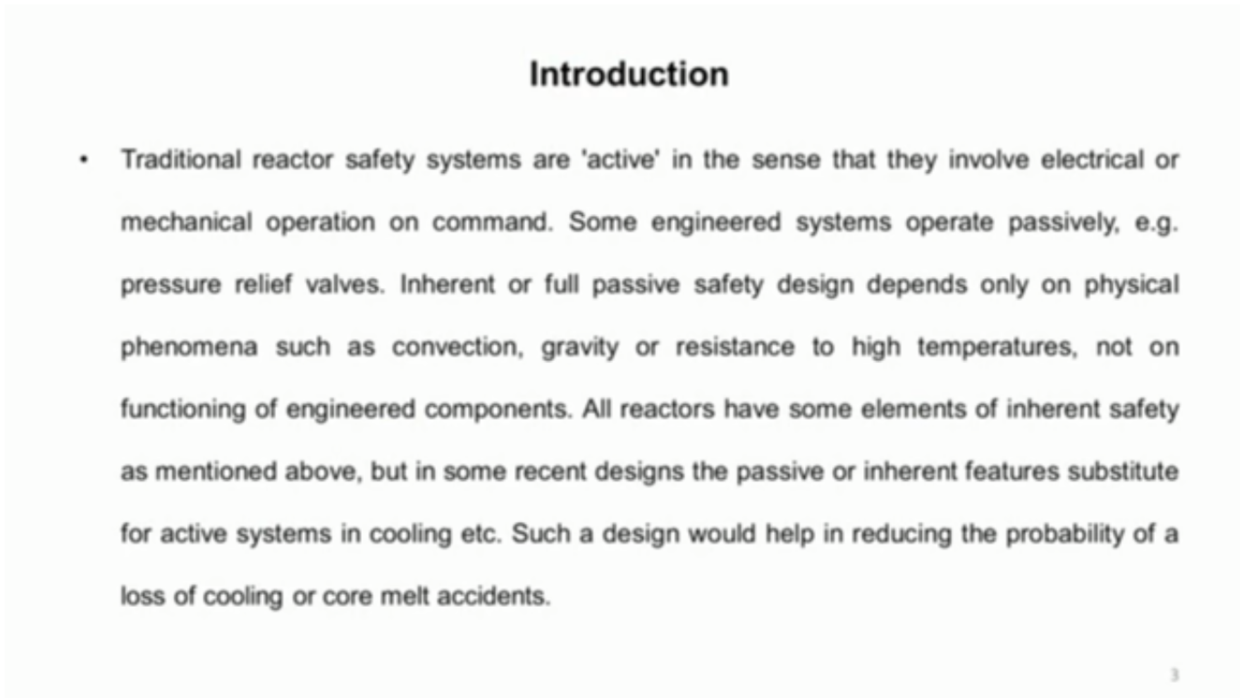

Now another approach, if suppose you require a coolant for a reactor cooling and you don't want to rely on a pump, so you put your tank at a high level, and then in that case in case your primary pump fails, the pressure comes down and a non-return valve can open and the water will come down from the tank just by means of gravity. So this is again a sort of a passive or also called as inherent safety feature of that design.

Now it is difficult to make everything passive. So in all the reactors, there is an element of active safety features and element of passive safety features that are being followed. So the idea is by introduction of passive safety features, we are not depending upon active component that can fail on demand and thereby, we are reducing the probability of a core cooling not happening or a reactor shutdown not happening. So here, basically, we are reducing the probability of failure of a shutdown or a decay heat removal, thereby, contributing to the safety.

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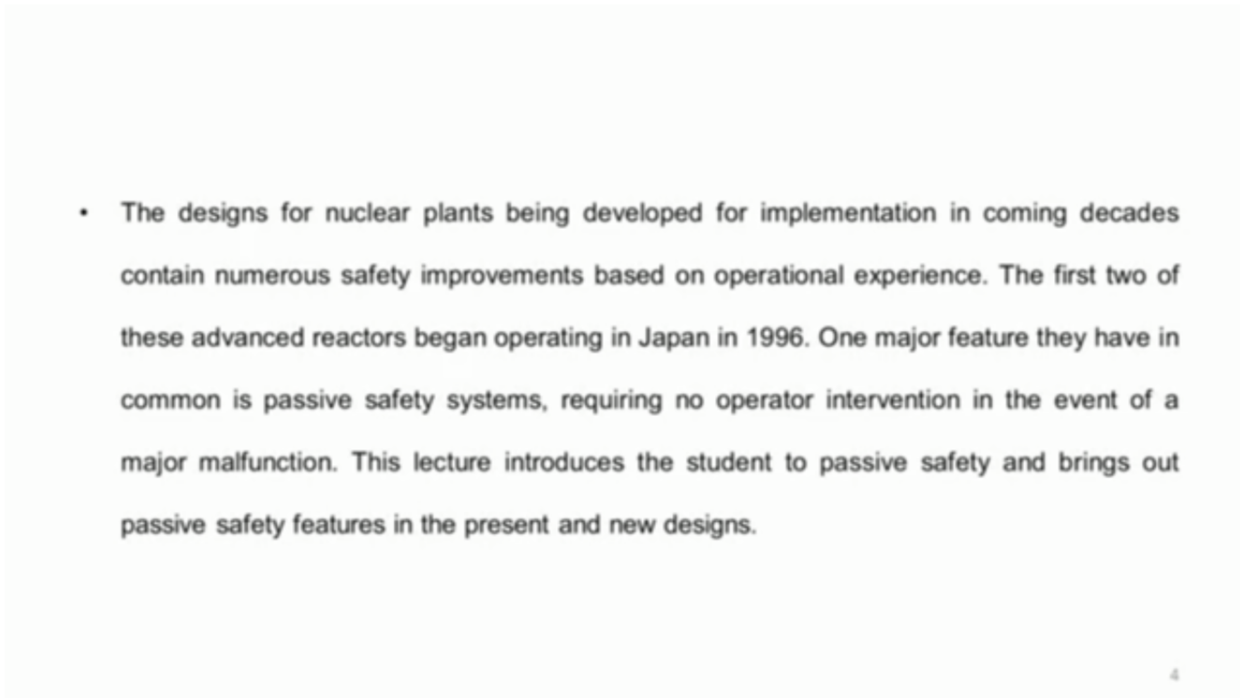

Now if you see the nuclear reactors, they have been operating for quite few decades, and they do have many of the passive features, but then the, in fact, in Japan, they have a reactor called as -- it's a boiling water reactor, enhanced safety boiling water reactor and this reactor is in operation to demonstrate the passive safety features, but then with the happening of the accidents at Chernobyl, Three Mile Island and Fukushima, there is a desire to introduce more and more safety features.

Now in this module, we will try to cover the passive safety features in the present designs as well as new designs, which are being talked about in the nuclear reactor area, but before going further there is need to define the terms.

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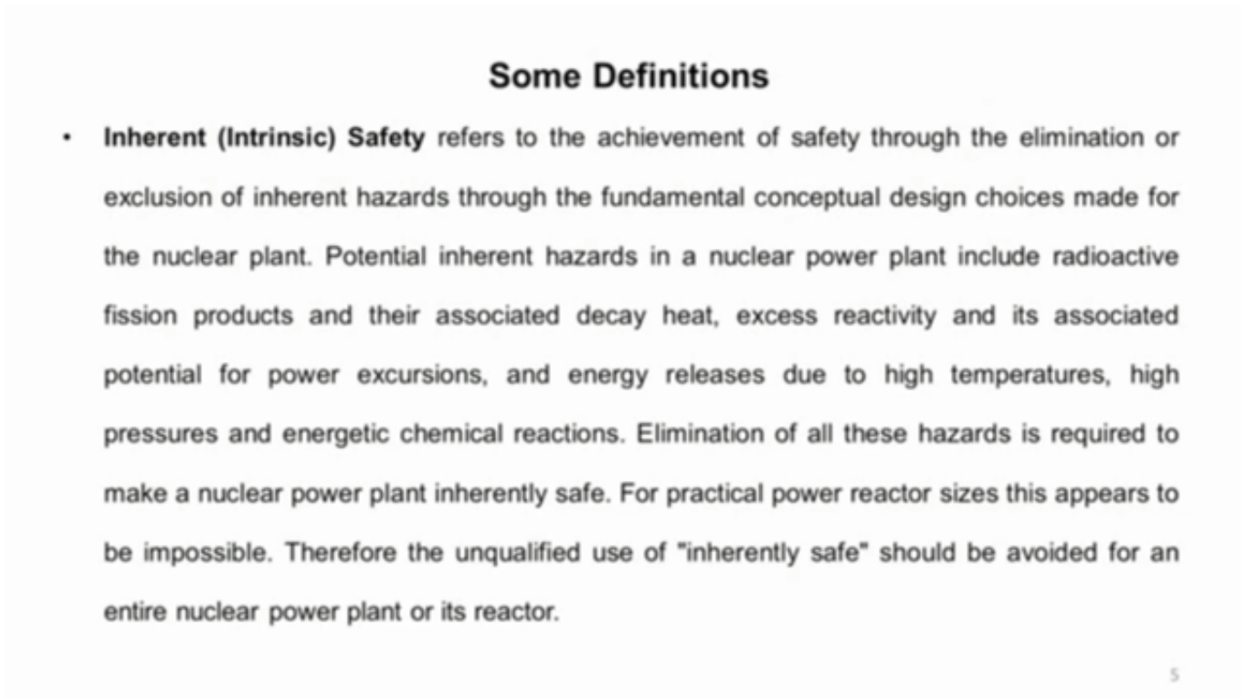

For example, this term Inherent Safety is one of the words which is used quite frequently when we talk about safety. It actually means intrinsic safety and what does intrinsic safety mean? Intrinsic safety necessarily means the achievement of safety through the elimination or exclusion of inherent hazards based on the design choices for the nuclear power plant.

Now what are the hazards in a nuclear power plant? That fuel failure might happen. The radioactive fission products might come out. Then decay heat needs to be removed. Then there could be if something doesn't happen, the reactor is not shut down, so the decay heat doesn't get removed. There could be fuel melting. There could be energy releases. There could be high pressures generated due to the reaction of the hot fuel with the coolant etc., etc.

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Some Definitions

- **Inherent (Intrinsic) Safety** refers to the achievement of safety through the elimination or exclusion of inherent hazards through the fundamental conceptual design choices made for the nuclear plant. Potential inherent hazards in a nuclear power plant include radioactive fission products and their associated decay heat, excess reactivity and its associated potential for power excursions, and energy releases due to high temperatures, high pressures and energetic chemical reactions. Elimination of all these hazards is required to make a nuclear power plant inherently safe. For practical power reactor sizes this appears to be impossible. Therefore the unqualified use of "inherently safe" should be avoided for an entire nuclear power plant or its reactor.

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Now really speaking in a practical way if you look at, it is not possible to make -- take care of every step. So very carefully, whenever we say the word inherently safe, you cannot say a reactor is inherently safe. Some for some events maybe it is an intrinsically safe. So the unqualified use of inherent safety needs to be avoided.

