**Indian Institute of Technology Madras**
**Present**

**NPTEL**
**NATIONAL PROGRAMME ON TECHNOLOGY ENHANCED LEARNING**

**NUCLEAR REACTOR AND SAFETY**
**AN INTRODUCTORY COURSE**
**Module 15 Lecture 30**
**Passive Safety Cont…**

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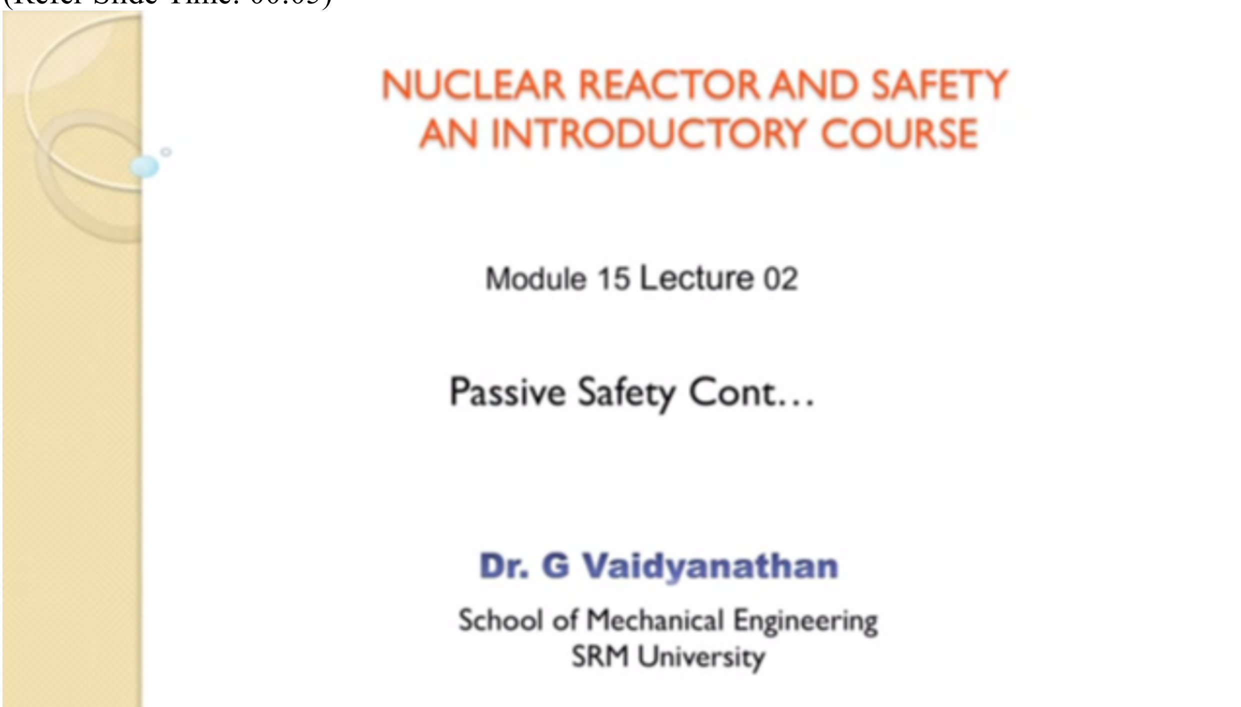


Good morning, students. In the last lecture, we talked about passive safety.

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And in this lecture we will continue with some more features. Just to recapitulate what you heard in the last lecture, I introduced you to the difference between passive safety and active safety. Basically, in passive safety, active components like based on mechanical energy or based on electrical energy are not involved and the process happens through natural loss.

I had also given you that an absolute passive system is difficult because you do require some energization, some signal at some point. So this has led to the classification of different types of categories of passive systems starting from the most passive to the minimum passive and this basically helps in assessing the reliability of the system.

Now when we talk about safety, I mentioned to you that we are talking about two important things in the safety of a nuclear reactor.

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One is the shutdown. That is the reactor must be shut down in case of any event. Similarly, the decay heat removal system must be there. So you must have some coolant, which could pass through the core and take the heat out of the core to another environment. So here last time we saw some of the shutdown systems and also the decay heat removal systems which were acting in a passive manner.

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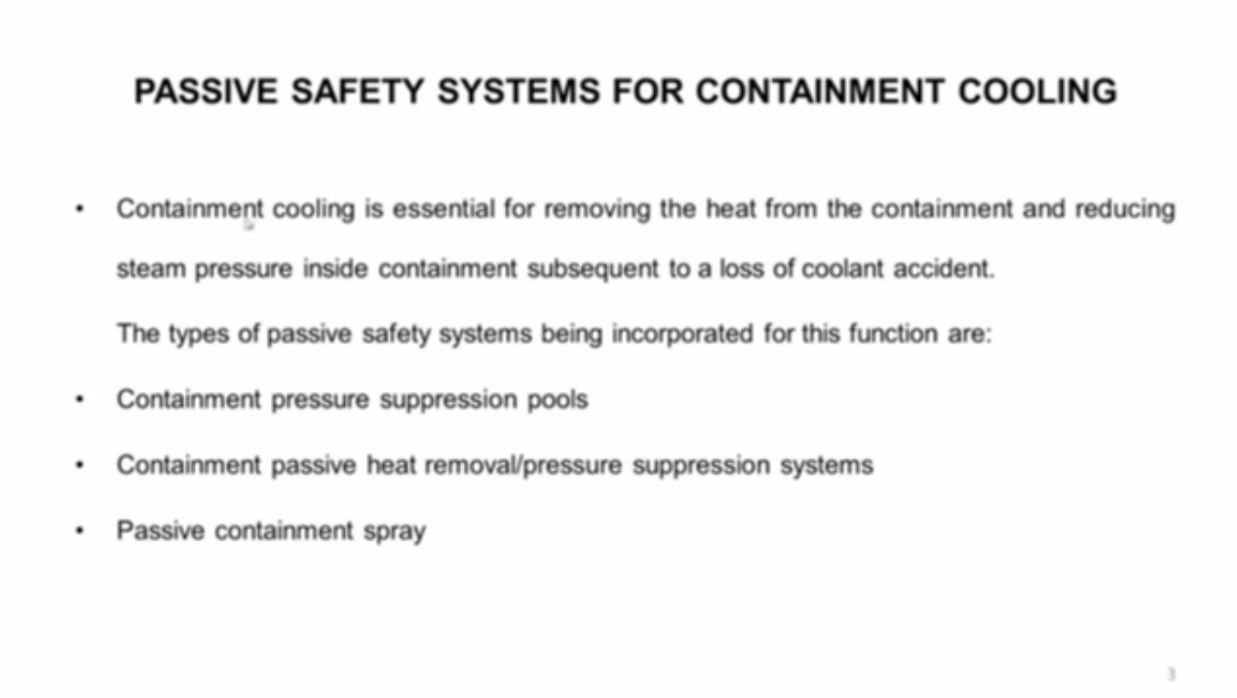


Now today if I look up, we will talk about the passive safety systems for containment cooling. Now why is containment cooling essential? You know in case of a loss of coolant, let us say a pipe has ruptured, the water has come out and the -- it flashes into steam inside the containment. So there is an increase of pressure and heat which is being taken to the containment. So the heat, if removed from the containment, would help in two ways. It will maintain the temperature of the containment. Not only that it will be able to help you in reducing the pressure within the containment. So let us look what are?

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## PASSIVE SAFETY SYSTEMS FOR CONTAINMENT COOLING

- Containment cooling is essential for removing the heat from the containment and reducing steam pressure inside containment subsequent to a loss of coolant accident.

  The types of passive safety systems being incorporated for this function are:
- Containment pressure suppression pools
- Containment passive heat removal/pressure suppression systems
- Passive containment spray

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So there are two types of containments. One is a containment pressure suppression pool. So here, basically, we are looking for taking the -- the containment cooling whatever is there, so the whole thing, water, whichever cools the containment is taken to a pressure suppression system. The other is the containment passive heat removal and the third is passive containment spray. We just will see the three how they are.

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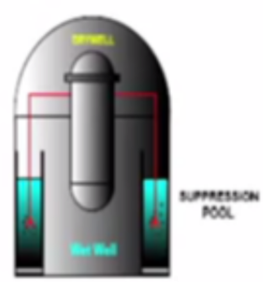
- **Containment pressure suppression pools**
- Containment pressure suppression pools have been used in BWR designs for many years. Following a LOCA, steam is generated into the drywell (the primary containment) following vaporization of liquid and/or steam expansion, both of these coming from the primary system typically due to a break. From drywell the steam-non condensable mixture is subsequently forced through large vent lines submerged in the water in the suppression pools. The steam condenses, thus mitigating a pressure increase in the containment. This is a Category B and C passive safety system.

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We take up the containment pressure suppression pool. This is basically has been used for the boiling water reactor designs for many years. Following a LOCA, as I said the steam is generated in the primary containment. That is essentially because the water flashes into steam and then it really pressurizes the thing. So this steam coming out into the containment is forced through lines, which are vent lines and they are submerged. If you see here the -- these lines are submerged in a suppression pool.

What is a suppression pool? Basically it is a pool of water through which this steam is passed and the steam will condense. The moment steam condenses, automatically, the pressure will come down in the containment. Here it is not completely passive because there needs to be a system to vent it to the suppression pool. So it is partly a Category B and partly a Category C passive system as we shall see.

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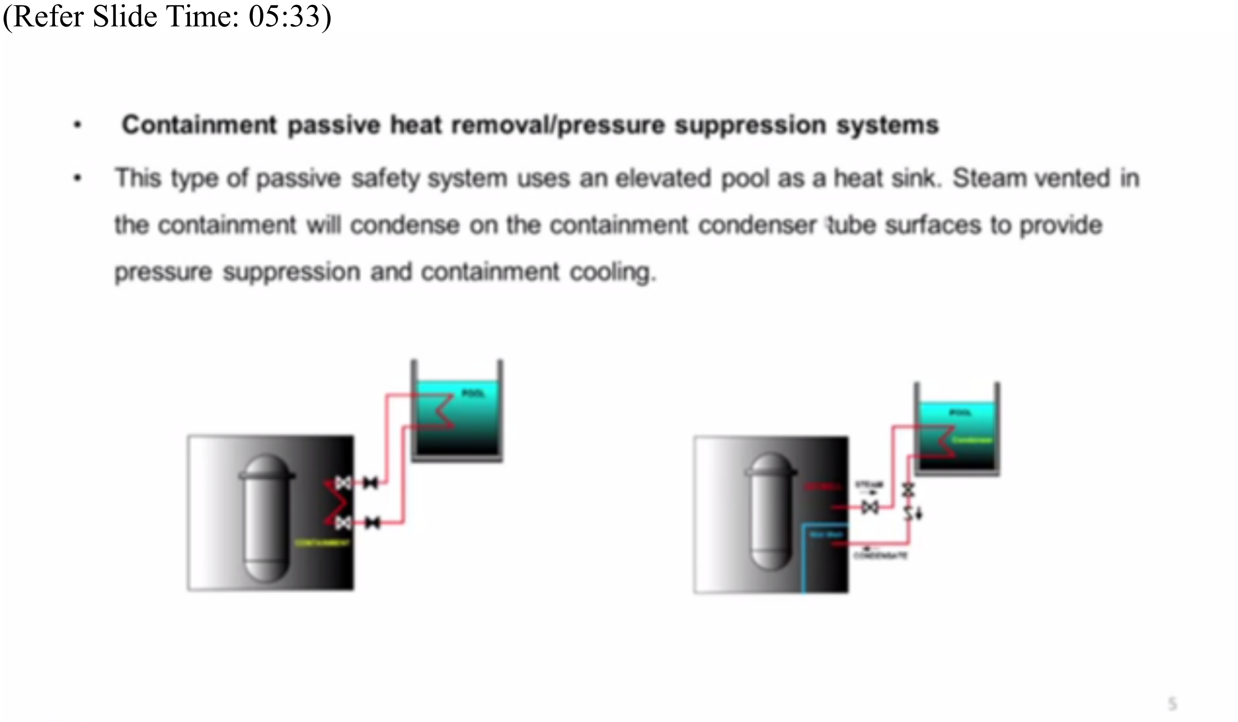

Next we talked about containment passive heat removal. Here what we do? We have a tank at a good elevation and this contains a pool of water and here the steam which is vented into the containment, actually, it condenses on the -- this -- this will have water circuit. The steam will heat up this water in this pipeline. Once the water gets heated up, it will reduce in density, and it will go up, and that will push the water down and here when the water gets cooled, it will push the water down. So this way there is a natural circulation set up and the heat, which is coming into the containment is getting continuously removed.

