INDIAN INSTITUTE OF TECHNOLOGY MADRAS.

Indian Institute of Technology Madras
NPTEL
National Programme on Technology Enhanced Learning

NUCLEAR REACTOR AND SAFETY
AN INTRODUCTORY COURSE

Module 11 Lecture 02
Engineered safety Systems cont…

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Good afternoon today in this lecture. I will continue with my talk on the engineer safety systems maybe just to start the lecture in a lighter mood in the lunchtime one of my old friends was a call me and we phoned me after a very long time and he said where are you staying, I said such and such a place I am staying in such an apartment then he said which floor I said the first floor then he said we first floor you could have triggered the top floor anywhere lift must be there I said see we have two lifts but I just looked at an event in which power failure is there and both the lifts do not work it is a common mode failure.

So then how we like climb so he loved he said now I understand your background oh you are a nuclear safety person so that is how everyday life we look everywhere will this fail if this fails what we should do so we always think before so that is the thing any continuing further.

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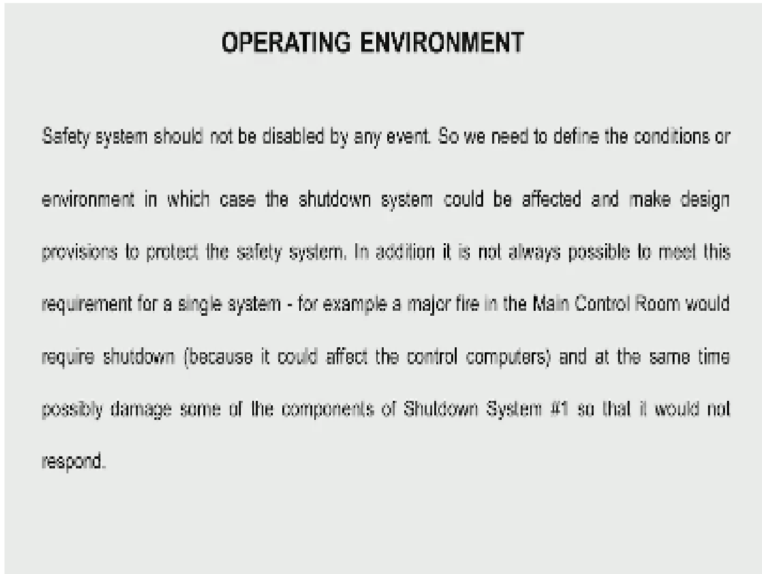

We have seen that the Sharon system the measurement channels the sensor so everything we put them in the different places then the environment in which they operate or is surrounding in which they operate it should not get affected due to any event that means if a signal has come from the sensor going to the logic then from there to the controller. I system and the controllers everywhere no event happening in the environment should affect that then only it can be safe for example let us take there is a fire in the control room so you cannot reach inside and it could you will not be able to shut down.

The reactor at the same time and maybe if some wires had got burned it would not respond so it is very much essential that the independence of that to surround systems right from sensor to the shuttle system they have to be layout should be such that they are independent.

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- The shutdown systems in PHWR act mostly within the moderator, which protects them from some of the effects of accidents. Shutdown system cables and instruments are separated to the extent practical so that a local fire will not wipe out both shutdown systems. This is an example of where absolute protection is not possible - one can only separate cables so far, and a large fire in an area could disable a shutdown system. The approach then is to ensure that it cannot disable both shutdown systems, which is done by placing them in widely separated areas (90^0 to 180^0 separation) of the plant. The shaking due to an earthquake must not prevent the shutdown system from actuating nor slow it down.

Now you take the shuttle systems of a PHWR we saw that the control rods are there in the moderator within the moderator also your poison injection system is also in the moderator of course we do not presume afire but suppose there was fire in one and our near the control rods we do not want the poison injection system to be affected so we try to separate it we put it about 180 degrees away if this is on this side or 90 degrees we put the poison injection from this side to that extent.

We can do there so even when you engineer the system sometimes it is not possible you can have a barrier fire barrier such that the fire does not go but complete independence may not be possible but our endeavor would be to have maximum independence, so in short what I can tell, that there is need to keep the different systems as much of a possible so that any on one system could not affect the other system but still there is a chance that it will not be totally independent but our endeavor is we should make it you take an earthquake of course it will affect both the systems but we have to see that it is designed for you know that you have quick all the mechanical components are designed.