You would be surprised when I am talking about this definition, in fact, in the 1980s, there was a widespread use of these features of inherent safety with the new designs coming up, but then the International Atomic Energy Agency in Vienna they had a specialist meeting on this subject so that everybody should understand in a common way what is meant by the different safety, what is passive safety, what is active safety, etc. So it is very important. So nobody can say that okay, this reactor is inherently safe. For a particular event, it can be safe. For a particular event, it may not be safe. So you have to provide some sort of engineered features to see that that event doesn't cause a catastrophe or in case it cause, it is you are not able to do, how do you take care of that event or the consequences you can mitigate?

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- On the other hand, a reactor design in which one of the inherent hazards is eliminated is inherently safe with respect to the eliminated hazard. Elimination of one or more of these hazards does, however, give a reactor an inherently safe characteristic. Note that the hazard must be eliminated deterministically, not probabilistically - for example a plant is inherently safe against fires if it has no combustible material.
- When an inherent hazard has not been eliminated, engineered safety systems, structures or components are provided in a design to make its use acceptable without undue risk. Such provisions generally aim to prevent, mitigate, or contain potential accidents. Although an objective in their design is to make them highly reliable, they remain in principle subject to failure (however low the probability of such failure), unlike inherent safety characteristics.

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Now let us say a reactor design in which some of the inherent hazards is eliminated. Then surely, we have an inherently safe characteristic for that particular event. So now we have seen earlier that any hazard must be eliminated both deterministically and not probabilistically.

Now, for example, a plant is inherently safe against fires if it has no combustible material. So it is deterministically is safe. Now when this inherent hazard has not been eliminated, suppose you are not able to eliminate such a thing, then as I mentioned we need to have an engineered safeguard system or engineer some structures. Suppose let us say fire is there. So you see the fire should not sprint to the nearby areas. You have structures which are fire resistant so that the fire in one doesn't move to the other. So you need to provide structures or systems so that the risk is not undo. You do have a risk, but it is not undo.

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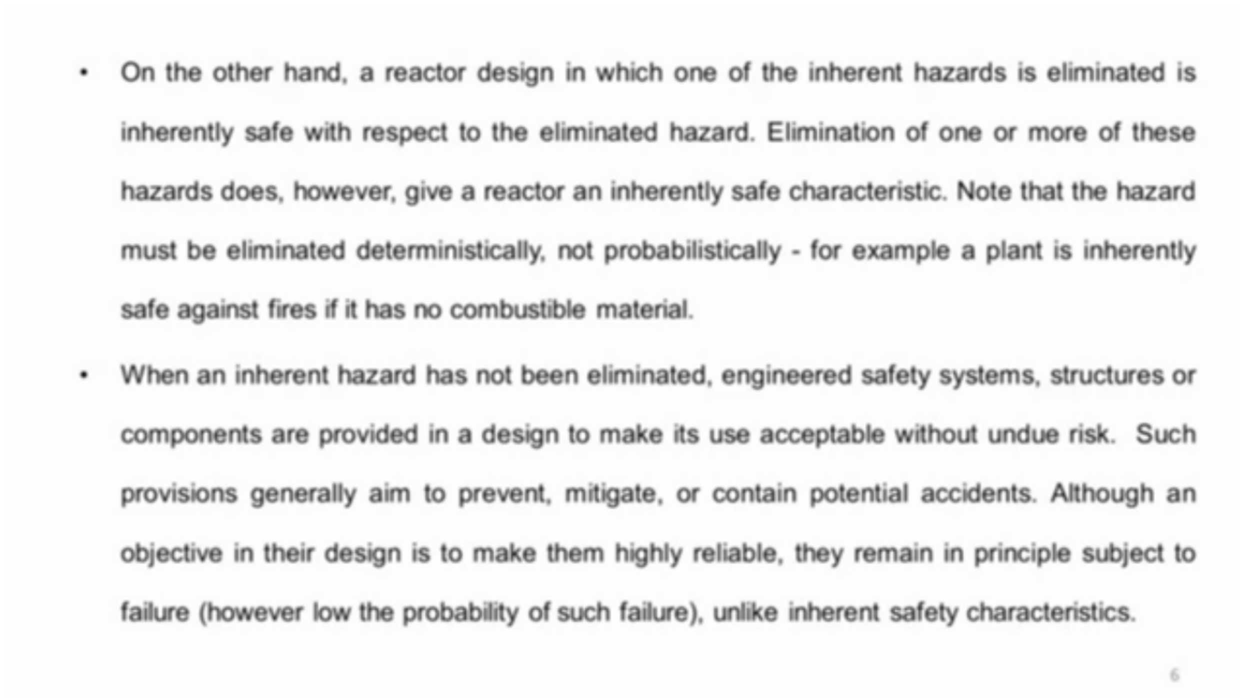

Now as I say -- so that means what are these provisions essentially are? One, to prevent. In case it happens, to mitigate and contain the effect of or the consequences of the accidents.

Now why we talk about all these things? Because even though we make all the efforts in the design, manufacture, construction, commissioning, testing, we do quite a good quality assurance so that we achieve -- we achieve a very minimum failure rate. Still in principle, they are subject to failures. So we need to take care to mitigate the consequences.

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- **Active and passive safety** describe the manner in which engineered safety systems, structures, or components function are distinguished from each other by determining whether there exists any reliance on external mechanical and/or electrical power, signals or forces. The absence of such reliance in passive safety means that the reliance is instead placed on natural laws, properties of materials and internally stored energy. Some potential causes of failure of active systems, such as lack of human action or power failure do not exist when passive safety is provided. In its broadest sense, passive safety emphasizes the use of natural forces (gravity, self-correcting neutronic feedback) and de-emphasizes systems which require large amounts of electricity (pumps), rapid automatic response, complex logic, or high energy.

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Now we said active and passive safety. So now active and passive safety essentially describe the manner in which the engineered safety systems, or structures, or components function. This is essentially distinguishing whether they rely on either mechanical or electrical power, whether they depend on any signals to actuate, or any other forces to actuate.

Now in case there is no need of any reliance on external mechanical or electrical power or signals, then the absence of such thing, it means it is basically based on the natural laws like gravity flow and it is not going to be a function of any active system failure or human action. So then this is referred to as a passively safe system.

So what does it mean? A passive safe system basically works on natural forces like gravity and in case of neutronics, you have a negative feedback system. That is in case the temperature or power goes up, then the feedback effects are such to oppose the increase in power so that the power gets reduced and eventually the temperature also get reduced.

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So it doesn't involve systems which require large electrical systems, let us say for cooling electrical driven pumps, or a complex logic, or high energies. So passive systems do not rely on external source of power or signal.

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- However, it is important to note that passive devices remain subject to other kinds of failure, such as those resulting from mechanical or structural failure or willful human interference. Therefore, passive safety is not synonymous with inherent safety or absolute reliability.
- In brief we have the following definitions:
- **Passive Component**: A component which does not need any external input to operate.
- **Active component**: Any component that is not passive is active.
- **Passive system**: Either a system which is composed entirely of passive components and structures or a system which uses active components in a very limited way to initiate subsequent passive operation.
- **Active system**: Any system that is not passive is active.

Now having said this, one must remember that even passive devices, they remain subject to different kinds of failures. Now you take a non-return valve. It must open based on the forces, but could be if it has not be utilized for a very long time, it could fail when really required. So let us not say that if it is passive safe, it is absolute safe, or inherently safe. No. Still it involves certain amount of active systems or active devices. So passive devices also need to be supervised or we -- what we say surveillance need to be conducted even on passive devices.

Now you have a problem. Now let us say I have a motor for cooling. Motor -- motor driven pump for cooling. I want to know whether it will work. So I just have to put on the power -- power supply to the motor and see whether the pump is running and supplying water. I can always check it anytime.

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But it is a passive system. How do I check because the need for such a thing has not arisen? There is no manual switch. So remember passive system is not synonymous with either inherent safety or absolute reliability. This point I am trying to make because there is a feeling in many of the young designers that if I make a system passively safe, it is as good as inherently safe. It is a system which will operate with high reliability. No.

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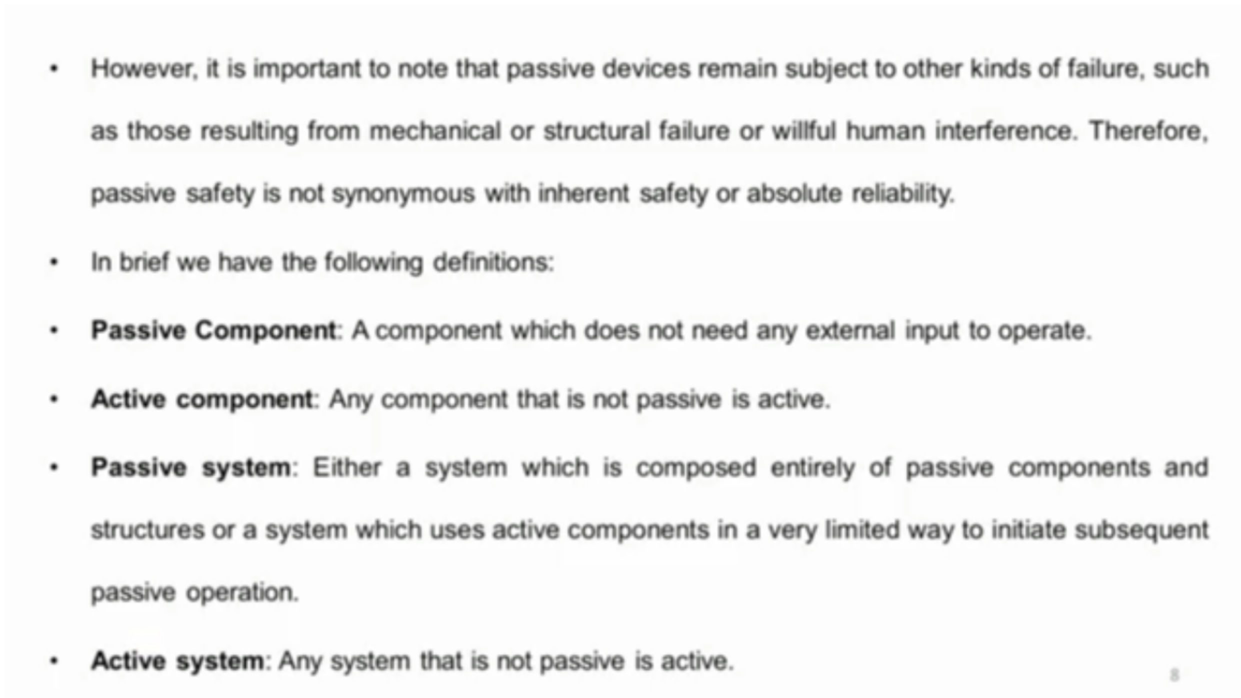

So in brief we can make the following definitions: Passive component is one that does not need any external input to operate. The simplest definition. Active component is one that is not passive. So a one which is not passive is active. Then passive system means a system which contains lot of components, so all the passive component systems or structures, which use active components in a very limited way. This essentially comes in a limited way because somewhere there is need to actuate, some signal needs to be actuated. Subsequently, it may be a passive operation. So a passive system has all the passive components, but still it can use some active -- one active component to initiate the passive system and active system is one which that is not passive.

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So if you look up here, there is a bit of active component initiation in the passive system.

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- Passive systems rely on natural laws, properties of materials, and internally stored energy. Thus heat removal from a reactor by thermo-siphoning (natural Convection) to an elevated tank of water is passive, at least until the water runs out. In practice most 'passive' designs do allow active signals since there is usually a need to switch from active heat removal systems for full power operation, to passive decay heat removal systems after an accident.