Of course, this was an indirect means by having a heat exchanger. There could be the other means of having the steam directly go through this coil to the pool, and then this pool would condense and that condensate would come here to the suppression pool.

So, essentially, as I mentioned earlier, for any natural convection, your sink of the heat sink must be at a higher level, must be at a higher level than the heat source. So this is a very important point to be kept in mind.

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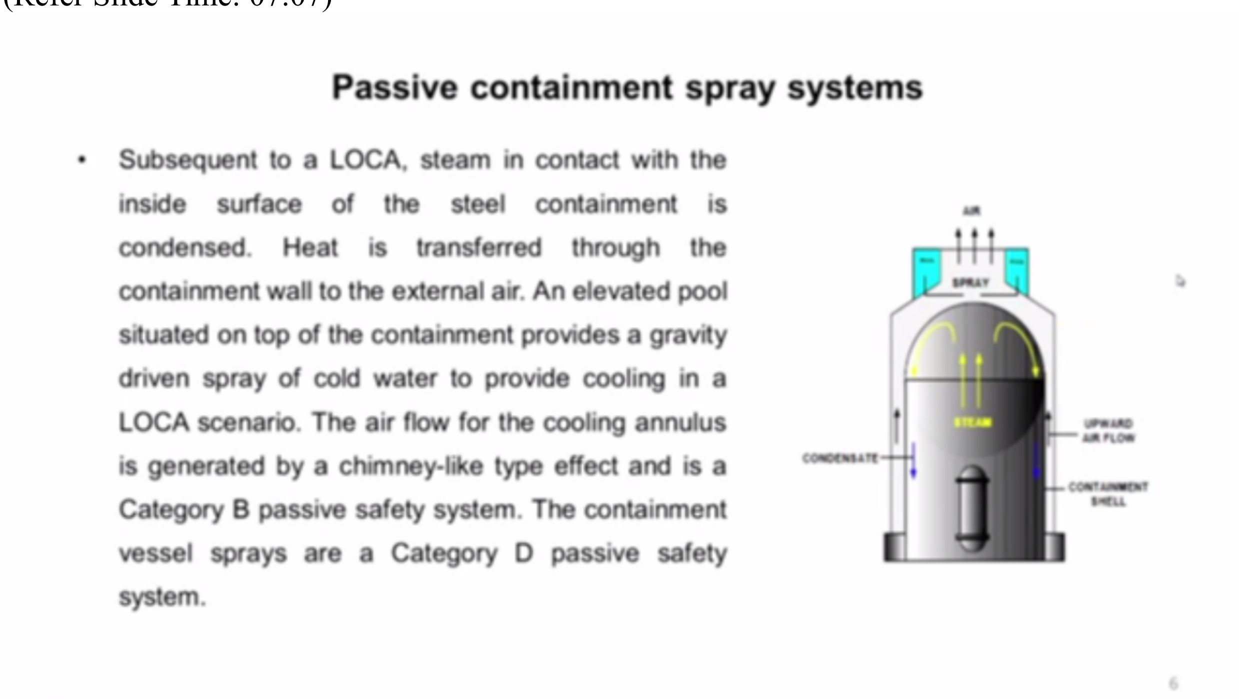


Now we go to the passive containment spray system. As the name indicates, the passive containment spray means that you're spraying water. So what -- let us have a look. After a loss of coolant accident, steam is in contact with the inside surface of the steel containment. This is the steel containment and steam is in contact. Whatever stream is produced is in contact with this.

Now so heat is transferred to this wall. This wall can conduct the heat to the external air here in the space, and this external air picks up the heat and goes up. In addition to this, there is a pool at the top and this from this pool, you have a spray of water. So here, basically, if you see, you have air flow cooling the annulus besides water also. So this way it is able to effectively remove heat and this at the top there is a spray, so the spray needs to be actuated. You require a signal.

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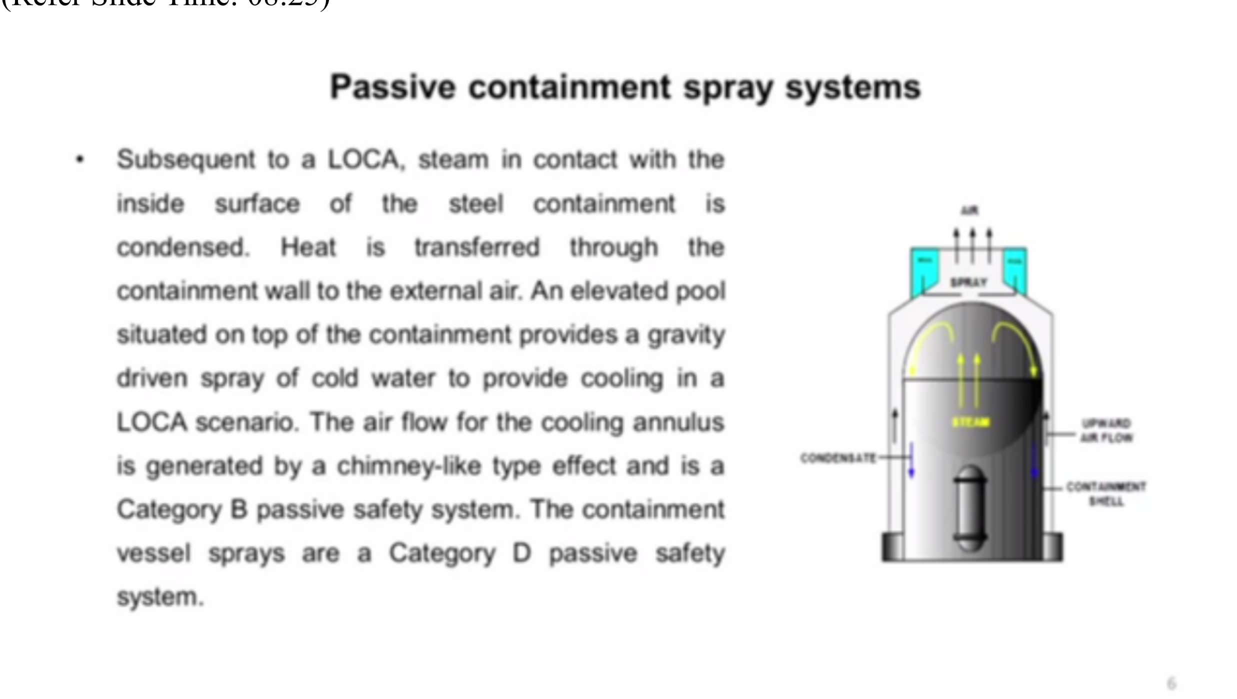


So this containment vessel spray could be categorized as a category D passive system while the air cooling could be put in a category B. So you see that this sort of thing is actually has been used in most of the many of the pressurized water reactors.

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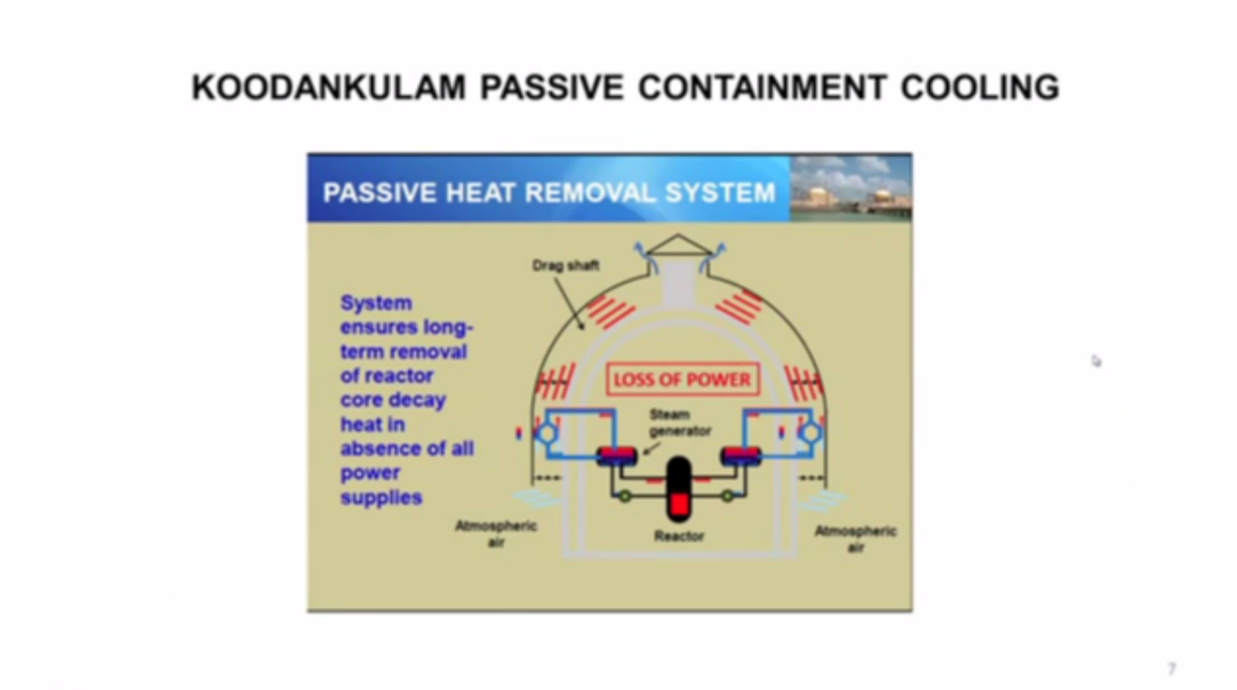


And here I just show you what is the passive containment cooling system adopted in the Kudankulam reactor which has -- which is in operation in Tamil Nadu. So here, exactly, as I mentioned, there is a air going through and in fact, if you look in the actual building, there is a lot of annulus space, so atmospheric air is entering like this, picks up the heat from the containment, and then goes out and so this way it is able to do even when there is a power failure, there is no power, still you are able to do. That means you are not dependent on any electrical power or mechanical power. You are able to do by natural convection. So it is not that we are talking in the air it is actually happening and if you go to the Kudankulam Power Plant, you can have a real nice look at it.

Now all of you know that when you have a loss of coolant accident, it is quite likely that the clad will get overheated because the heat is not getting removed. So the clad Zirconium will react with the steam and at a temperature above 350 to 400 degree centigrade, we saw that it forms Zirconium hydride and releases hydrogen also.

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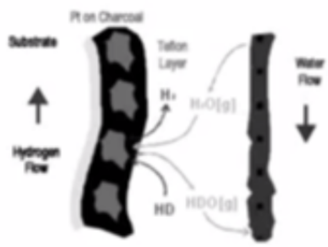
## Hydrogen Removal

- Here Passive Autocatalytic Recombiner (PAR) can be used. These simply offer a catalyst-coated surface to the containment atmosphere and as the air/steam/hydrogen mixture flows through, the hydrogen and oxygen are catalytically recombined .




An exothermic reaction occurs at the surface of the catalyst plates when hydrogen and oxygen are present in the atmosphere. The heat of the reaction, combined with the vertical arrangement and spacing of the catalyst plates promote natural convective flow through the recombiner. Warm humid air and un-reacted hydrogen are exhausted through the top grating.