So they do not vibrate and even under that what you call earthquake the control rods are able to go.

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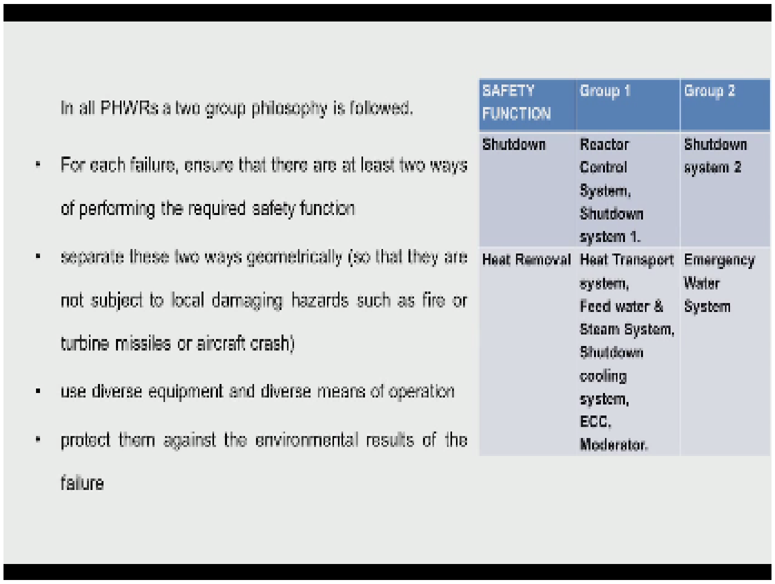

In the pressure is a water reactors we follow this two group philosophy that is for each failure first is there are two ways of performing a required function then separate them geometrically we follow a two-group philosophy in the case of Pacific pressurized water reactors we said two ways of performing a required safety function like detection then trip signal all should be two divers and they are geometrically, so that any fire hazard or a turbine music or anything does not affect and we use diversity in the equipment's so that and they are real diversity for example, I have a motor two pumps one pump would be manufactured by one company other prompt.

You might be another company so like that we try to build in as much of diversity into the system design so that I am assured that everything will not form here let us look at the safety function of Shutdown then it is a reactor control system which will be the control rods adjuster rods then in case then shutdown system one these are all grouped into one group this shutdown system 2 is the other group that means there is a independence between this group 1 and group 2 then heat removal while heat transport system the feed water the steam system the shutdown cooling systems emergency core cooling moderator anyway they cannot be really independent they are all in one group the emergency water system.

Which we can take out from the water which I will talk to you later is other independent system so this to group philosophy is what is followed in our pressurized heavy water reactors.

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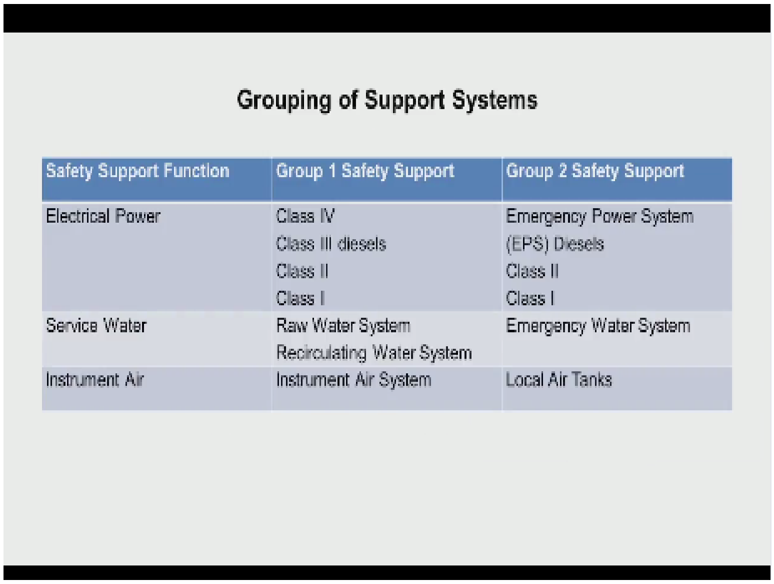