- Current power reactors mainly use a combination of inherent safety characteristics and engineered safety systems, whose function may be active or passive. In the past decade there have been many proposals for applying different technologies to reduce reliance on active systems. These new designs are expected to be effective in contributing through simplification to improved economics in terms of construction costs, operation and maintenance costs, ease of operation and reliable equipment and systems.

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So let us take positive systems as an example. I talked about the gravity flow. So that is based on the law of gravity. Then passive system also could mean the using the properties of materials. All of you know in two metals, when they are heated and they have a different expansion coefficients, then they can move and actuate a system. For example, a thermostat is one.

Now coming to a reactor, we have as we shall see later, magnets materials which change, lose their magnetism beyond a certain temperature. So if the temperature of the reactor goes up, it loses its magnetism. So here we are using the magnetic properties of the material.

Then the third one is the internally stored energy. This, the best example is a spring-loaded safety relief valve. The spring has a pressure so that it should not go open normally be open and when the pressure crosses the limit set, it is able to compress the spring and then release and once the pressure goes down, it will again close.

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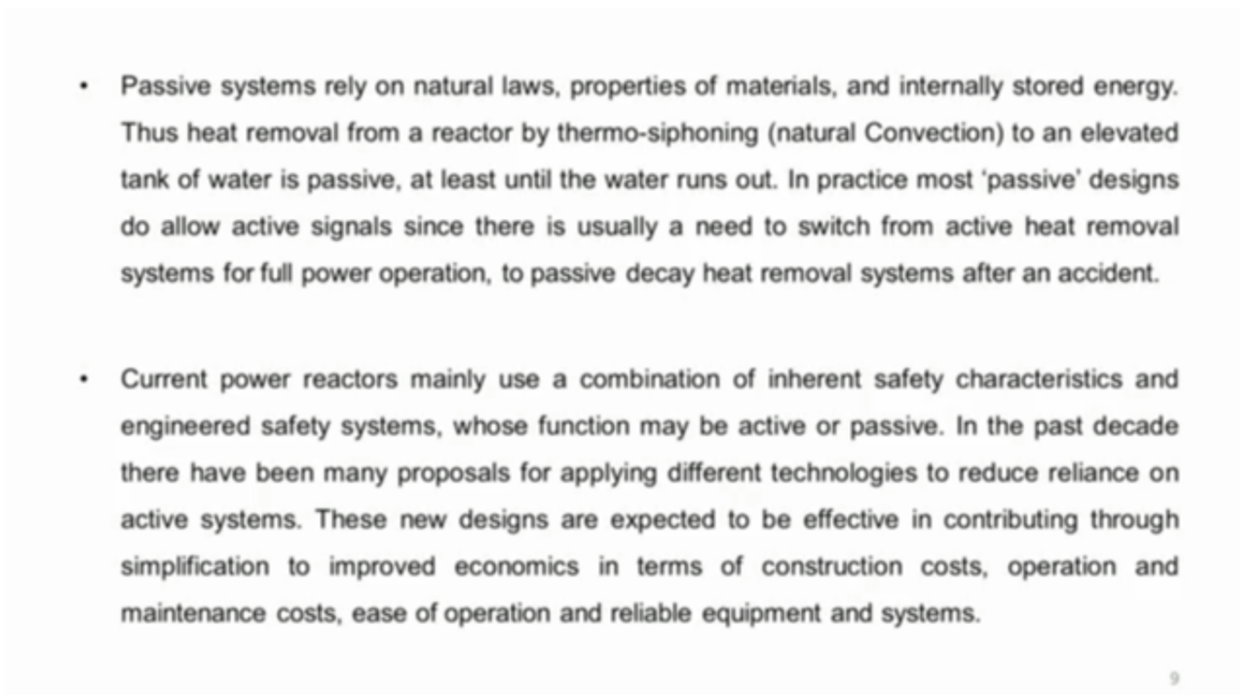

Now heat removal by natural convection, as we saw here from a gravity tank to a core, which is down, but here if you see the word thermo-siphoning that means cold water comes down, goes into the heat source, here is the reactor, gets heated up, becomes light, goes up, back into the cold water source. Again, it continues. So that means it is a continuous flow by natural convection. So that means we need to design any natural convection system should have the source of heat below and the sink of heat at the top because this will aid the natural convection. Other way if you keep, it is not possible. So in most of the passive designs, we mentioned as we said active, we do an active signal, which is needed to actuate this system.

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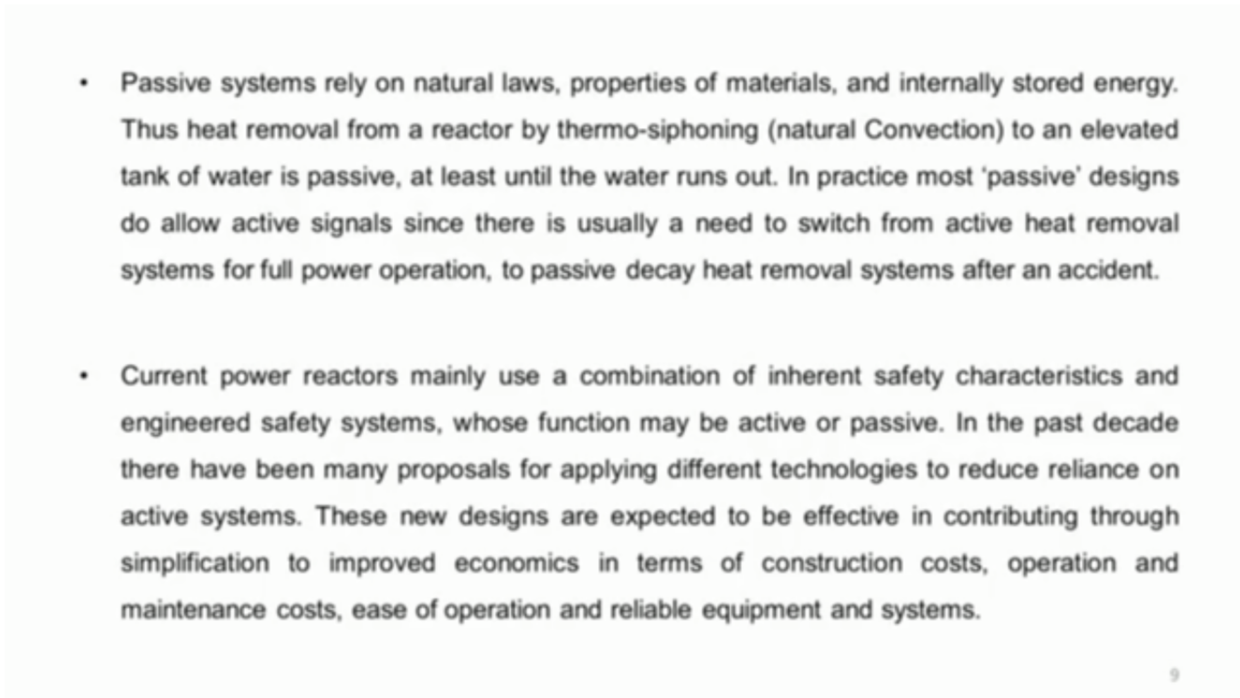

Now most of the current power reactors use a combination of the intrinsically safe characteristic, safety characteristics like the negative reactivity coefficient or the negative feedback coefficient, and engineered system, which may be active or pass. As I mentioned you in the past decade many proposals for applying different types of technology are being brought out to reduce reliance on active systems. However, these new designs need to be cost-effective. They need to be really prove their reliability through operation experience and also their complexity with which they operate. Essentially, they should be very simple.

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CATEGORIES OF PASSIVITY

Characteristic	Category A	Category B	Category C	Category D
Signal Inputs of Intelligence	No	No	No	Yes
External power sources or forces	No	No	No	No
Moving mechanical parts	No	No	Yes	Either
Moving working fluid	No	Yes	Yes	Either
Example	Barriers such as fuel clad, containment; core cooling relying only on radiation or conduction to outer structural parts	Heat removal by natural circulation to heat exchangers in water pools, from the core or containment	Rupture disk or spring-loaded valve for overpressure protection; accumulator isolated by check valve	Shutdown System #1 and #2 in CANDU

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Now looking at that in every passive system there is a degree of activity -- active system, the International Atomic Energy Agency has made a categorization of the degree of passivity. Now this degree of passivity refers to four different elements. One is the signal input to actuate that safety feature. Then the second one is external power source or forces. The third one is moving mechanical parts like damper for an air exchanger and moving working fluid.

Now the Category A is one which is totally passive. That means the signal input is passive. There is no external power source, no mechanical parts and no working fluid. So, basically, if you can which systems are like this, you could talk about the fuel clad, the containment and core cooling, which is dependent on radiation only. Some of the designs are there wherein the reactor vessel, as the temperature goes up, it radiates heat to the surroundings and thereby removes the decay heat. So, basically, it will be conduction through the structural parts and radiation from the outside. So this is -- doesn't involve any moving fluid. Hence, it is a totally passive system.

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CATEGORIES OF PASSIVITY

Characteristic	Category A	Category B	Category C	Category D
Signal Inputs of Intelligence	No	No	No	Yes
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Moving working fluid	No	Yes	Yes	Either
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In Category B, there is a moving fluid, which removes the heat. So here comes those systems like heat removal wherein the natural convection takes place through the reactor and that heat is given to a sink through heat exchangers or the containment cooling through natural convection of air. These things come under the Category B.

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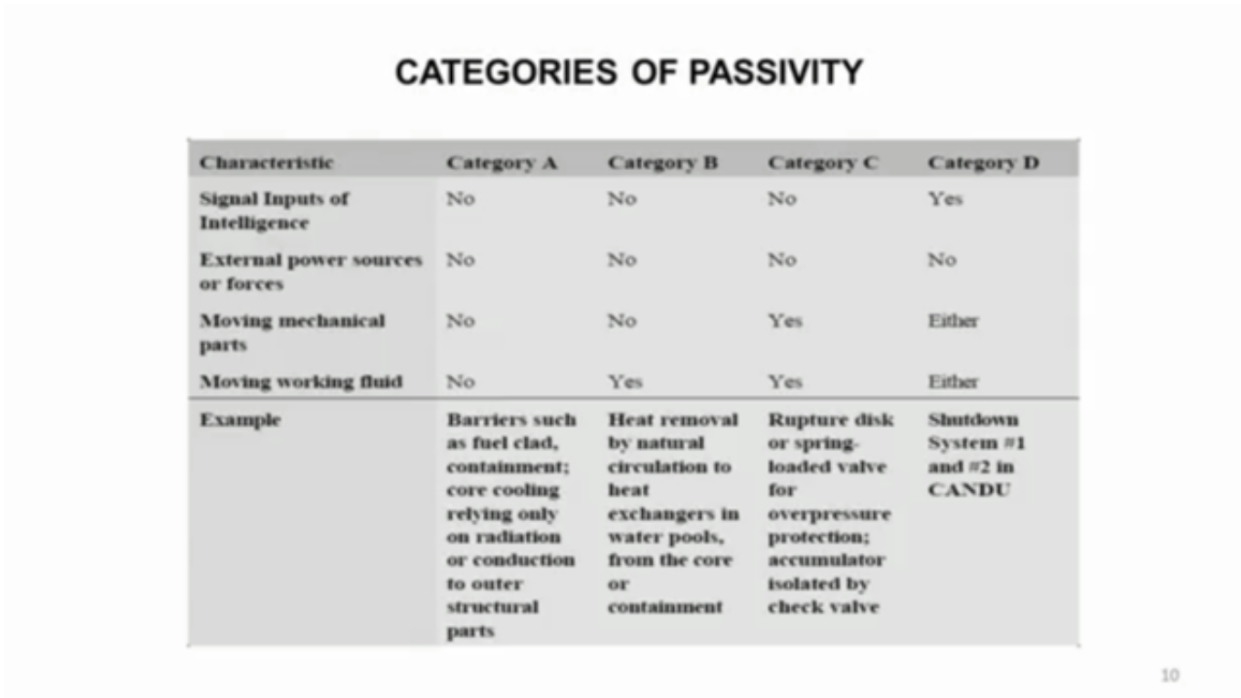

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Example	Barriers such as fuel clad, containment; core cooling relying only on radiation or conduction to outer structural parts	Heat removal by natural circulation to heat exchangers in water pools, from the core or containment	Rupture disk or spring-loaded valve for overpressure protection; accumulator isolated by check valve	Shutdown System #1 and #2 in CANDU

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Then in category C, we do have a moving working fluid and also moving mechanical parts. Here the best example as I said is a spring-loaded safety valve or a rupture disc, which is given for over power production or an accumulator or a gravity, you know, tank kept at a very high level with a check valve. So the check valve is a mechanical moment. So that is another type of degree of passivity. We call it as category C.