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So this hydrogen should -- would be there in the containment and we know that hydrogen concentration in an area if it goes more than about 4 to 9%, it can catch fire. So one of the important things or which is safety should be regarding how to remove the hydrogen or to see how the hydrogen can be burnt ourselves so that it does not cause an explosion.

Now why this point is being talked about? You know both in the Three Mile Island reactor accident and the Fukushima accident, hydrogen was produced. Luckily for us in the Three Mile Island, the -- there was no explosion, but in the case of Fukushima, there was an hydrogen explosion. It was not a nuclear explosion, mind you, it was a hydrogen expression.

So people have done research and already lot of autocatalytic recombiners have been developed, and now since we want it to act without any other energy source, either electrical or mechanical, there has been a development of Passive Autocatalytic Recombiners. Let us see what these are.

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## Hydrogen Removal

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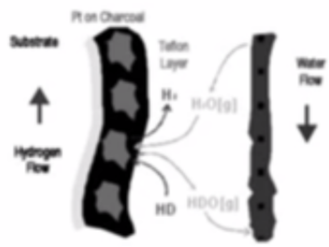


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Now this Passive Autocatalytic Recombiners are basically a means to see that the hydrogen comes in contact with the air so that the hydrogen and oxygen are recombined catalytically. What does this mean? An exothermic reaction occurs at the surface of the catalyst plates when hydrogen and oxygen are present in the atmosphere. The heat of the reaction, combined with the vertical arrangement and spacing of the catalyst promotes natural convective flow. I mentioned know if it is the horizontal there cannot be much. In a vertical way, there is a natural convection through the recombiner and warm humid air and the unreacted hydrogen are exhausted.

So this is a passive autocatalytic recombiner. Basically, it is platinum put on a charcoal substrate is there, and here the hydrogen is coming -- water and whatever water, it becomes water, it condenses down.

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- The PAR operates over a wide range of temperature and humidity levels, most notably at low temperatures and high humidity (condensing). The catalysts have high activity for hydrogen oxidation and are not deactivated by water vapour or steam and are specially formulated to operate over a wide range of temperatures. The catalysts have also been shown to be unaffected by high radiation doses or PWR molten-core aerosols.
- The PAR unit is installed in a mounting support, which is anchored to containment concrete or welded to structural steel. Supports for floor- and wall-mounting were seismically-qualified for use in a design basis earthquake.

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So this sort of passive hydrogen recombiners have been designed and they operate over a wide range of temperature and humidity levels, and they are very good for converting hydrogen to water, and they are not deactivated because of the flow of water or water vapor, and these developments have taken place in Canada and France, and today most of the reactors are provided with passive autocatalytic recombiners.

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- The PAR operates over a wide range of temperature and humidity levels, most notably at low temperatures and high humidity (condensing). The catalysts have high activity for hydrogen oxidation and are not deactivated by water vapour or steam and are specially formulated to operate over a wide range of temperatures. The catalysts have also been shown to be unaffected by high radiation doses or PWR molten-core aerosols.
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Now these recombiners will be mounted onto the concrete and so that -- and not only that, remember in case of a seismic condition, this should not fall down because that is the time when you can have a real accident. So in that condition, this should -- so they are also seismically qualified. So it is a passive system and also seismically qualified. So these are important aspects. If you just see in safety, we look for as absolute safety as possible even though absolute safety is not possible.

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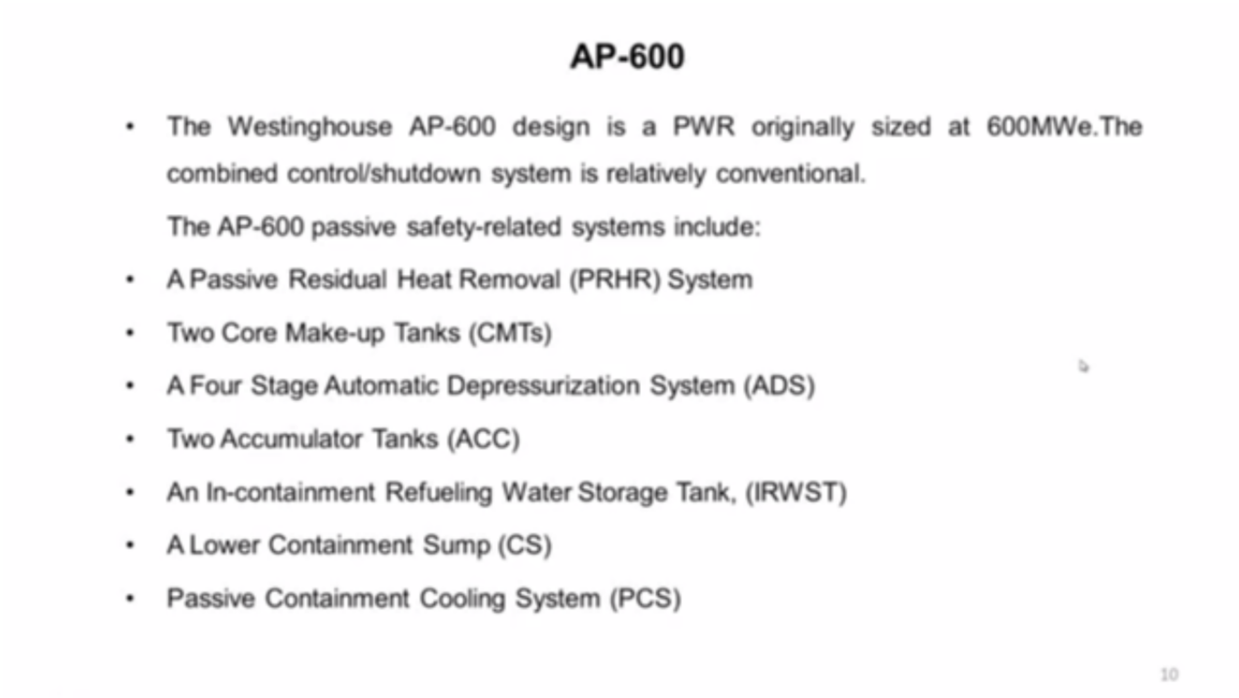


Now just to give you an example of reactor designs, which are already developed, there is the reactor called as AP-600. It is an advanced pressurized water reactor. The original design was 600 megawatt electrical. Now we do have a AP-1000 design also. In fact, AP-1000 design construction is going on for some plants in China.

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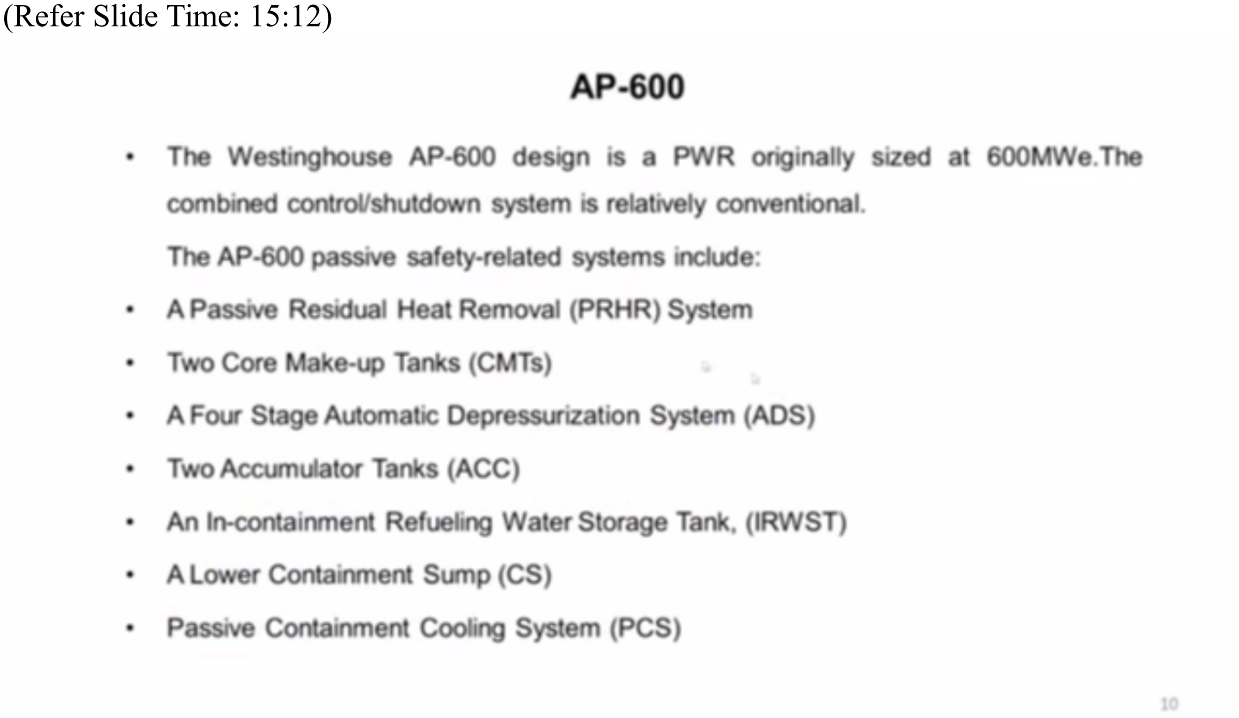


So what does this AP-600 passive related safety systems? Let us look at it. It has a passive residual heat removal system as I mentioned based on natural convection and cooling. I will give you the details later. It consists of two core make-up tanks that means it has two tanks, which can -- which have got enough water for cooling the core. Then a four-stage automatic depressurization system.

Suddenly, what is this depressurization system coming? You know these core tanks can put in water into the thing. They are at a low pressure. There is no force -- flow, so the pressures will be less. So that means you have to depressurize the system. Then only you can put water into the system. So that is why we talk about automatic depressurizing systems.

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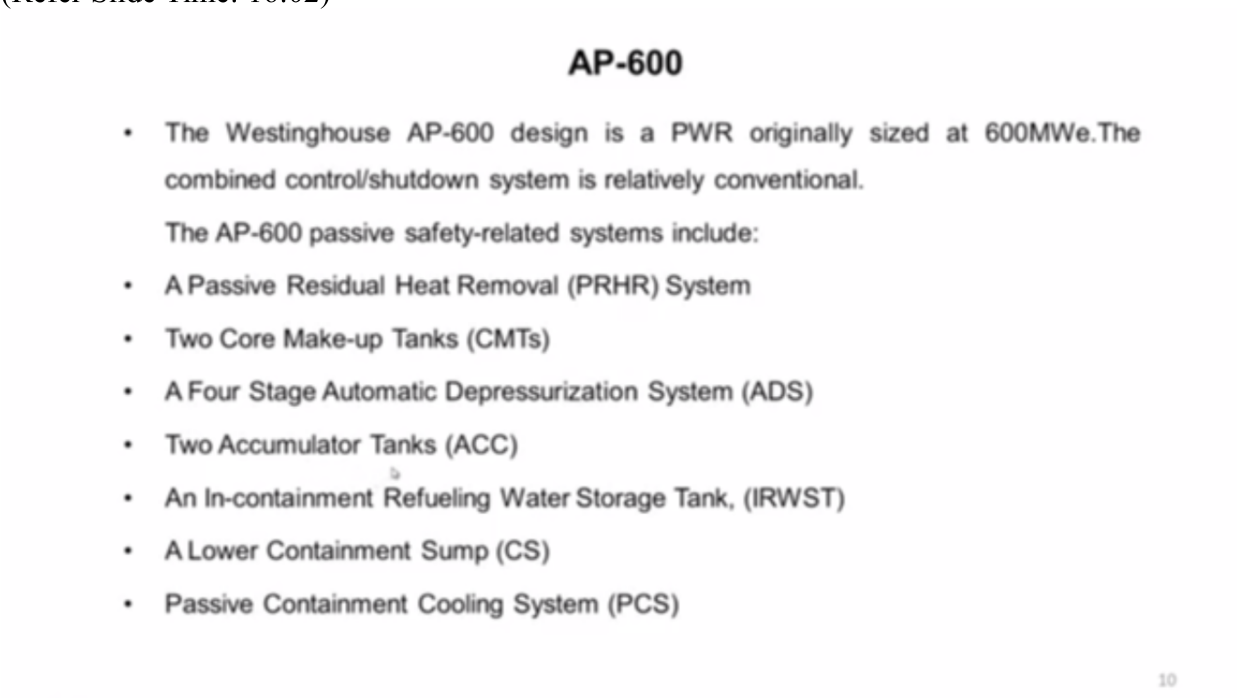


Then accumulator tanks so that you have enough water inventory. Then not only that, you see it contains a refueling water storage tank. This is a very important. You must note here, refueling water storage tank. That means this is essentially got to do with the spent fuel.