Safety Support Function	Group 1 Safety Support	Group 2 Safety Support
Electrical Power	Class IV Class III diesels Class II Class I	Emergency Power System (EPS) Diesels Class II Class I
Service Water	Raw Water System Recirculating Water System	Emergency Water System
Instrument Air	Instrument Air System	Local Air Tanks

Now we talked about the main systems so we also group the support systems what are the support systems you have electrical systems you have water service water systems which can use for cooling the different equipments or you could have some air conditioning ventilation instrument tab for the operation of the valves which would instrument air means it is not a normal error it is air which is devoid of moisture. So that the instruments do not get bad so quality of the air is good so all these systems are the support systems here also we categorize them into two groups and they are independent the class four power supply means the off-site.

The class three diesel's then the class to battery and of course the class one total this actually we called a UPS system and these are dedicated battery systems they are all in both the groups they are given they are separate they are independent similarly in the water systems we have the raw water system and there circulating water system in one group emergency water system which we saw is the other group then we have instrumentation air system as a whole which is normally in operation is a group 1 and local air tanks are the other one so this way the grouping is there for the other system also.

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HEAT REMOVAL

- The normal path of heat removal would be through the steam generators and steam water system.
- In case of a turbine trip, the steam water system becomes unavailable. Under such conditions the steam is discharged through Main Steam Safety Valves (MSSVs) on the steam header to the atmosphere.
- Dumping of 60% steam directly from steam generators to condenser is used for poison prevention - that is, if the turbine trips on a transient, instead of shutting the reactor down, the reactor power set back to the level just sufficient to prevent a poison-out due to xenon buildup. Steam is dumped directly to the condenser, bypassing the turbine.

Now let us come to the heat removal as mentioned shut down next cool heat removal what is the normal path of heat removal it is from the core to the steam generator and it runs the turbine mind you the all the energy which goes to the steam is not used in running the turbine that is why we call it the efficiency of the plant. If suppose in a pressure high water reactor my heat energy is something like 675 megawatt thermal I finally get about 220 to 230 megawatt electrical so what is there is this residual heat that heat is what whatever steam comes out of the turbine has still that heat and that heat needs to be removed and that is why we need a condensate cooling water system.

Which we have been talking about in the earlier lectures we take water from a river or a sea we cool the condenser this is true of any nuclear thermal power plant or a nuclear power plant where steam turbines are used now so that is a normal route by which the heat would be removed but suppose let us say that are buying a stripped so with the turbine stripped then what to do then we have the safety valves on the stream headers which will blow out the steam and to the atmosphere and as goes out what water will continue to enter and remove the heat from the steam generator of course when the turbine is stripped we will surely trip the reactor there is one more feature.

Which is available that we have a line which by passes the turbine and directly goes to the condenser this line is normally closed but in case there is a turbine trip immediately that bypass line opensand all the steam and we have a power set back to 60% and that steam goes to the condenser and anyway cooling water pump is operating only the turbine is trip now the power is there electrical power is there is cooling water pumps are running and it is removing the heat, the reason for this is very simple.

In case there is a trip because of some grid disturbance your turbine. I stripped let us say frequency trip or there is a voltage surge it has tripped nothing has happened in the plant and we can again come back to power fast but suppose. I trip the reactor my power has come down now xenon build-up starts and we saw will the xenon build-up starts after shutdown until eight again comes back we cannot start the reactor because there is a lot of negative reactivity.

In the system so we do not want that delay to happen in restarting the system for a minor fault so what we do we bypass the content by pass the turbine and send it to the condenser and in case it is a minor problem. We again load the turbine and come back otherwise we shut down the reactor then.

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- If for some reason the main feedwater pumps are not available, one or more auxiliary feedwater pumps powered by Class III electrical power (generated by station diesels), or directly by a diesel engine can remove decay heat.
- In some designs, the dousing tank located in the top portion of the containment can supply a longer-term source of water by gravity to the steam generators. Since it is a low-pressure source of water, the steam generators must be depressurized before it is brought in.
- Most recent reactors have a seismically qualified source of water (e.g. a large pond) for use after an earthquake. This Emergency Water System (EWS) has its own seismically qualified power and pumps, and can supply water independently to the steam generators for about 3 days.