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CATEGORIES OF PASSIVITY

Characteristic	Category A	Category B	Category C	Category D
Signal Inputs of Intelligence	No	No	No	Yes
External power sources or forces	No	No	No	No
Moving mechanical parts	No	No	Yes	Either
Moving working fluid	No	Yes	Yes	Either
Example	Barriers such as fuel clad, containment; core cooling relying only on radiation or conduction to outer structural parts	Heat removal by natural circulation to heat exchangers in water pools, from the core or containment	Rupture disk or spring-loaded valve for overpressure protection; accumulator isolated by check valve	Shutdown System #1 and #2 in CANDU

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Then the category D basically is differentiated that it requires a signal input. Active signal input it requires. So this essentially refers to the shutdown systems. Any shutdown system for a reactor has to actuate on a particular signal. So that signal is passive. Rest of the things -- that is active. Rest of the things may be passive. So the idea of this sort of categorization helps in carrying out the reliability calculations and comparing the different systems for high degree of passivity. So to say Category D is the least passive and Category A is the maximum passive.

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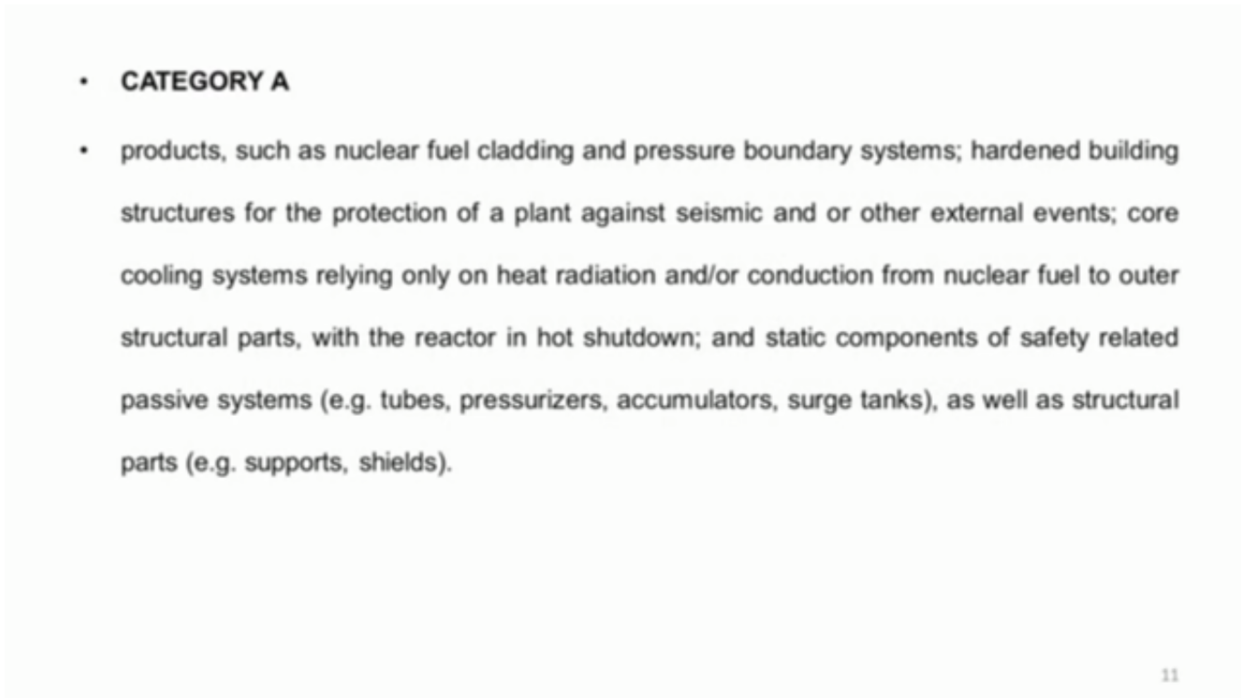

Now let us look at Category A. So the fuel cladding is one and the pressure boundary system, the reactor vessel or the building structures, which are protect -- given to the plant. Now as I mentioned core cooling systems that rely only on heat radiation.

Now one might ask if radiation itself could remove the decay heat from the core? Why at all we should think about other external cooling? Unfortunately, the radiation is a function of the amount of surface area available. More the surface area available, surely, it will be more, but when you take a large reactor, the radius of the reactor is doesn't increase in proportion to the power. So radiation heat removal is possible only in small reactors of small powers.

In fact, one of the proponents of safety, passive safety, many proponents, they say, you have small reactors, which can be even shop fabricated and they can very easily remove decay heat based on radiation. So this sort of application could be there for small reactors only this heat removal by radiation is possible. Of course, the tubes, pressurizers, accumulators etc., are to some extent passive systems.

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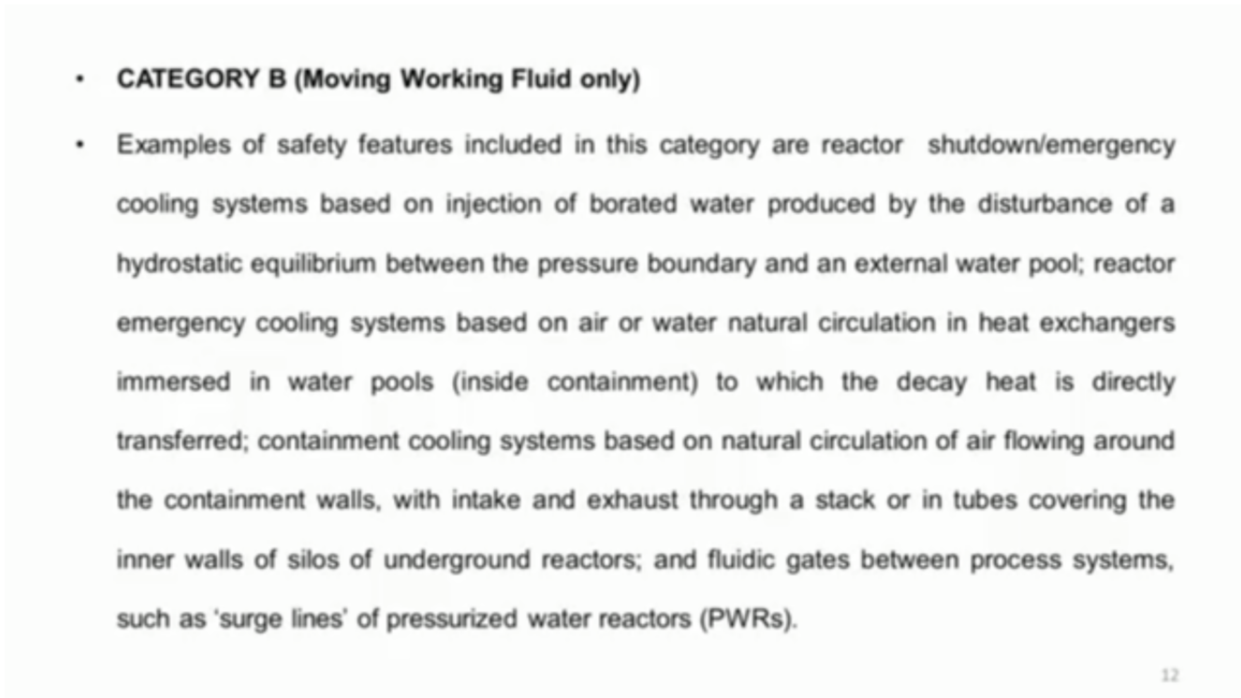

Now Category B. We saw that moving working fluid is there. So here we talk about the shutdown or emergency cooling system for reactors where in when we say reactor shutdown, we have a tank of water which is contains lot of boric acid and the water with boric acid gets into the reactor based on the pressure difference. That is normally it is in touch, it is in contact with the -- there is no valve between the tank and the reactor system, but the reactor pressure being high, it is able to hold that borated water above. The moment the pressure comes down, the borated water gets into the pool and shuts down.

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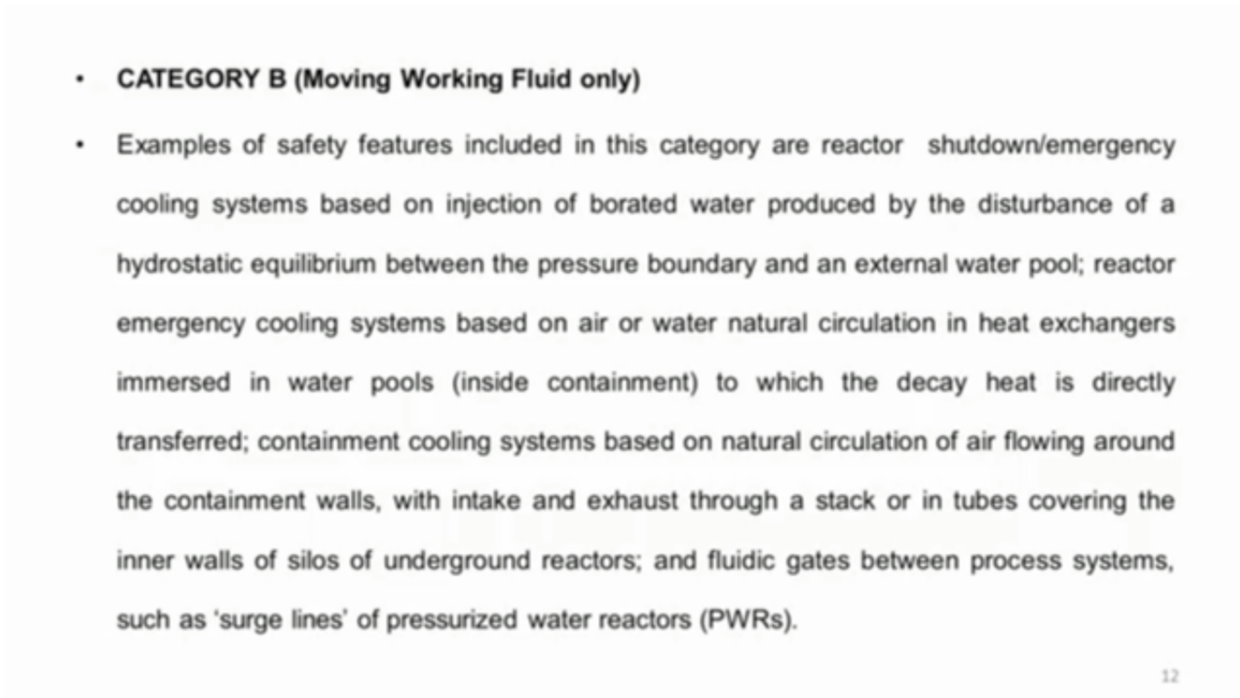

In a similar way, this also could be used for cooling the reactor in case of an emergency. That is you have the decay heat system wherein it is -- which is based on air or water natural circulation, which is suppose let us say there is a failure of the pipe. Lot of water would have come in to the containment. So you have a heat exchanger in the containment and that is linked to a air heat exchanger, water to air heat exchanger outside where the air moves in to the natural convection and removes the heat from the water to air exchanger. This sets up the natural circulation flow in the heat exchanger and the heat from the containment walls etc., is removed. The air of course it goes out through the stacks. We do have such systems in lot of pressurized water reactors.