So the spent fuel as I mentioned to you produces some heat because of the fission product decay. So under the case of that case, the spent fuel cooling has to be continuous, even though the heat level is less, maybe, initially, about 5% of the full power, and then gradually coming down. Nevertheless, this has got to be cooled.

In fact, in the case of Fukushima accident, the spent fuel storage was not cooled. It did not get the enough cooling supply. That was also one more reason. So they have put in the loop the refueling water storage tank.

Then a sump, a lower containment sump so that the thing is getting collected and of course, not the least, the passive containment cooling system, which we saw some time back. Let us see what further.

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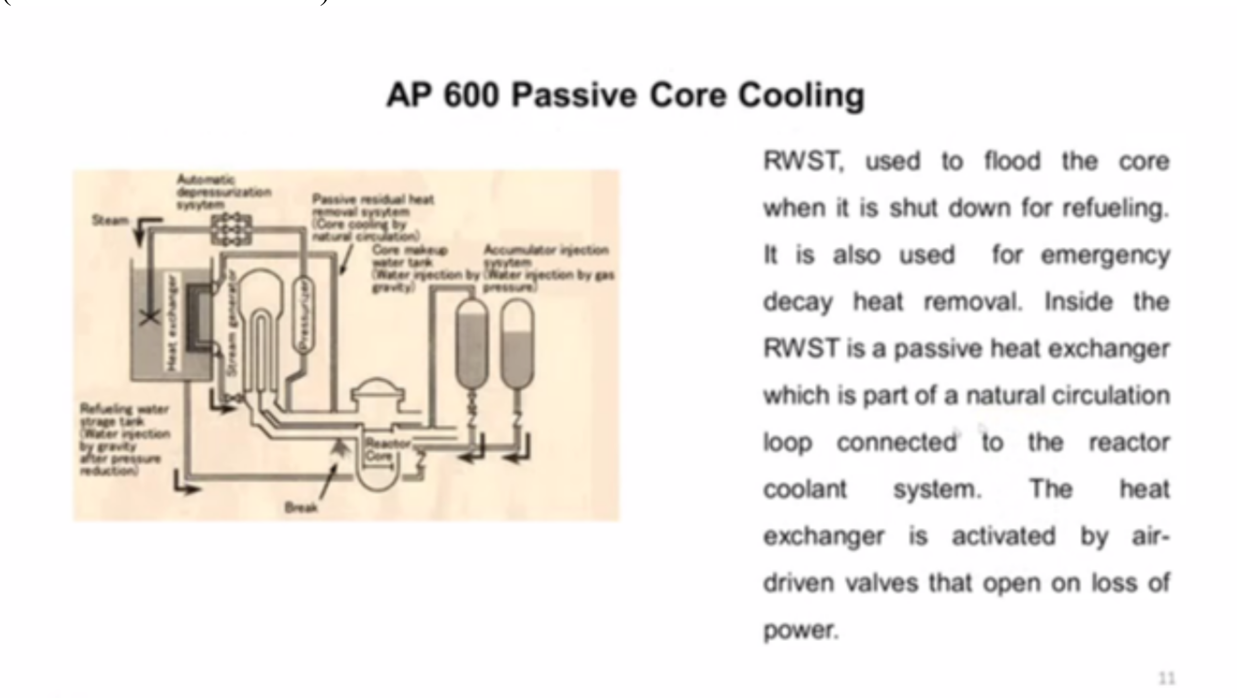


Here you see the figure of the AP-600 core cooling. So this is the refueling water storage tank, and this goes. Here you have the break. So this refilling water storage tank is normally used to flip the core when it is shutdown for refueling and it is also used for emergency decay heat removal.

So what is there? Inside this tank, you have a heat exchanger, and this heat exchanger is part of a natural convection loop like this, like this, then like this back. So this is one. This is the passive residual removal system and here you have got the depressurization systems to bring down the pressure. Besides these are the accumulators, which can supply water to the reactor core again to cool.

Now this heat exchanger needs to be activated. They are all activated -- that valves are there which are activated by air driven valves.

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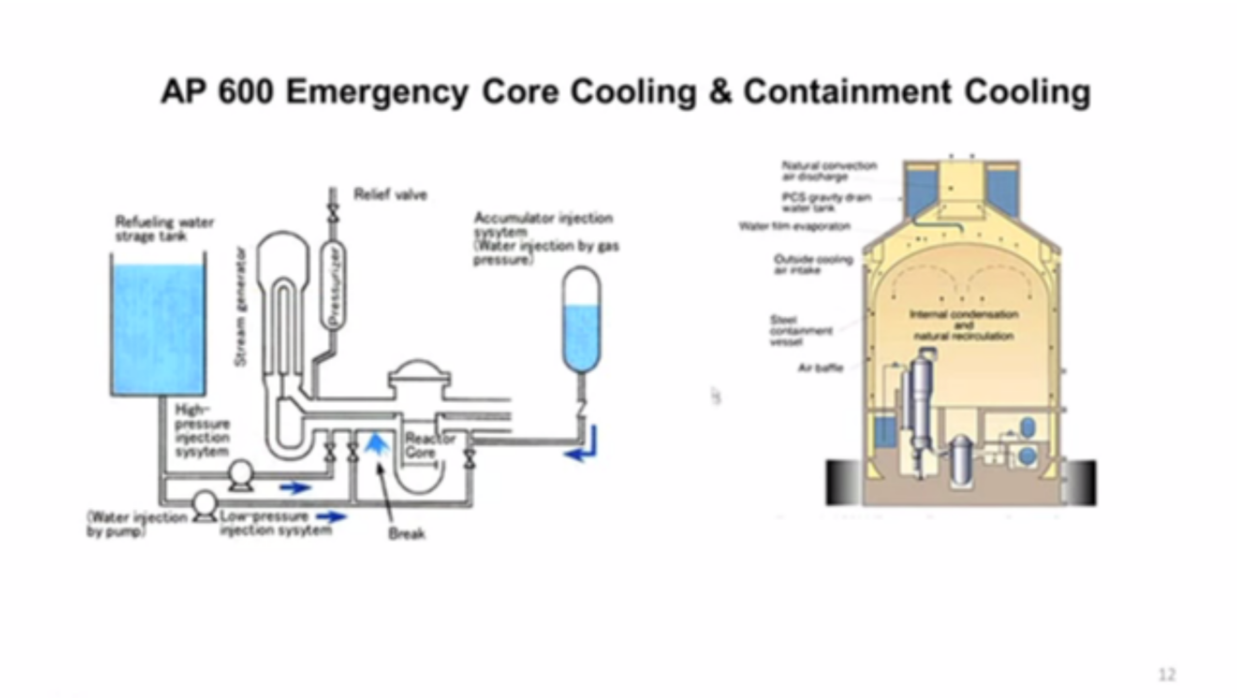


So this gives you a figure of the emergency core cooling as well as the containment cooling. This is the emergency core cooling, as we saw, it comes from the refueling water storage tank. There is a small low pressure injection pump, which pumps into the core. Then you have accumulator injection also. Here basically, what is happened? You have gas pressure. The moment the pressure in the reactor comes down as a consequence of reduction of pressure, this water also is able to enter. So this way emergency cooling is assured in the AP-600.

Coming to the containment cooling, exactly, what we saw about the Kudankulam, you have got a steel containment. The steam comes and this is getting cooled, and you have a gravity-driven water tank from where water is also falling on the containment. So this way the heat is getting removed.

I can tell you, you might wonder why this sort of a cooling, this sort of a cooling can help you to remove some of the decay heat, not a complete decay heat because the idea is this is actually to protect the containment. This cannot be the main path for decay heat removal. This is to basically protect the containment because if the containment integrity must not be lost at any stage because if the containment integrity is lost, then you can have the fission products coming out to the atmosphere. So, basically, this is to keep the temperature of the containment within limits.

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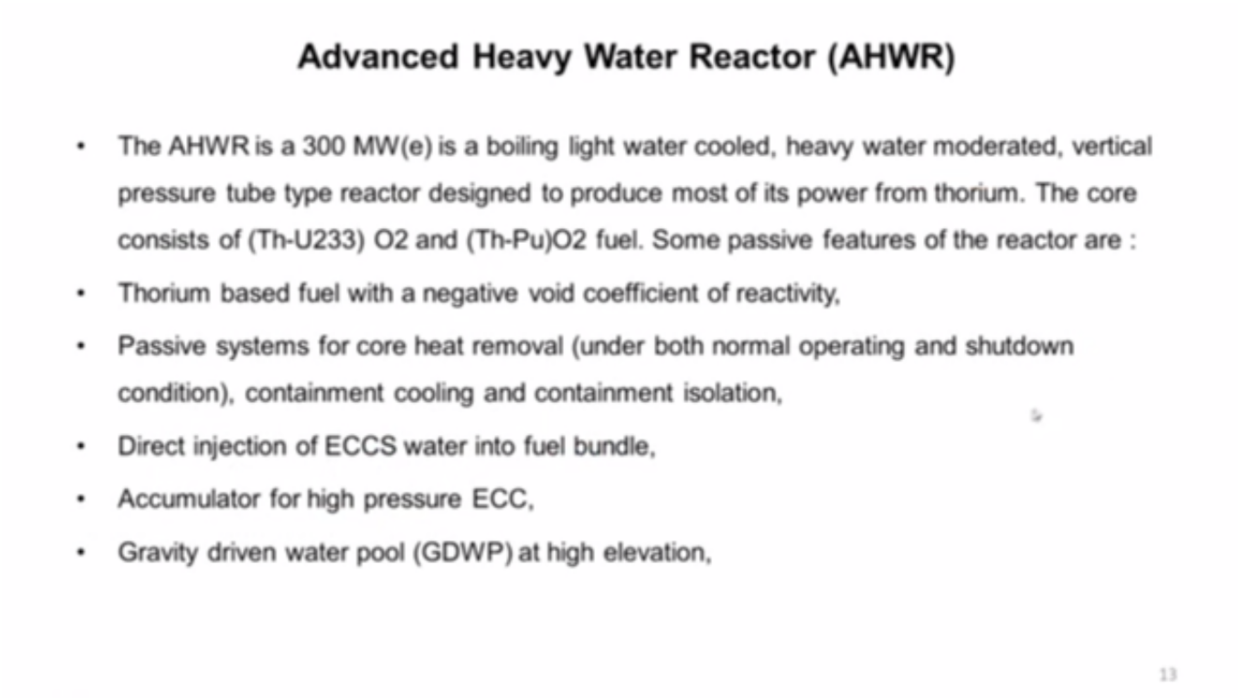


Yeah. Now having looked at some of the passive features of this AP-600, I would be failing in my duty if I don't give you some ideas about the advanced heavy water reactor, which we are developing in India, and it is quite gone quite a long way, and we should be able to have the start of the construction in a year or two, and this advanced heavy water reactor idea is we have tried to put as many passive safety features as possible. So that is the idea and we have taken the experience of the pressurized heavy water reactors.