Let us say our main feed water pumps are not available due to some cause then we have auxiliary boiler feed pumps or which we call which is a auxiliary they are not the same size as the main pumps they are smaller pumps and they would be running on diesels, which is there is a there is a station diesel generator which powers this and again there in the station diesel generator also we have redundancy we have if I require one diesel is sufficient. I would provide two sometimes we provide 200% diesels or 450% results all these are all you know engineering the system considering economics.

And availability and in some cases we have diesel engine driven diesel engine driven pumps which can remove the decay heat we normally use such things for the fire water safety pumps because in case of a fire do not use it could happen that the wires can get burnt so we have a diesel driven pump in many of the designs we also have yet dowsing tank. Which is located in the top portion of the containment means within the containment and it can supply a good amount of water flow by gravity flow to the steam generators and remove the decay heat but mind.

You the pressure are low whereas the steam generated pressure operation pressure is high in case of a pressurized hey what reactor it is of the order of 45 to 50 bars. So what I have to do if I feel that I have to use the water from the dowsing tank. I need to reduce the pressure depressurize the steam generator to a low pressure so that water can enter of core most of the plants built in the last decade or so we have separate source of water a large pond which is even designed to withstand a civic condition so that it can give water under the worst circumstances and we have called this as the emergency water system and it has got its own pumps.

Which are again seeing speaker to qualified these compounds can operate even and receives my condition and supply water independently that is what we called as the EWS system and time duration is something like three days.

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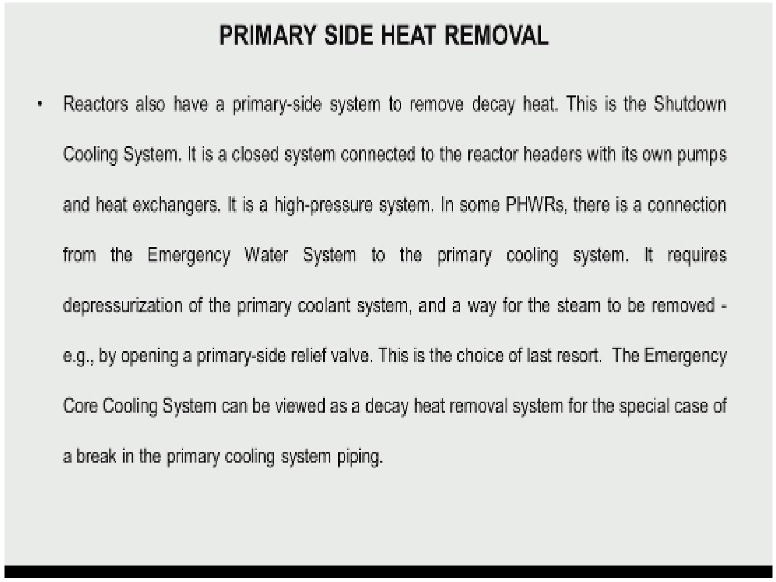

Now till now we have been talking about the decay heat removal on the secondary side of a ph w our waterside. But now let us come to the primary side that is a heavy water-cooling we have a showdown cooling system so that even when the reactor is around we have a closed system and this system is a separate system which it is own pumps and heat exchangers heat exchangers would be cooled by anyway service water and this would remove that heat directly from the primary. We do have an arson ultimate safety here link with the emergency water system which.

I mentioned just in the last slide so that should it require in case of an emergency. I can link this emergency cooling water system to that of course emergency core cooling is also there for the primary sodium supplier the primary heat transport system that would normally come in picture but this one the emergency water system is like a last result.