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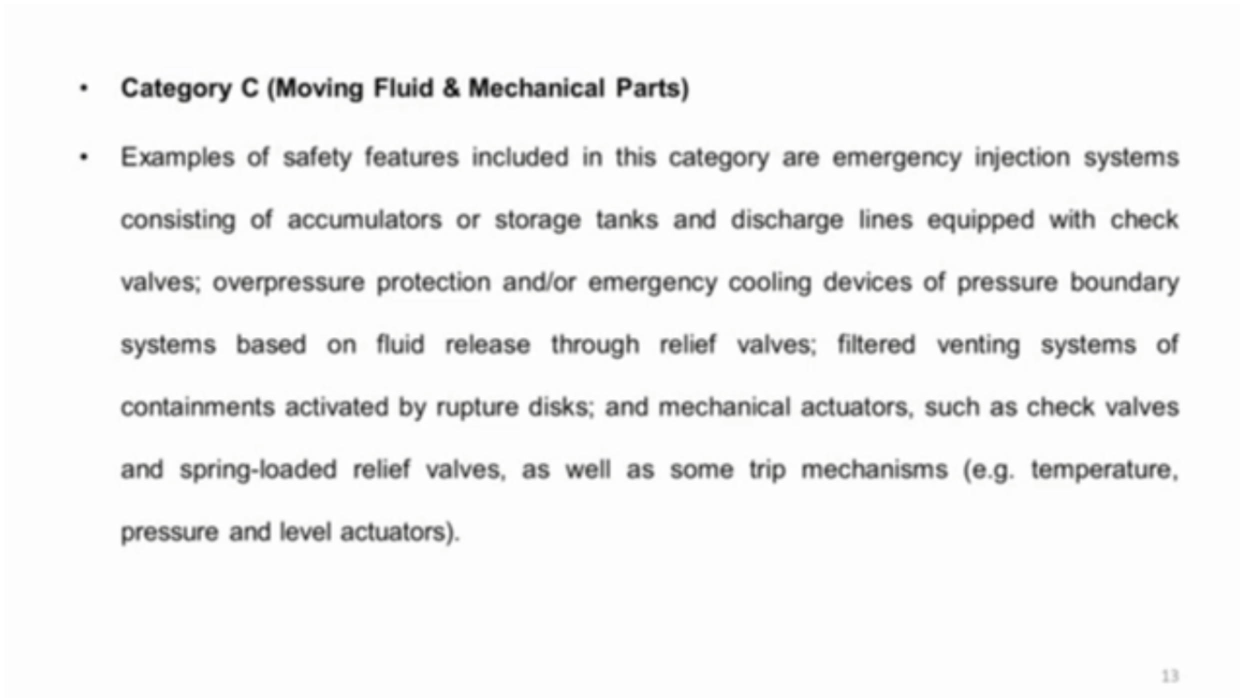

Then the category C, we said mechanical parts, come a moving fluid. So the best example are the emergency injection systems in which you have accumulators or storage tanks which are provided with check valves, and overpressure protection, and also emergency cooling devices of the pressure boundary systems, so where in the fluid goes through the relief valves. So I gave the example of a spring-loaded relief valve where the -- it opens or it could be a pressure operated relief valve, which will open when the pressure rises, again, comes down. Then so these are such sorts of examples which are belong to the category C.

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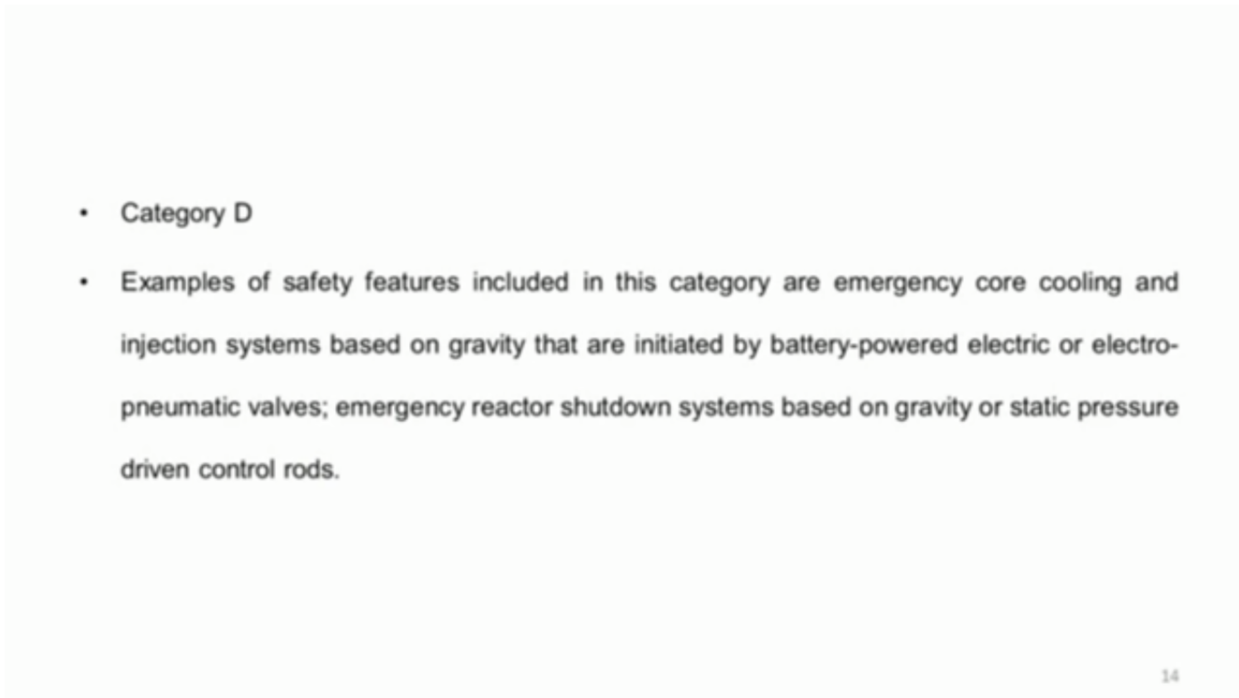

So category D, which is the least passive, is essentially based on battery-powered electric, or electro-pneumatic valves, or emergency shutdown systems based on control rod drives falling and control rods falling under gravity or this thing, but they do require a signal that the major thing is they do require a signal for actuation.

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PHWR/ CANDU REACTOR SHUTDOWN SYSTEMS

- CANDU shutdown systems are passive in the sense that once they are actuated by a signal, the devices themselves are inserted into the core via gravity (shutoff rods) or stored energy (spring assist to the shutoff rods, and gas-driven poison injection). This places them into IAEA Category D above. However negative feedback does not necessarily shut down the reactor after, say, an inadvertent insertion of positive reactivity (control rod withdrawal) - it simply allows the power to rise and then equilibrate at a level where the negative reactivity due to the higher fuel temperature offsets the reactivity addition of the control rod. One still needs to be sure that the power can be removed somehow (by passive means) and that the fuel is not damaged. A strong negative coolant temperature feedback has the added concern that a fast insertion of cold water could cause a rapid power increase before the negative fuel or coolant temperature has time to compensate it.

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Now let us look at the pressurized heavy water reactors. Why I talk about pressurized heavy water reactors is that we have 20 such reactors in India in operation. So let us look at -- they are also called the, as I mentioned earlier, they are based on the Canadian design. So they are also called as Canadian Deuterium Uranium Reactors. In India, we call them as the pressurized heavy water reactors after we have modified the systems to our own designs, our own safety criteria.

So the shutdown system here, they are actually actuated by a signal. that is let us say the temperature is crossing. The flow is coming down. These signals, the safety logic looks into that, sees whether it is a genuine signal and actuates a shutdown, but then once a shutdown is actuated, the rods, control rods themselves go inside the core. They are, of course, spring assisted so that they can push the thing faster and achieve shutdown in minimum time.

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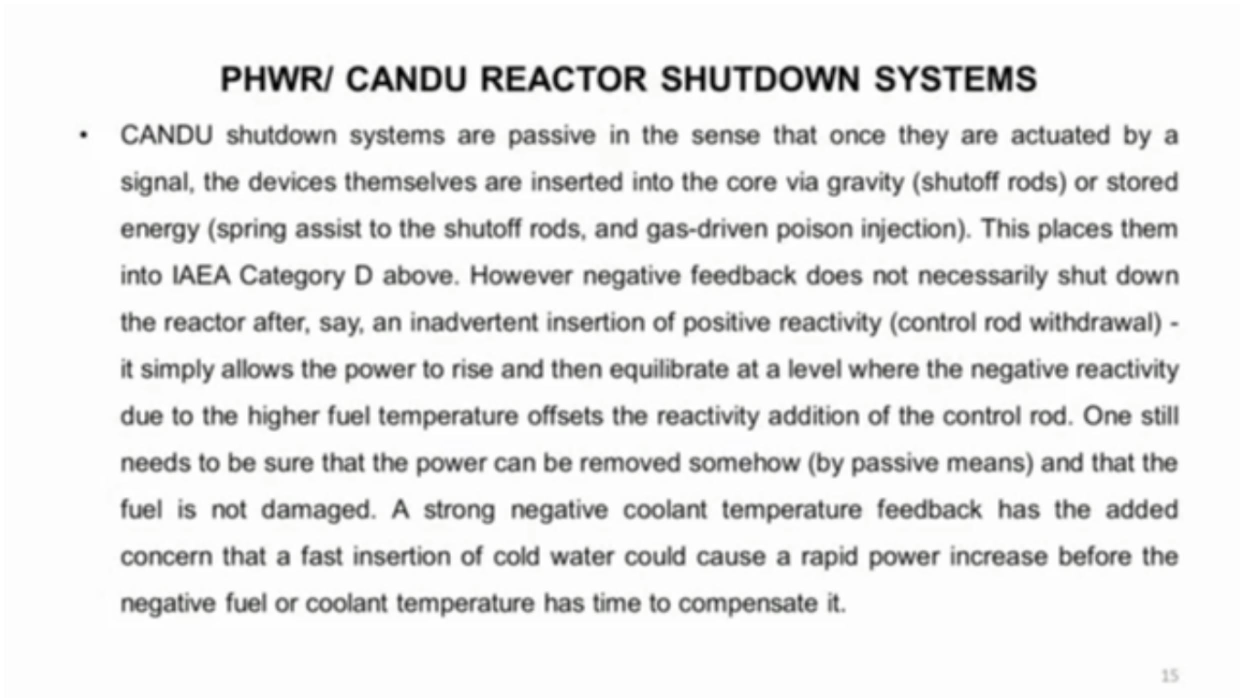

Then the other one which we use in all our reactors is the poison injection system, which is a gas-driven system in which we have gas accumulators, which are at a pressure less than the reactor. The moment there is a need for a reactor trip, the pressure equalization takes place between the gas -- gas accumulators and the reactor and the poison, the water containing the borated thing which is called as poison then falls down into the core and shuts down the reactor. So this comes under Category D because it requires a signal to actuate.