So what it is? This advanced heavy water reactor is a 300 megawatt electrical is a boiling light water cooled and heavy water moderated vertical pressure tube type reactor. This vertical pressure tube unlike our all our PHWRs are horizontal pressure tubes. This is a vertical pressure tube and the core consists of Thorium, Uranium 233 in oxide form and also Thorium, Plutonium in oxide form. So, basically, we are using the Uranium-233 from -- which is obtained from the other reactors like the pressurized heavy water reactors and the Plutonium which are getting from the heavy water reactors as well as our fast reactors.

Now one of our main idea is how to use this advanced heavy water reactor with Thorium breeding with a self-sustained Thorium breeding. It is something like you put a fuel into a reactor and the Thorium. The thorium breeds generates fuel and it sustains. So that was our idea.

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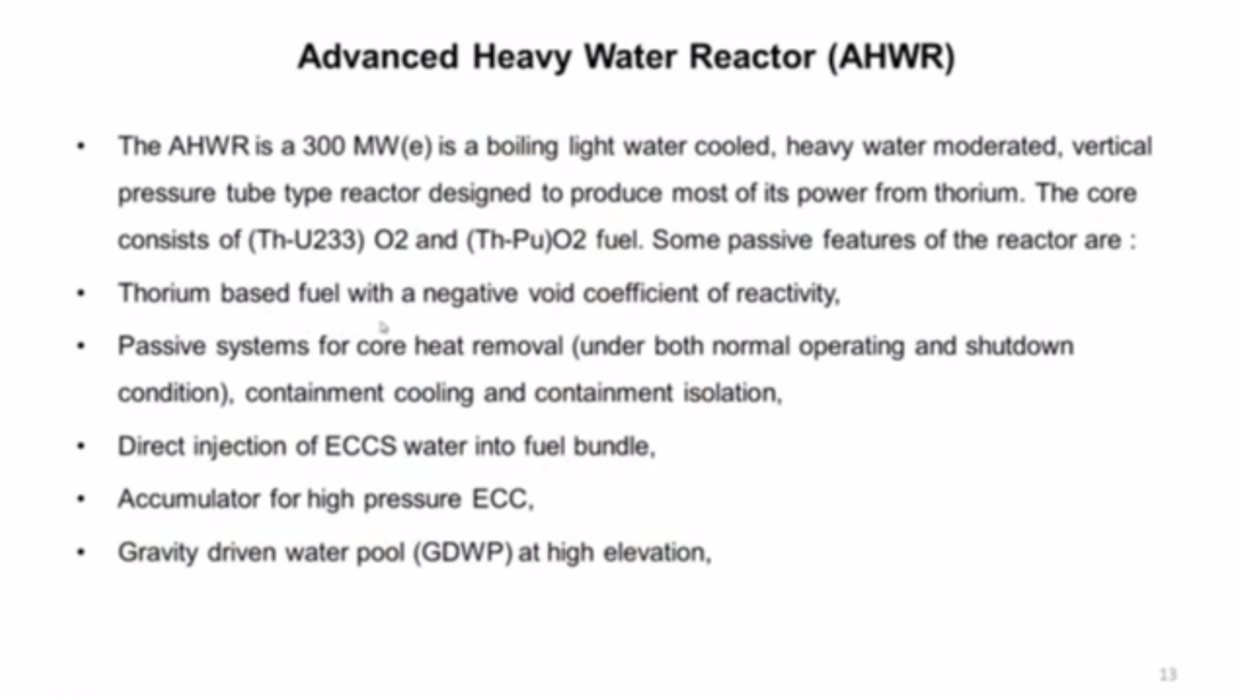


Now here the Thorium-based fuel is basically advantageous because it is a negative void coefficient of reactivity unlike Uranium. Then we also in this advanced heavy water reactor, we have passive systems for core heat removal, both under normal operating and shut down conditions. Just underline the words under normal operating.

So really speaking under normal operation itself, we don't have a pump. We have only natural convection. We set up the natural convection slowly and go up on power. Yes, the rising of power would be slow, but it is a passive.

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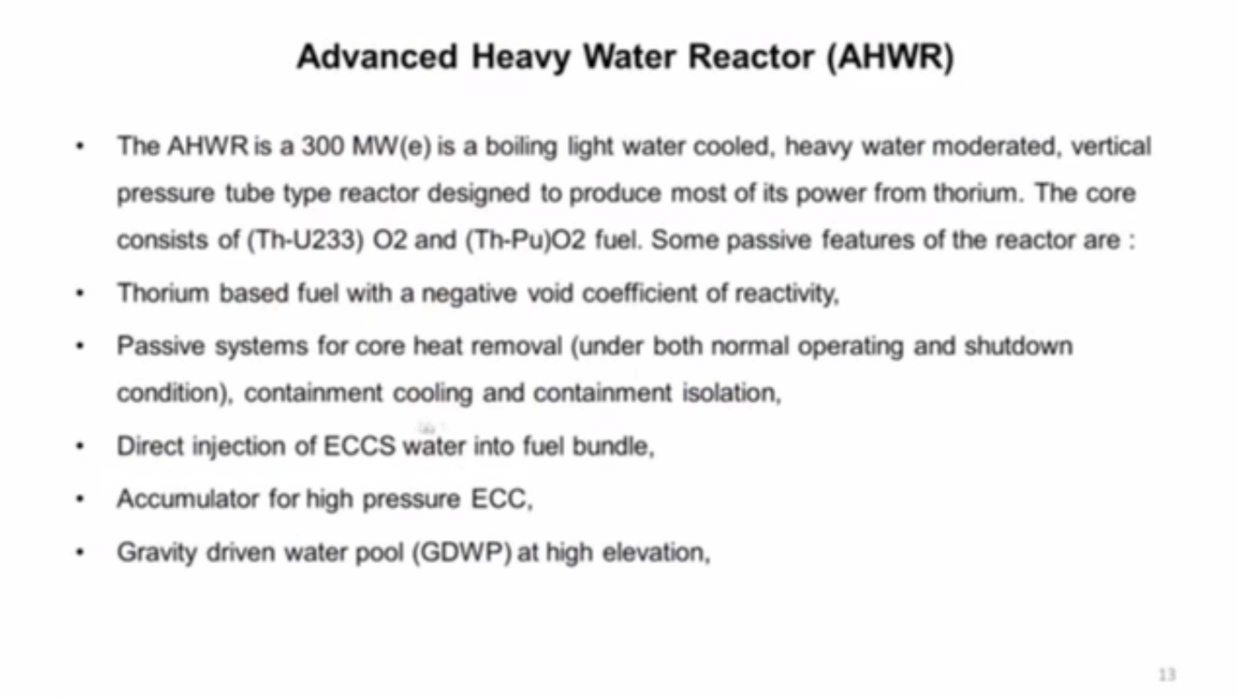


So it is one of the unique designs in the world, and it also has passive containment cooling and passive containment isolation. And what are the other features? Direct injection of emergency core cooling system water into the fuel bundle. Then we have an accumulator as we saw everywhere you needed accumulator for high pressure ECC. Then we have, again, a gravity-driven water pool at a high elevation because as I said then only the water will be able to flow inside.

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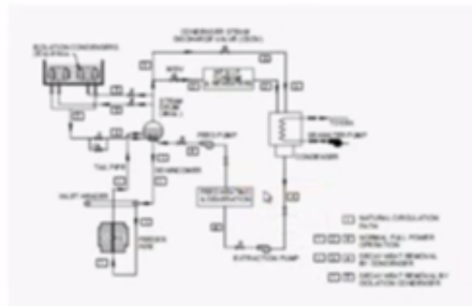
## AHWR Passive core cooling system

- In AHWR, natural circulation is used to remove heat from the reactor core under normal as well as shutdown conditions. The two-phase steam water mixture generated in the core flows through the tail pipes to the steam drum, where steam gets separated from water. The separated water mixes with the sub-cooled feed water and flows down the down-comers to the reactor inlet header. From the header it flows back to the core through inlet feeders.



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Let us look at how the AHWR passive core cooling works? As I mentioned natural circulation is used to remove heat from the reactor core under normal as well as shutdown conditions so that then from the reactor you get a two-phase steam mixture and it flows through pipes. Then it flows through the steam drum where it gets separated from water. The water comes through this down comer back into the inlet header and the steam goes to the turbine, and this is a bypass across the turbine in case turbine is not available and rest of the system is similar to a conventional or any other nuclear power plant.

So if you see here this is by natural -- that is the water getting heated, rising up, this itself is by natural circulation. So, basically, we will raise the heat in the core and by raising the control rods and slowly the power will rise. The power will rise. Then the temperature would rise. The flow would develop like that.

Now I can tell you this being a new feature, we have already set up lot of test loops to see how this process can be optimized. In the Indian Institute of Technology at Mumbai, we already had set up a 2 megawatt loop which has been in operation and has given lot of feedback for us in deciding how we will start up the reactor.

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- Larger density differences between hot and cold legs are possible to be achieved in two-phase flow systems compared to single-phase natural circulation flow systems. The absence of pumps not only reduces operating cost, but also eliminates all postulated transients and accidents involving failure of pumps and pump power supply. Steady state flow prevails in a natural circulation loop when the driving buoyancy force is balanced by the retarding frictional forces. However, the driving force in a natural circulation system is much lower compared to a forced circulation system. With a low driving force, measures are needed to reduce the frictional losses. The methods adopted to reduce frictional losses include, elimination of mechanical separators in the steam drum and the use of large diameter piping. The larger pipes increase the amount of coolant needed in the primary system.

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So as I mentioned, the large density difference between the hot leg, which is the core and the cold leg, which is the steam generator, they are all possible to be achieved in two-phase flow systems. Only thing is the why -- why not you go for a pump? The idea is if you have a pump, again, you must have a standby pump so that you can assure that it will be there. Not only that, you have a pump, then you have to consider all the events related to a pump trip, a pump seizure, and pump trips are one of the most important in case when you lose power. So it may be a power supply failure or any other failure. So you get rid of all these transients. So the absence of pumps not only reduces operating costs, but also eliminates all postulated transients.

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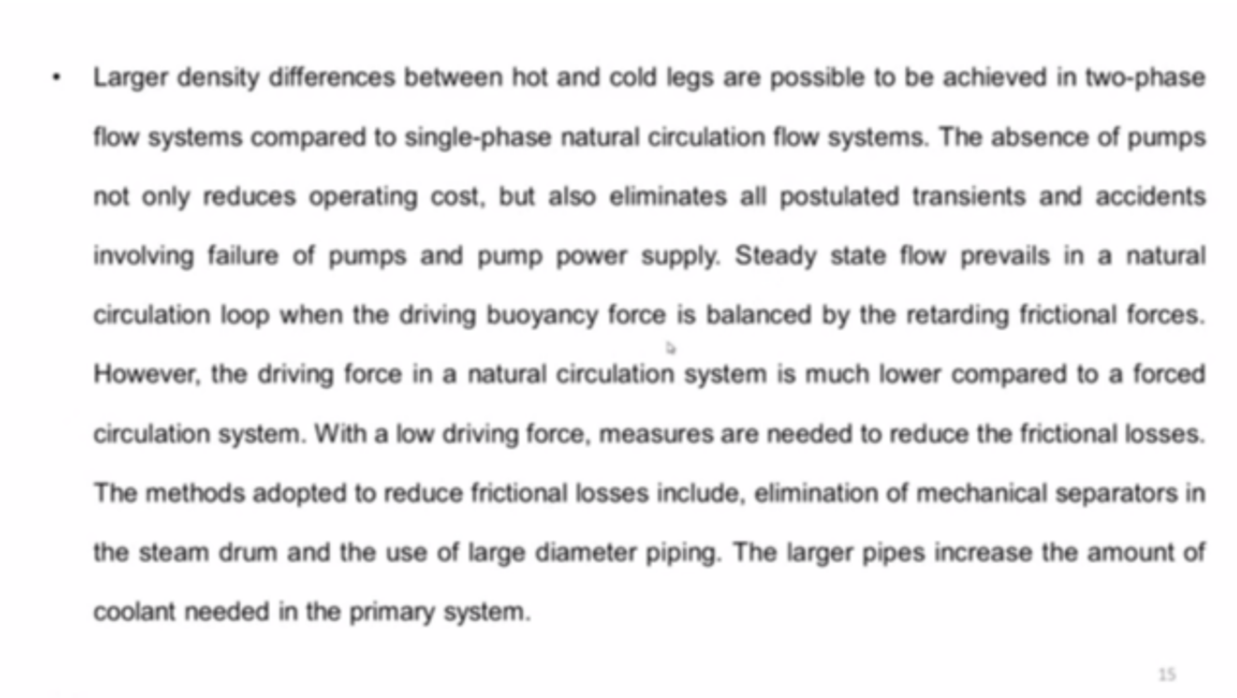

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And steady state flow will prevail in a natural circulation system. There is no difficulty as long as your buoyancy force is balanced by the retarding frictional forces. So it sets up. Yes, the natural circulation flow will be much lower. You require a large driving force. So one of the ways is how to minimize the frictional losses in the pipe. So we have to design the system in such a way that frictional losses must be minimized. So we use big diameter pipes. Larger the diameter, lesser is the friction pressure drop. We try to reduce the number of bends. We reduce the number of valves. Not only that, we also eliminate mechanical separators in the steam drum because mechanical separators, again, they have a pressure drop.