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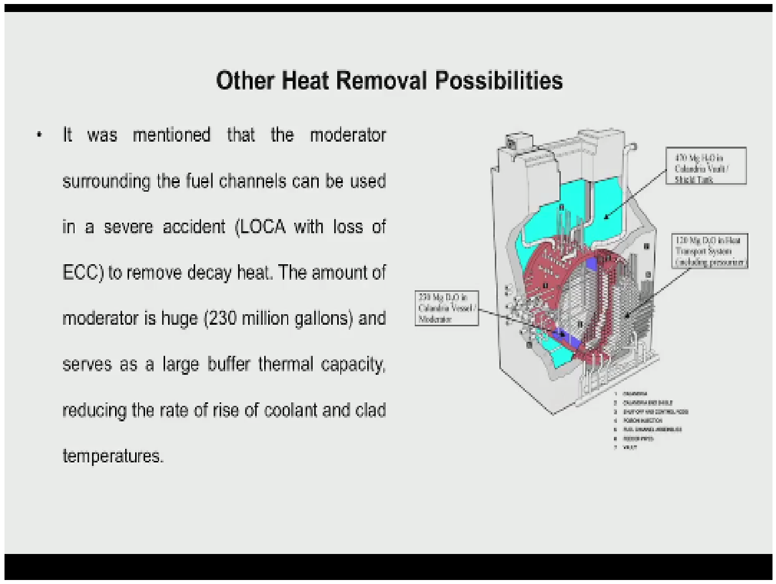

Then are there any other ways other than this these are the main things by which the heat is removed.I mentioned to you that the whole contains moderator which is independent of the equivalent the coolant water goes through the channels comes out goes to the steam generation comes back but this moderator which surrounds the tubes is there so this vessel in a 600 megawatt plant has something like 230 million gallons of heavy water similarly you have in the heat transport system something like 120 million gallons and you have a shield cooling tank.

They are also light water is there which is about470 million gallons so all these are buffers, so what this buffers help you they will take the heat there by the temperature rate of rice will be lower so thermal capacity so these are able to take the heat thereby they give you a good time by which you could act and save the situation this cannot this is not the main these are only like added advantages.

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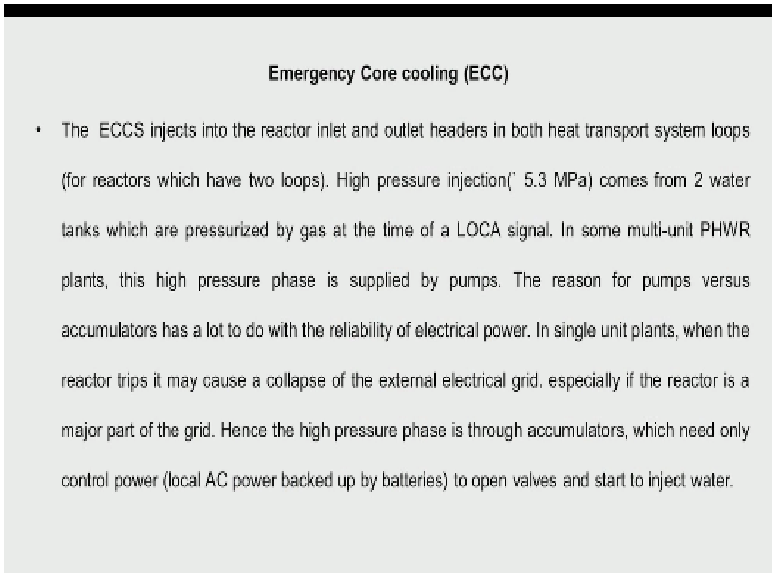

Now we will go to the emergency core cooling now this emergency core cooling system when it will come that means there is a large loss of coolant in let us say there is a break in the inlet header or there is a break in the reactor outlet header and the coolant hey water is flowing out so if it is flowing out it is not coming back to the system what to do so we need to push in the emergency core cooling system what happens it should come on automatically. So what happens we have the pressure comes down normally the pressure should be of the order of about nine mega Pascal eight to nine mega Pascal’s when it comes down to about5.3 mega Pascal’s.

The section of the high pressure emergency cooling starts and generally when you have a multi-unit heavy water reactors you can always get supply from somewhere and you can always give the supply to the pumps in the other ones now the idea is if you have a single unit then it is difficult so in case of a single unit you go for tanks or accumulators which are pressurized so that it can feed the reactor with the heavy water so that the cooling of this reactor core is ensure now these opening the valves and other actions they are all normally done based on AC power.

This is backed up by the batteries that are you have an inverter which makes the DC voltage of the battery to AC and operates these valves.