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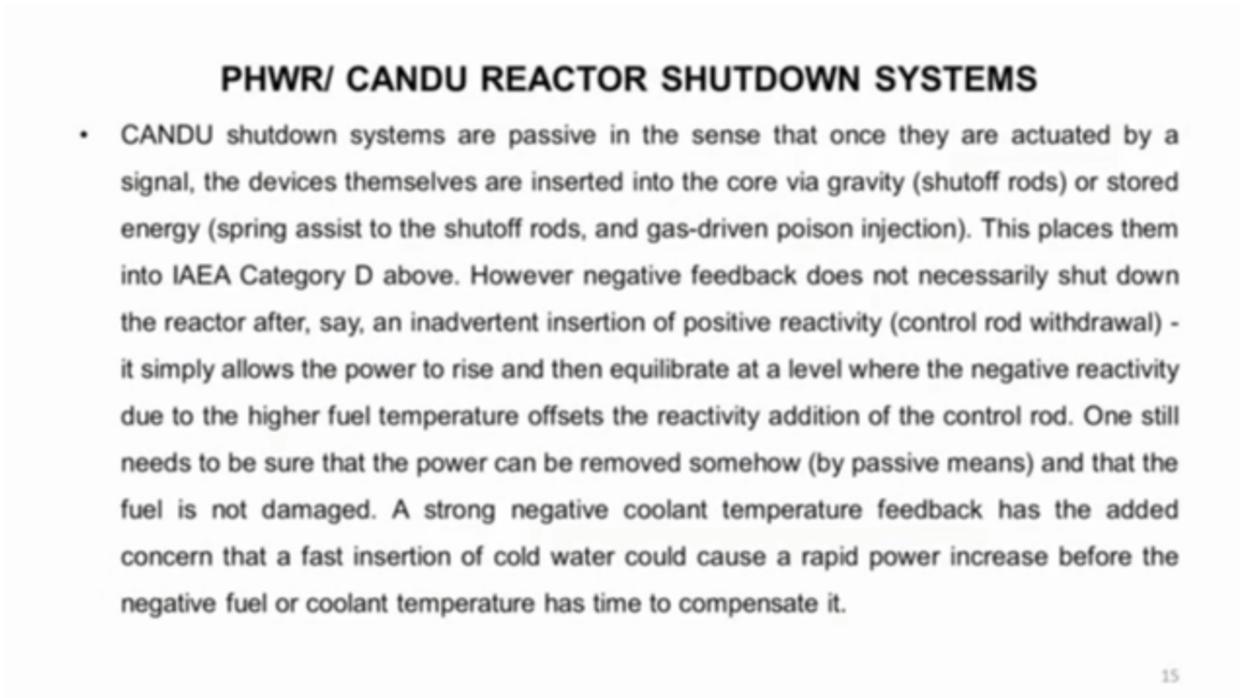

Now negative feedback if you take is we saw a very important feature, intrinsic feature of the reactors, designs, but then if it is an inadvertent insertion of reactivity, that means we are taking a control rod out without any limit, then in that case the power will rise fast and there will be no time for the feedback because the temperature has to rise. Then only the feedbacks will come. So it may not be able to provide safety under all circumstances.

Then there is also another effect. If suppose let us say a cooling event where in the flow comes down because of a pump trip, the coolant temperatures would increase. Then slowly, your clad and other temperature increase, try to bring in the negative feedbacks, but let us say we have put a -- designed the reactor with a very large negative feedback.

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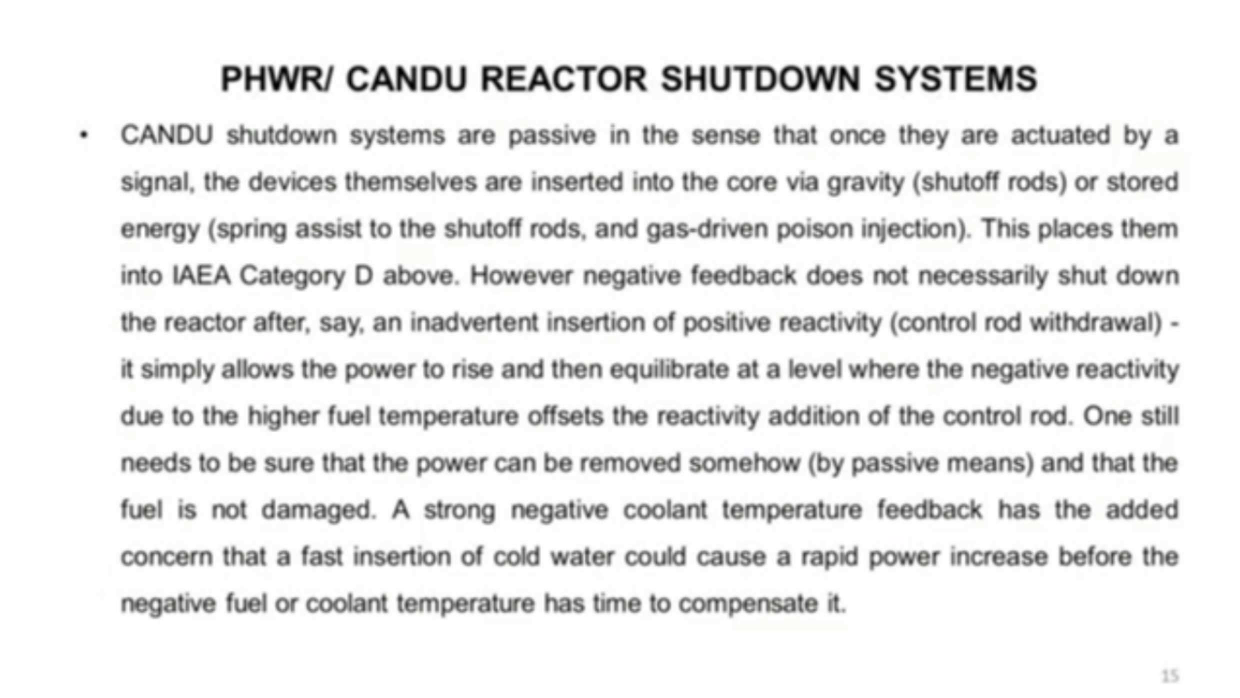

Then we have to look at a event in case there is a over-speeding of the coolant pump at a very low power and it caused overcooling of the reactor, then this effect will become positive. So when -- whenever we do a design, we have to do it for a very, very optimum negative feedback. So this is a very important aspect to be kept in mind in the design of the negative feedback reactivity.

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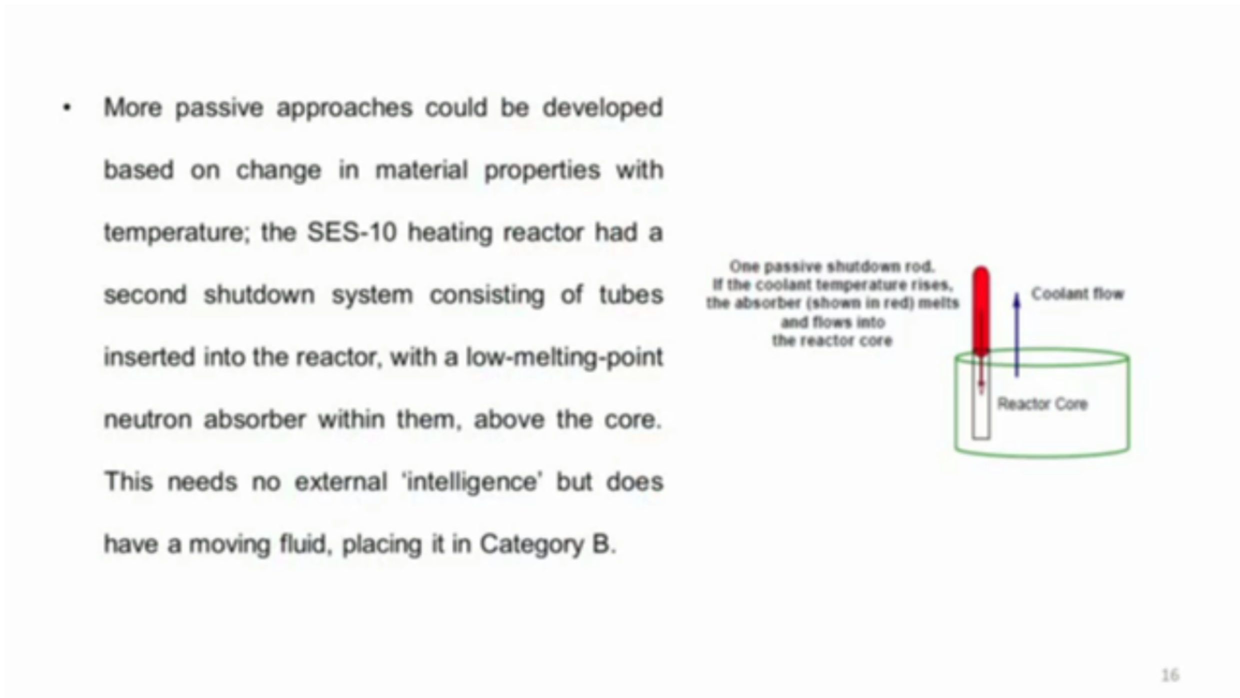

Of course, many passive systems or approaches are being developed. In fact, one of the reactors called the SES-10 reactor, it was more used as a heat source. It had a first control rod, of course, was the first system by which the reactor was getting shut down. The second one consisted of tubes, which had low-melting-point nuclear absorbers within them and when the coolant temperature rises, this would melt and fall into the reactor. So this could come under something like a Category B of passivity.