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Emergency core cooling system (ECCS) is designed to remove the core heat by passive means in case of a postulated loss of coolant accident (LOCA). In the event of rupture in the primary coolant pressure boundary, the cooling is initially achieved by a large flow of cold water from high pressure accumulators. Later, cooling of the core is achieved for three days by low pressure injection of cold water from gravity driven water pool (GDWP) located near the top of the reactor building.

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Now regarding the emergency core cooling system of the AHWR, in the event of a rupture of any pressure primary coolant boundary, so, initially, you have the water flow from the high-pressure accumulators. Then later this gravity-driven water pool will continue to cool the reactor for nearly three days. There's been a small low pressure injection pump, which can pump this water into the core. So this, of course, is the passive decay heat removal. Here you see already it is passive even under normal conditions. So it is also passive under the any case of a power failure condition.

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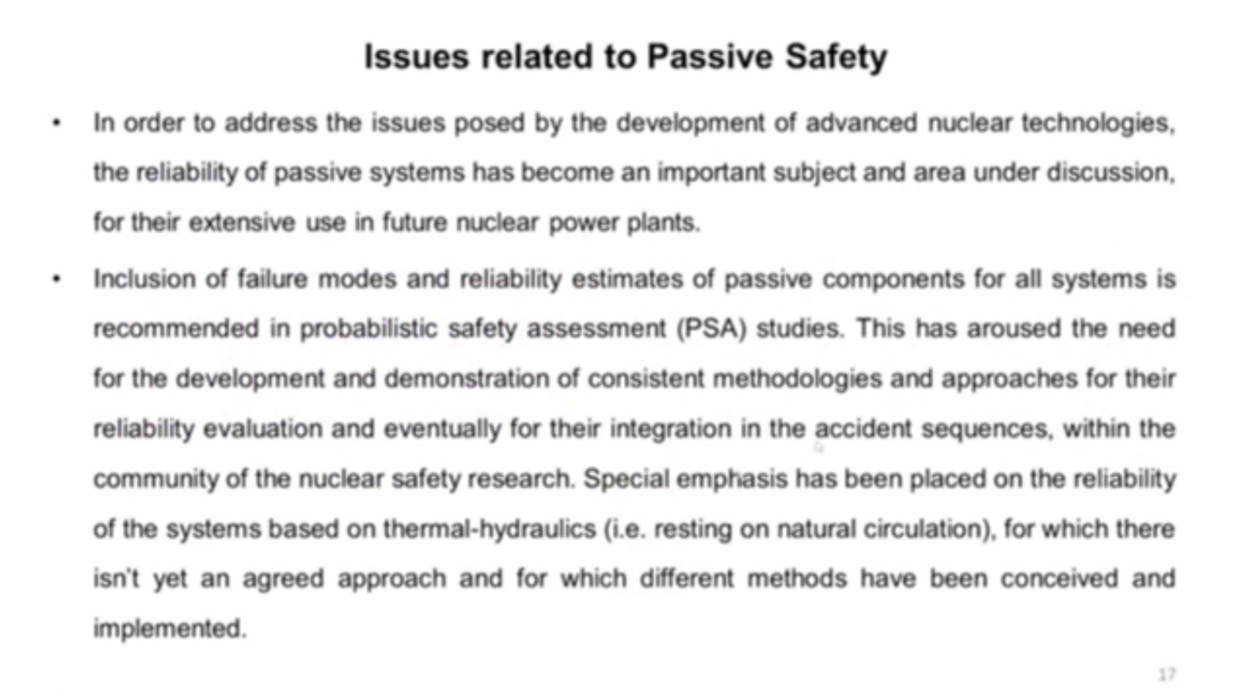


Having talked about passive safety, then why not all people build reactors which are passively safe so can -- you can say that okay, I have achieved the safety? But then there are some issues which are important to be resolved.

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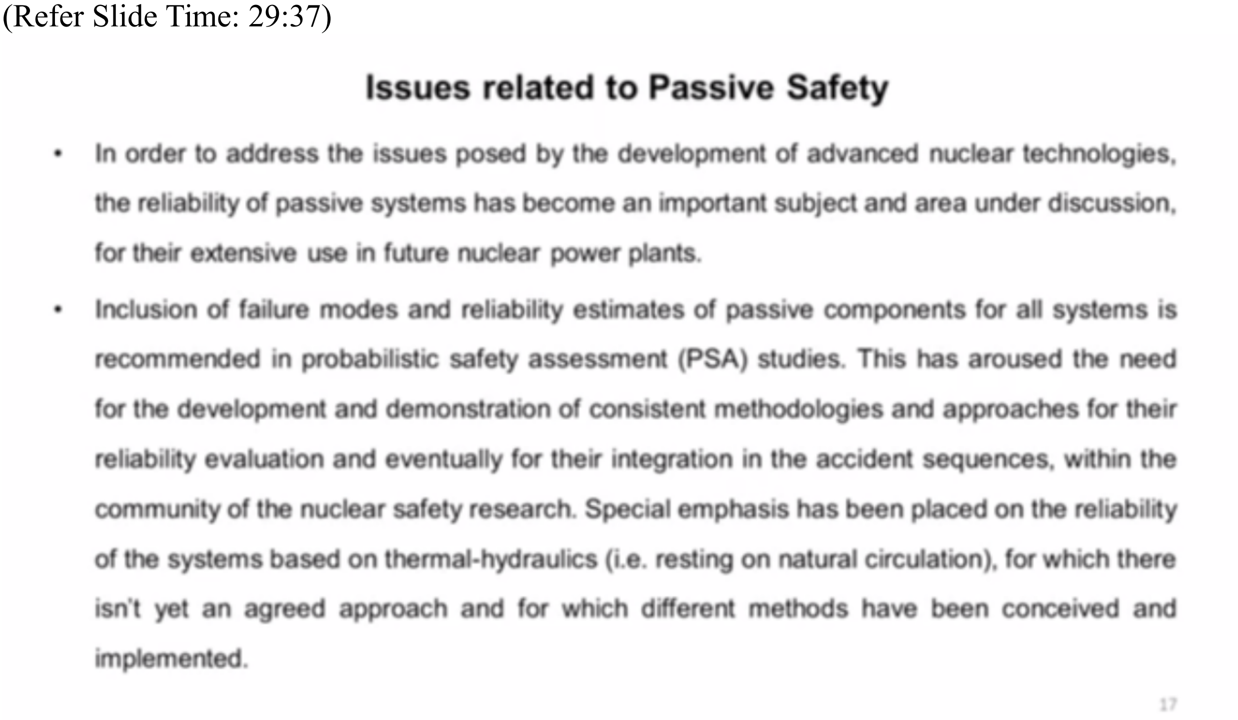


One and most important is how do you quantify the reliability of a passive system? Then how a passive system can fail? Very simplest example I can give you. Suppose I have a pump, which is running and going through the core. Water flow is going through the core. I have a standby pump. If I want to check whether the standby pump is going to operate, I just need to put it on and see whether flow is coming. That's all.

So I can monitor that system is a forced circulation, but I can -- I can monitor a forced circulation system, but if it is a natural circulation system, how do I monitor? Yes, you have the flows, but that flows will come in a system which is already in operation. A system which has to develop natural circulation, how do I do it?

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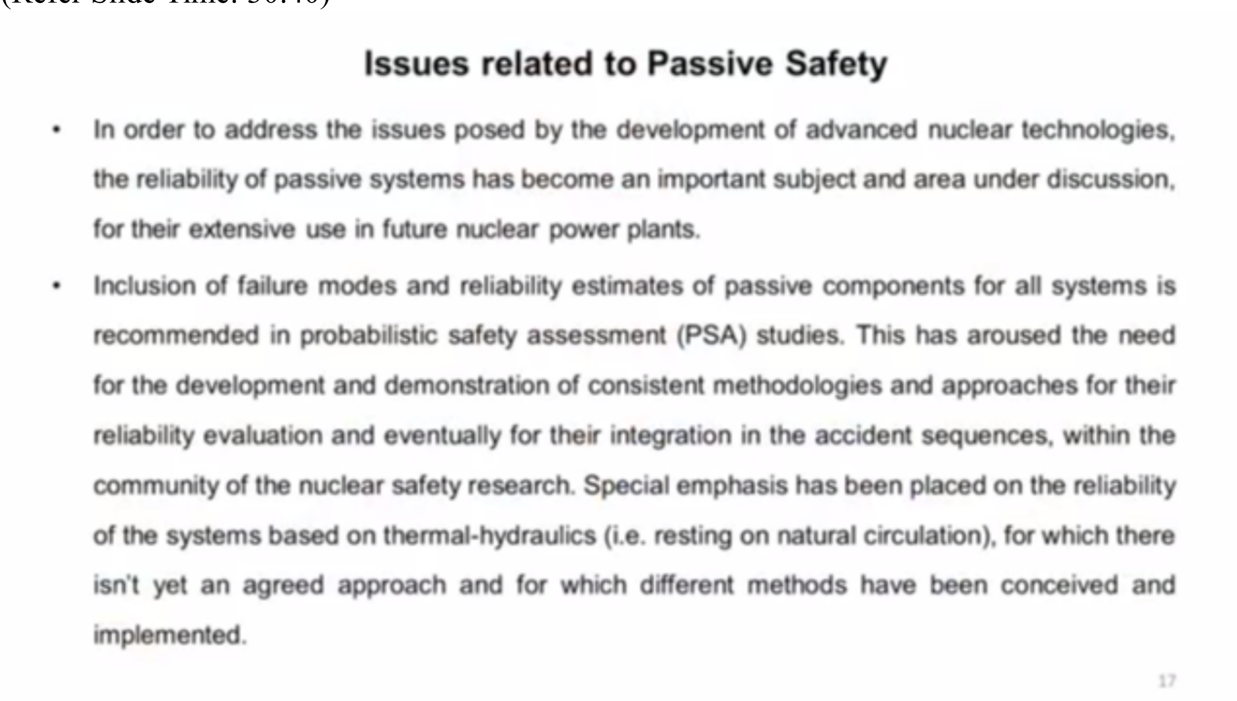


So one of the important issues is in what ways failure can be there and how to measure the reliability? So inclusion of failure modes and reliability estimates of passive components is one of the important things which has drawn attention and these are in progress. Today many methodologies have been evolved and consent is getting reached based on how we should make a probabilistic safety assessment of such passive systems, and most important is the natural circulation for which still there is not an agreed approach, but still it is in progress.