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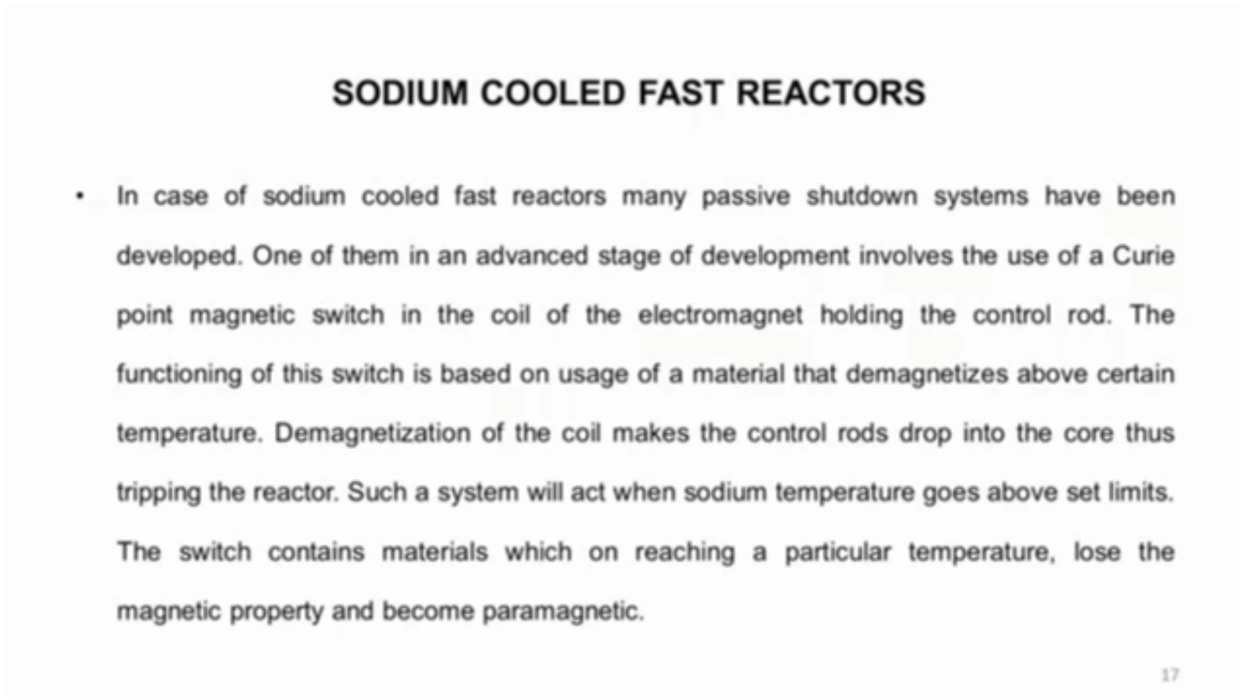

Now the other type of reactors which we have plenty or we are going to have a large number are the sodium cooled fast reactors. Now for the sodium cooled fast reactors, we again have the control rods. Presently, we use only the control rod systems of different designs to have a diverse shutdown system.

Now coming to the passive shutdown features, one of the designs which is in advanced level is the use of a Curie point magnet. That is, you know, here the control rods are held by an electromagnet, which has a coil, which gets current from a source to magnetize it, and it holds the rods. The moment the electromagnet, the current in the coil is removed, the electromagnet lose its magnetism and drops, but then the electromagnet is such a big thing, and if it has to lose its electromagnetism passively in case of high temperature, it will take a long time.

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SODIUM COOLED FAST REACTORS

- In case of sodium cooled fast reactors many passive shutdown systems have been developed. One of them in an advanced stage of development involves the use of a Curie point magnetic switch in the coil of the electromagnet holding the control rod. The functioning of this switch is based on usage of a material that demagnetizes above certain temperature. Demagnetization of the coil makes the control rods drop into the core thus tripping the reactor. Such a system will act when sodium temperature goes above set limits. The switch contains materials which on reaching a particular temperature, lose the magnetic property and become paramagnetic.

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So the idea is have a Curie point magnetic material in the coil of the electromagnet so that that Curie point magnetic switch will lose its magnetism beyond a certain temperature and then once the current is lost, this electromagnet loses its magnetism and the control rods drop into the reactor. Now the limits for this temperature is of the order of 600, 610, or 620 and we can design this by proper choice of material.

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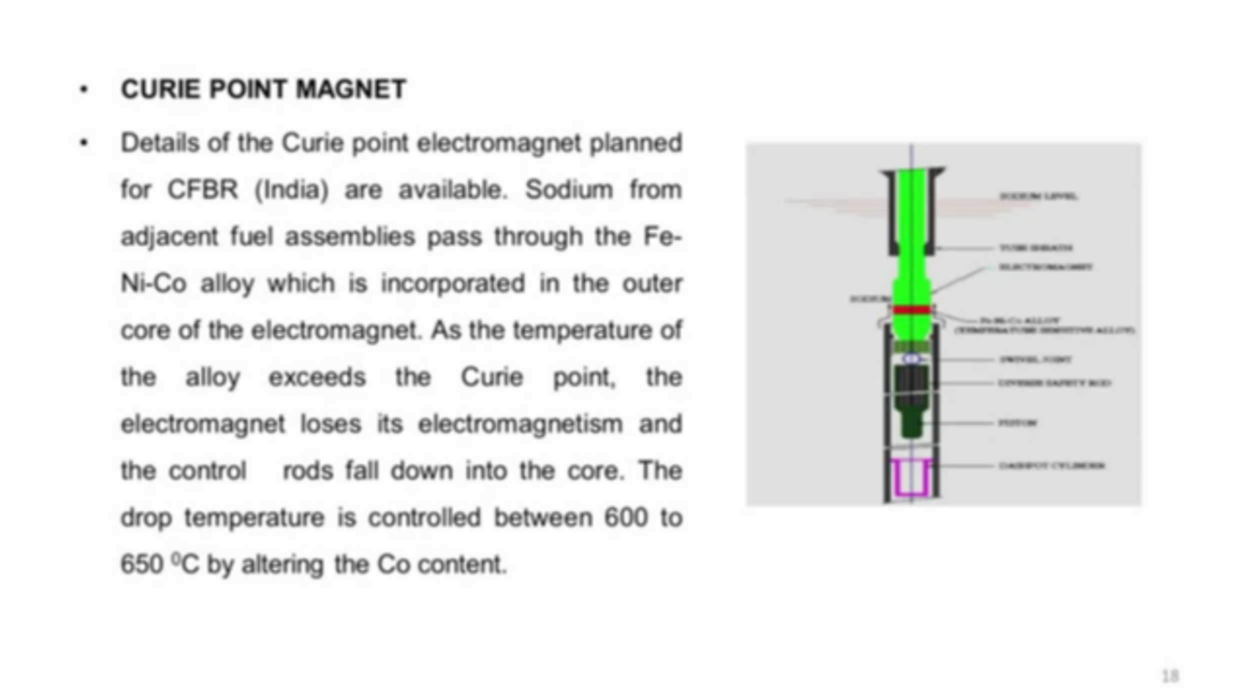

Here is the some details of a Curie point magnet that we are planning for the commercial fast breeder reactor in India. Sodium from the different assemblies goes through this space and then here you have the switch where you have a Curie point electromagnetic switch and then it has -- loses and it is composed of a iron-nickel-cobalt alloy. This iron-nickel-cobalt alloy is the one which comes into picture and it is very sensitive. the composition of the amount of cobalt is very sensitive to the temperature at which it lose its magnetism.

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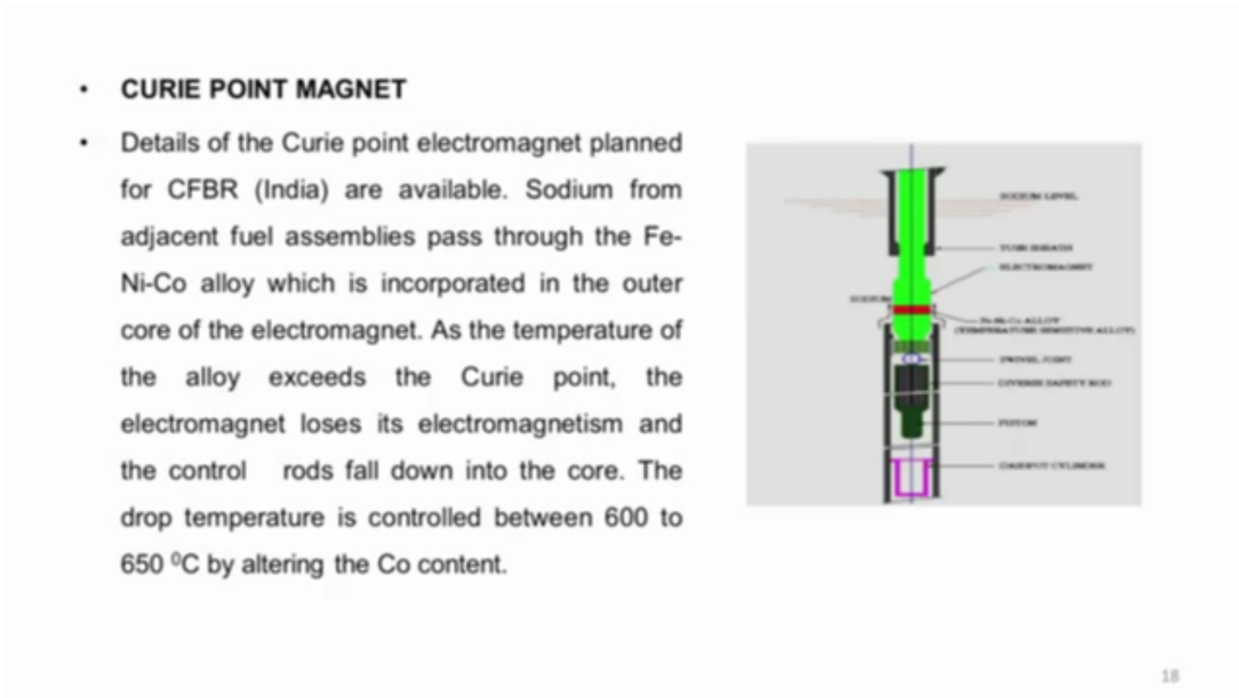

In other words, it is very sensitive to the amount of cobalt and we have carried out research wherein by varying the amount of cobalt, we are able to change the Curie point magnetic temperature between 600 to 650. So this is possible and this feature will be used in the commercial fast breeder reactor.

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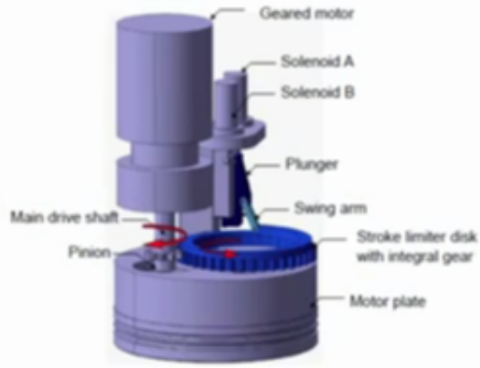
- Inadvertent withdrawal of control rods can occur due to mechanical or electrical fault causing transient overpower (TOPA) conditions. To avoid it a device is introduced that is based on the setting a stopper point by which the rod will stop at the point which is required to maintain constant power . This is referred to as stroke limitation device. This concept is being developed in France and India.



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Now coming to the other system, you know in case there is a loss of flow, temperature can increase, but if suppose there is a overpower. Let us say there is a control rod has been raised inadvertently. Then you have an overpower. So the only way in which we can take care of this event is by having a mechanical stopper. So we have a stopper at a particular height which will stop the max. So you cannot cross that level and that design of a stop, that design of the stopper is what is called as a stroke limiting device, and of course at different powers you have to set the limit at different places and this concept is being developed both in France and India and is being subjected to lot of testing now.

You might wonder if this is required, what are we doing in the present reactors? In the fast breeder test reactor at Kalpakkam, in spite of the fact that we have different signals to detect the overpower like power -- over power, temperature, reactivity etc., we still have made a circuit such that even if the control rod push button is kept for more than, you know, a certain time, it will trip the reactor. It will not allow the -- I am sorry. It will not allow the rods to move beyond that. It will trip the circuit so that no power supply is available for the control rods.

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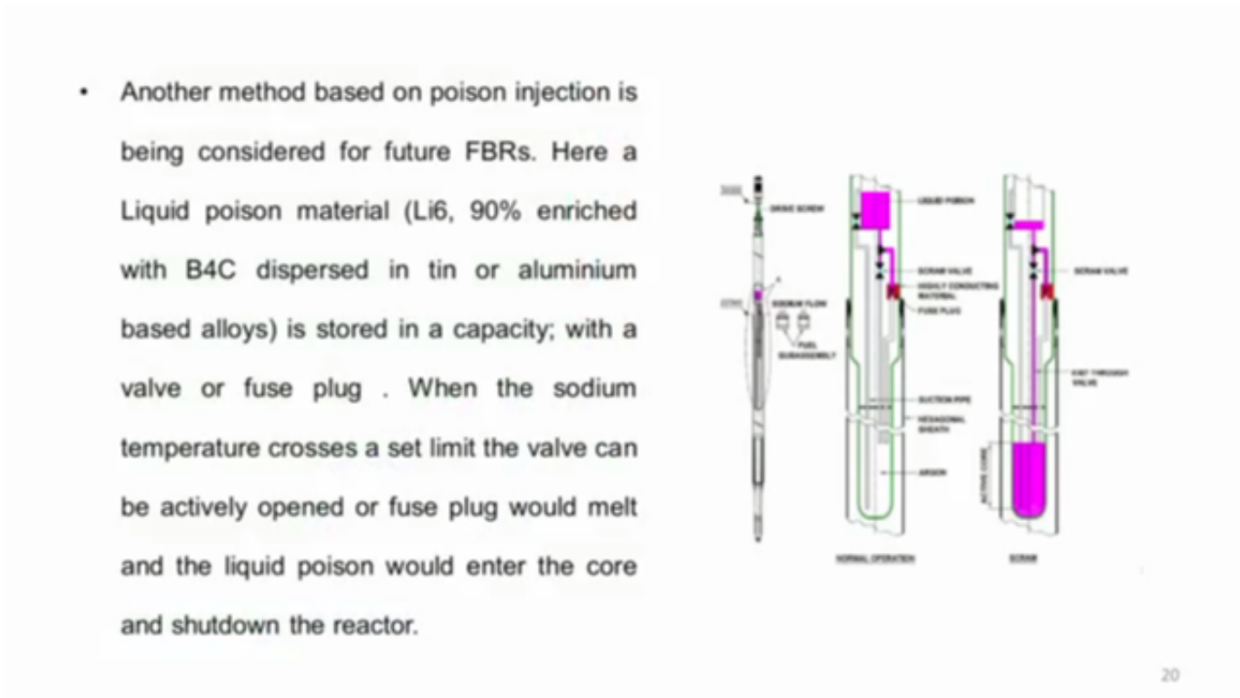

Another method is based on the poison injection like the thermal reactors. We are talking about a liquid poison where in Lithium-6 as poison along with Boron carbide which put in a tin or aluminum-based alloy with a fuse plug and this fuse plug will melt when sodium crosses a particular temperature. Now there is need to do. Suppose it has happened. After that how to remove this poison from the sodium? So this essentially needs some more area of work to be done.

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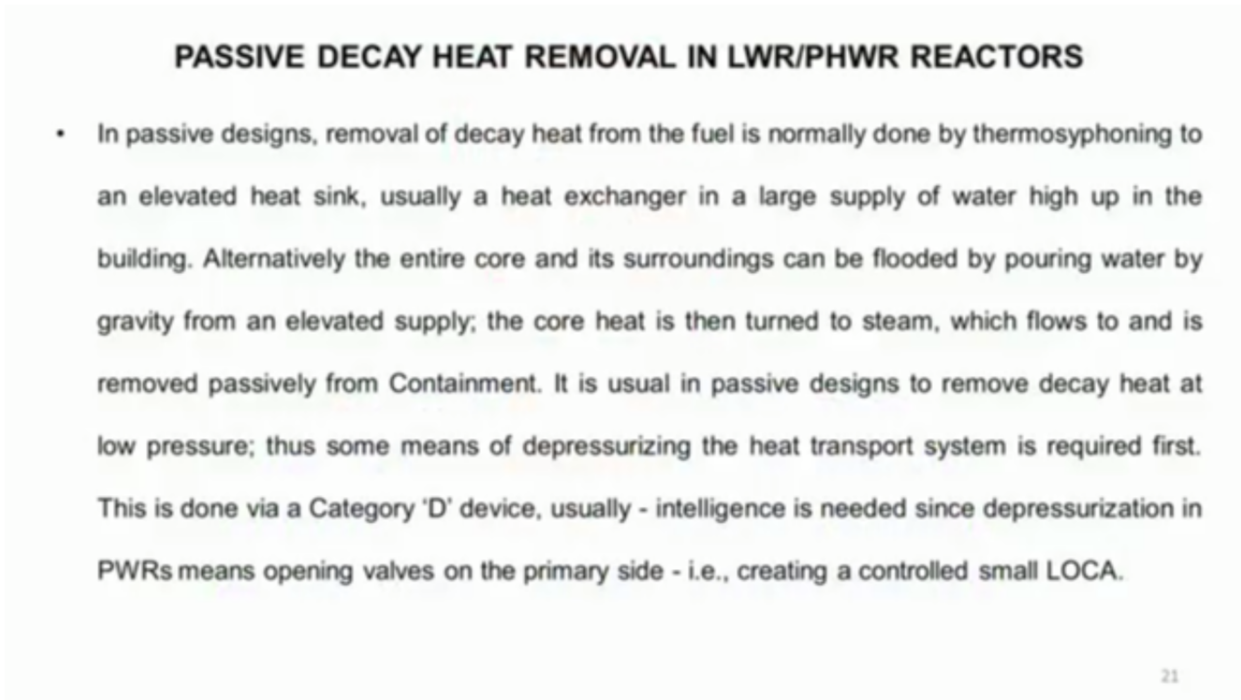

Now the passive decay heat removal is one. Now presently in our PHWRs, we do heat removal by natural convection in case the primary system is everything is okay. In case there is a power failure and no auxiliary coolant pumps are able to start, we do have natural convection cooling based with the heat exchanger. Then in some cases like our PHWRs, the moderator surrounds the entire core. So we have got the moderator system, which can remove the heat, then also the water, which gets converted to steam goes through a heat exchanger. It gets cooled by the means of some water or air, and then again come becomes as water.

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PASSIVE DECAY HEAT REMOVAL IN LWR/PHWR REACTORS

- In passive designs, removal of decay heat from the fuel is normally done by thermosyphoning to an elevated heat sink, usually a heat exchanger in a large supply of water high up in the building. Alternatively the entire core and its surroundings can be flooded by pouring water by gravity from an elevated supply; the core heat is then turned to steam, which flows to and is removed passively from Containment. It is usual in passive designs to remove decay heat at low pressure; thus some means of depressurizing the heat transport system is required first. This is done via a Category 'D' device, usually - intelligence is needed since depressurization in PWRs means opening valves on the primary side - i.e., creating a controlled small LOCA.

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So we since in all these cases if I have to put water under natural convection means the pressure in the system must be low. So for -- to actuate such system, I must depressurize my reactor. That means this depressurization is a active element. So this is a Category D device.

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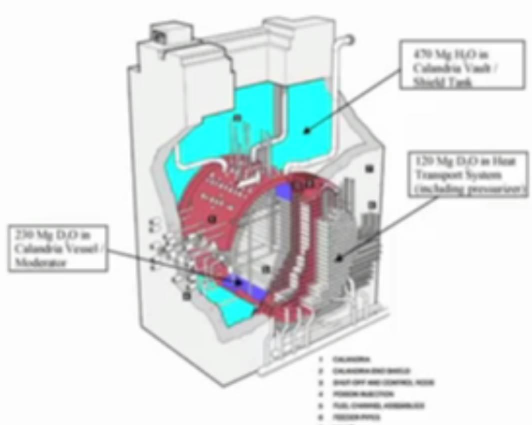
- PHWR/CANDU offers some inherent advantages in this regard, as already stated - there are two large volumes of water around the core (the moderator and the shield tank), onto which one could engineer passive, low-pressure heat removal. Heat removal from the shield tank is only of interest for severe accidents, since by then the core geometry will have collapsed. The disadvantage of the moderator is that with current pressure-tube designs, the fuel will be severely damaged if the heat has to be taken out only via the moderator.



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As I talked about the PHWR or the CANDU system, we have large volume of water in the moderator and the shield tank. So, however, that moderator alone cannot take the full heat, decay heat. We do require some other type of natural convection cooling through the core, but this does provide a good amount of time in which your core cooling system could be actuated.

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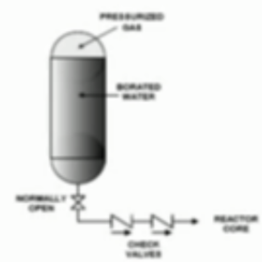
- **Pre pressurized Core flooding tanks**
- Pre-pressurized core flooding tanks, or accumulators, are used in existing nuclear power plants. They typically consist of large tanks having about 75% of the volume filled with cold borated water and the remaining volume filled with pressurized nitrogen or an inert gas. The contents of the tank are isolated from the reactor coolant system (RCS) by a series of check valves that are normally held shut by the pressure difference between the RCS and the fill gas in the tank. In the event of a loss of coolant accident (LOCA), the core pressure will drop below the fill gas pressure. This results in opening the check valves and discharging the borated water into the reactor vessel. This is a Category C passive safety system for conditions mentioned above.



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In many cases as we mentioned we have pre-pressurized tanks or accumulators, which are used and 75% of the volume is filled with cold borated water and the rest with pressurized nitrogen or an inert gas, and you have a series of check valves as I mentioned, and in case of a loss of coolant, the core pressure drops below the gas pressure and the water in the accumulator tank flows. So here this doesn't reverse signally. So it is a category C system.

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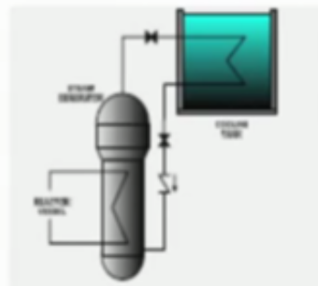
- **Passively cooled steam generator natural circulation**
- Some advanced PWR designs incorporate a system to remove decay heat passively through the steam generators. This is done by condensing steam from the steam generator inside a heat exchanger submerged in a tank of water or an air cooled system. These are Category D passive safety systems.



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Similarly, we have passively cooled steam generator called as natural under -- working under natural convection. So here as you see, you have the reactor core, a heat exchanger, which exchanges steam, which is produced is taken into a water, big source of water, and there the steam gets condensed and returns back to the core and continues the circulation. So steam generator water going to a accumulated tank, and the accumulator tank getting it cooled and then back. This is a passive system of Category D.

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Further we will see in the next lecture. Thank you.

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