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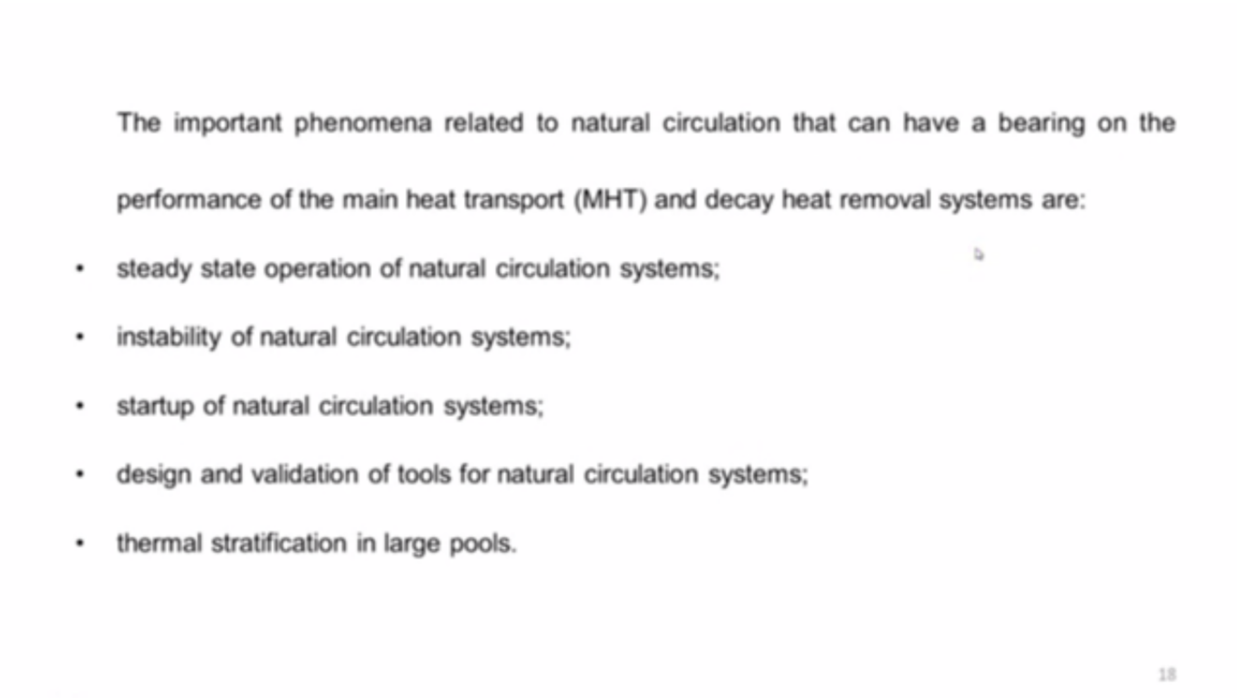


Then what are the important phenomena based on which natural circulation will happen? Yes, one is steady state operation of natural circulation systems. How they? suppose it is a single phase. Surely, you have no difficulty, but suppose it is a two-phase natural circulation. Then you have to think about what is called as the instability of natural circulation. Two-phase flow systems are prone to flow instabilities, so this is one area where enough attention needs to be given.

The other one is I talked about startup of natural circulation systems. As I talk to you about the advanced heavy water reactor where we want to start the reactor based on a natural circulation system. So it needs -- not -- it is not difficult. So only thing is it has to be given enough attention.

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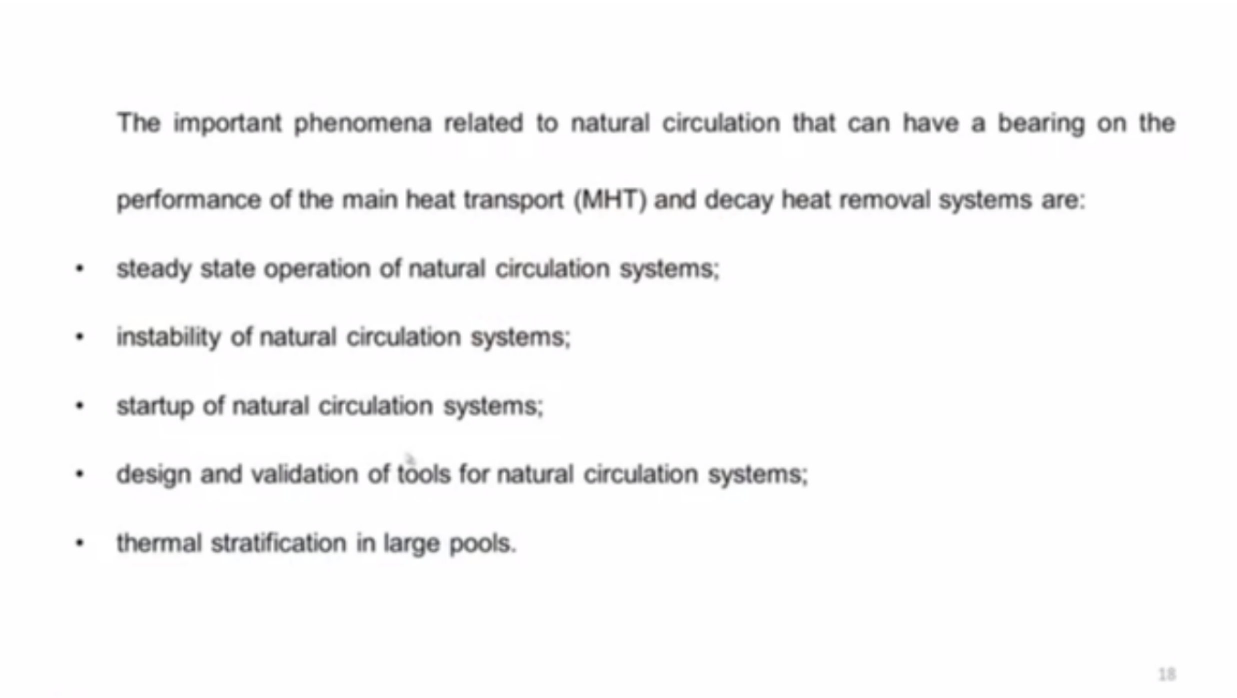


Then of course design and validation of computer codes, which you use for natural circulation systems. Believe here under natural circulation flow the velocities are low. So you must have enough data of friction factors and pressure drop correlations for such low flows, and when you have a low flow, you have, you know, when you have a pool, you have a thermal stratification. When a low flow, there won't be good mixing, and when there is no good mixing, the hot will be at the top and the cool will be at the bottom, so with stratification, and this itself can oppose your natural convection flow.

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- **Uncertainties**
- Since the magnitude of the natural forces, which drive the operation of passive systems, is relatively small, counter-forces (e.g. friction) can be of comparable magnitude and cannot be ignored as is generally the case with pumped systems. The relative uncertainties, mainly due to the lack of operational and experimental data address the deviations of the system performance from the expectation, mainly because of the onset of thermal-hydraulic phenomena that may defy the physical principle upon which the system is relying, so that the passive system may fail to meet the required function. The approach described in allows identifying the uncertainties pertaining to passive system operation in terms of critical parameters driving the modes of failure, as, for instance, the presence of non-condensable gas, thermal stratification and so on.

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Then what are the uncertainties? We talked about uncertainties. First and foremost, as I mentioned to you, the friction pressure drop. So in the case of a pump, you will have some margin. You can always have a increase the speed of the pump and then get a higher head and go ahead, but here it is not possible. So it should not happen that you design a reactor for 300 megawatt electrical and you are not able to reach the flow beyond 200 megawatt electrical. So lot of experimental data and experience is required to do this.

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- **Uncertainties**
- Since the magnitude of the natural forces, which drive the operation of passive systems, is relatively small, counter-forces (e.g. friction) can be of comparable magnitude and cannot be ignored as is generally the case with pumped systems. The relative uncertainties, mainly due to the lack of operational and experimental data address the deviations of the system performance from the expectation, mainly because of the onset of thermal-hydraulic phenomena that may defy the physical principle upon which the system is relying, so that the passive system may fail to meet the required function. The approach described in allows identifying the uncertainties pertaining to passive system operation in terms of critical parameters driving the modes of failure, as, for instance, the presence of non-condensable gas, thermal stratification and so on.

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So important is identify the uncertainties in terms of the critical parameters, the modes of failures, and how it happens in the presence of non-condensables. If air were there, non-condensables are there, the condensation process also will get affected. So how this and as I mentioned thermal stratification, so these add some sort of a -- I would not say that it is a fear. It needs attention. That's all because for everything you have to pay a price. For passive safety also, you need to pay a price.

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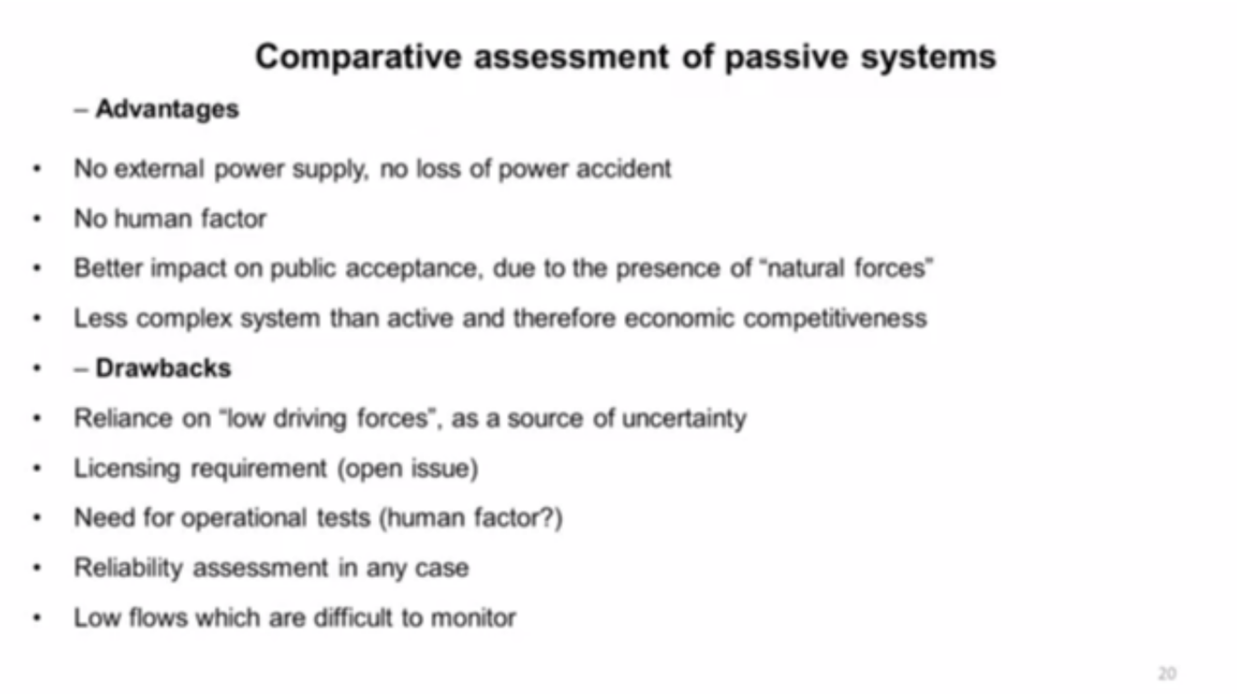


So in a comparative sense, let us look at the advantages and disadvantages or drawbacks of passive systems. Advantage, no external power supply, so no loss of power incident can be conceived because there is no external power supply, no human factor because it is based on natural laws, but as I mentioned there is a degree of human factor may be involved in case one has to actuate a button, better impact on public acceptance. The idea is that public would be able to accept such reactors with ease because you are dependent on the natural forces like gravity and buoyancy. So it is going to happen. Gravity is not going to fail you.

But then what are the drawbacks or the disadvantages? Low driving force, because the buoyancy forces are low. So it requires a very large height between the source and the sink. So more means it also increases your pressure drop. So you are relying on a system and just because you want to minimize pressure drop, you have large pipes. Then what about the licensing requirement? This is a very open issue. This needs a lot of -- so, in fact, you would be happy to note that at present our advanced heavy water reactor design is with the Atomic Energy Regulatory Board where they are going through the licensing aspects and how to license, this also will be a one of the issues which will be resolved.

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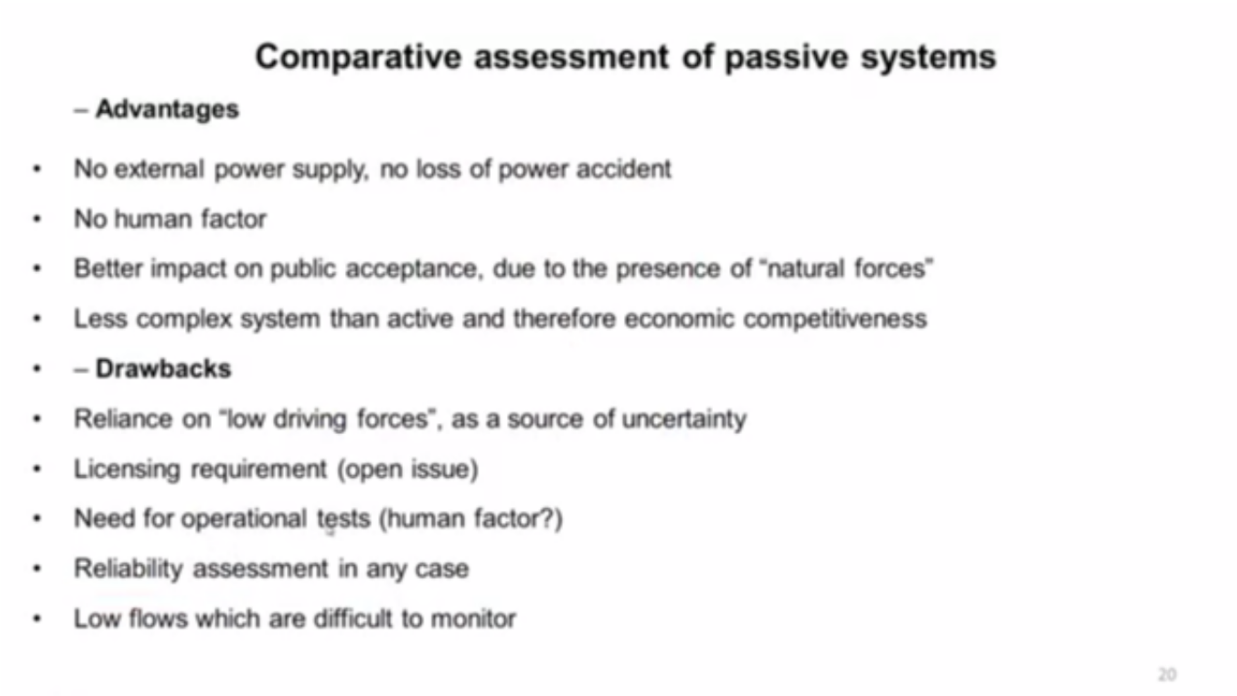


Then need for operational tests. Now testing of the system for operation as I mentioned monitoring, monitoring the thing, how we will be able to monitor? So here again, the person who's to monitor the systems and say that is working or not, here again a human factor is getting involved and of course, last but not the least, the reliability assessment. And as I mentioned earlier, the flows are so low, may not be difficult to, I mean, quite difficult to monitor sometimes because the flow is very much less.

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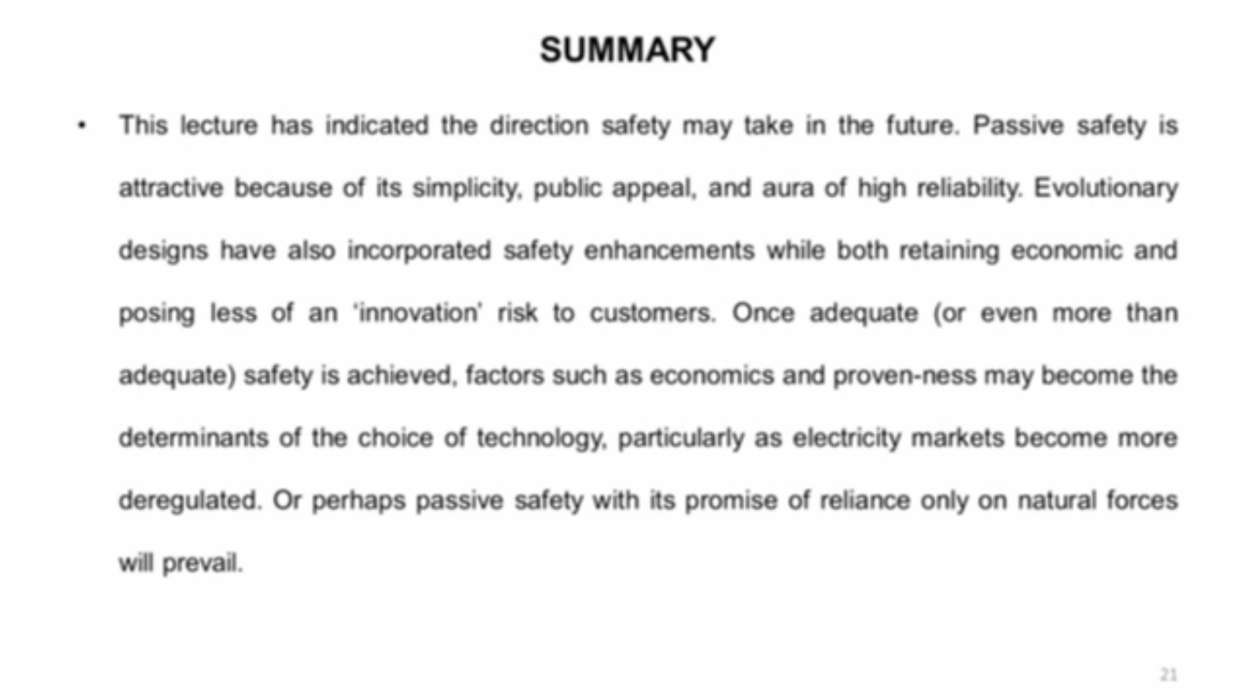


Yes, before summarizing, I would just compare the existing force systems or active systems to passive systems in a very simple way. Active systems I can say are known devils while passive systems are the unknown angels.

So in this lecture, last two lectures, let us see what we have covered. We covered the passive safety, what is passive safety, why it is attractive, basically, because of simplicity, public appeal and high reliability, but mind you reliability and passivity are not same. That is a major thing which I indicated in the beginning of my lecture. It is not necessary that the passive system is reliable. It needs to be made reliable.

Then many designs, evolutionary designs have been incorporated these enhancements. Of course, in -- while retaining the economic aspect, we talked about two reactors AP-600 in the USA and our reactor in India, the advanced heavy water reactor.

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## SUMMARY

- This lecture has indicated the direction safety may take in the future. Passive safety is attractive because of its simplicity, public appeal, and aura of high reliability. Evolutionary designs have also incorporated safety enhancements while both retaining economic and posing less of an 'innovation' risk to customers. Once adequate (or even more than adequate) safety is achieved, factors such as economics and proven-ness may become the determinants of the choice of technology, particularly as electricity markets become more deregulated. Or perhaps passive safety with its promise of reliance only on natural forces will prevail.

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So one is today it is not a proven technology, so it has to be proving the technology is going to be the major challenge and yes, if this challenge is met, it will be surely possible to have passively safe reactors in the next generation.

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## BIBLIOGRAPHY


- "Safety Related Terms for Advanced Nuclear Plants" IAEA-TECDOC-626, September 1991.
- IAEA, Passive Safety Systems and Natural Circulation in Water Cooled Nuclear Power Plants, IAEA-TECDOC-1624, Vienna, 2009.
- John C. Lee, Norman J. Mc Cormick, Risk and Safety Analysis of Nuclear Systems, John Wiley, 2011.
- T. Anderson, "An Overview of the AP-600 Design", American Nuclear Society Summer Conference, 1993.
- H.J. Bruschi, "Westinghouse AP600 - Executive Summary", Westinghouse Corporation, undated brochure.
- S. Raghupathy et.al, Innovative design Concepts and associated R&D for Future FBRs, IAEA Technical Meeting, Vienna, Feb 29-Mar 02, 2012.
- R.K.Sinha, A.Kakodkar, Design and Development of the AHWR-the Indian thorium fuelled innovative nuclear reactor, Nuc. Engg. Design236 (2006), 683-700.


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As usual, I have put here a bibliography for some of the systems. This is an IAEA, Passive Safety Systems and Natural Circulation in Water Cooled Nuclear Reactors is a very good document for understanding how the different developments are going on. This is the first one is the safety related terms, which I had explained to you in the first lecture. This gives you an overview of the AP-600 design, and we do have what innovative design concepts we are going to use for the future fast breeder reactors because we have two types of reactors in India. The pressurized heavy water reactor and the advanced heavy water reactors. So this paper deals with the passive safety of future fast breeder reactors and this with the advanced heavy water reactors. It is a very good paper.

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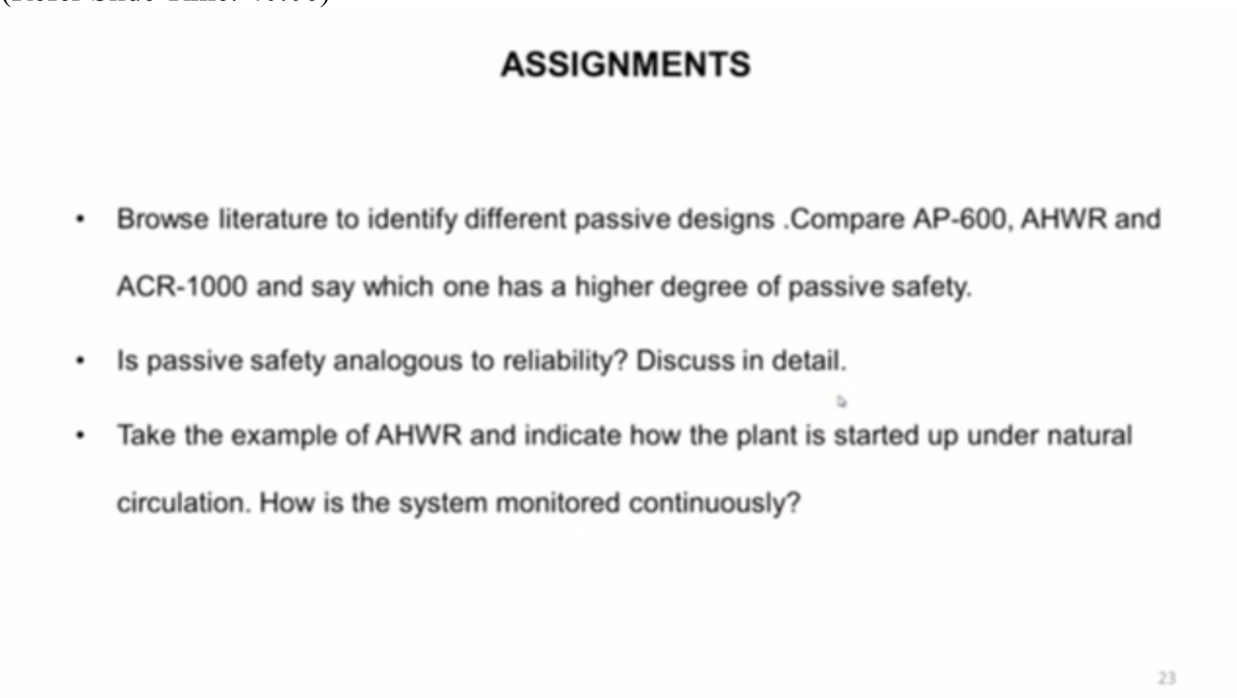


This is a small assignment for you to see whether you have understood and you may really probe this further. Thank you.

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