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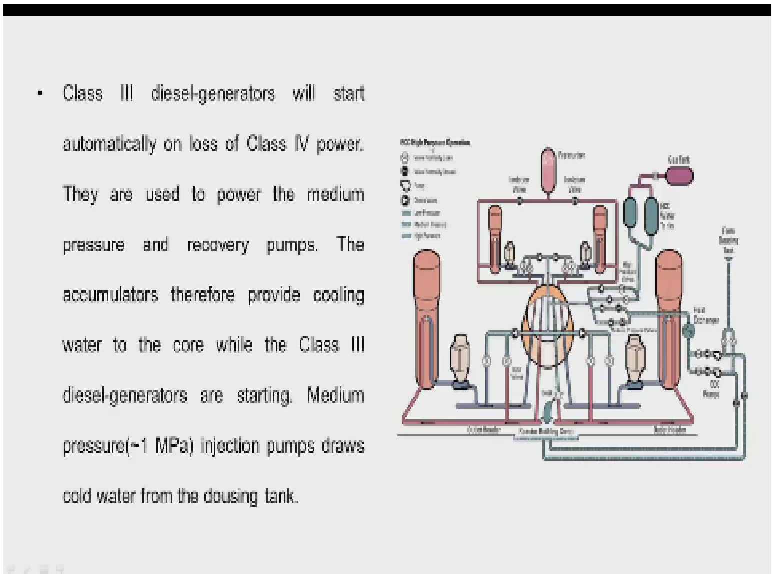

Now once the power is not there the class 3 diesel generators will start so class four powers as I mentioned is the grid power and class 3 is the diesel generator power so these are used to power the medium pressure pumps and recovery pumps. I mentioned you high-pressure injection like that one the pressure falls see you cannot use a pump under any pressure every pump has got your limit called as nominal.

I am sorry net positive suction head there is a requirement of that head at the section of the pump should that go down which the pressure comes down that will go down below that it will activate that is it will flash from water to steam at that temperature and then it will flash, so it cannot operate under all conditions. So we have a high-pressure injection. Then a medium pressure and last one called is a low pressure or recovery phase the medium pressure injections will take over at something like 1 mega Pascal's we taught that high-pressure injection takes over at5.3 mega Pascal's so this takes over at about 1 mega Pascal's and this draws.

The water again from the dowsing tank so this is where you have this is the kelindria this is the steam generator you have the gas tank which is connected to the emergency core cooling water tanks this just looks like that helium tank and your poison injection tanks and then that is going through the high-pressure systems and the pump to the calendar II a similar way the medium pressure goes but then after that how the system is going back to a sump which later will utilize for re-filling the core will utilize this water this water is not going out wasting weary utilize.

This water and this is the water coming from the dowsing tank these accumulators this from the dowsing tank for the medium pressure injection.

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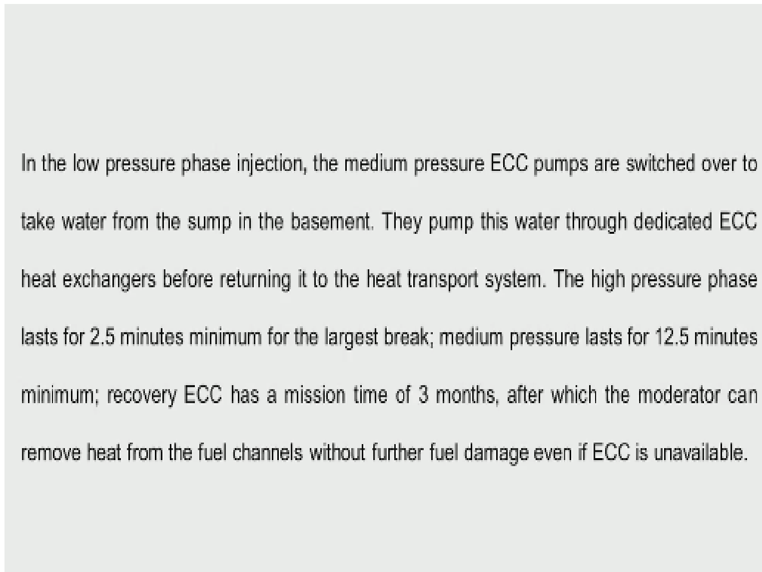

Then as I mentioned there is a low pressure injection so when the low pressure injection comes we switch on the ECC pumps to wait take water from the sump first it was the accumulator for the high-pressure injection it is the dowsing tank for the medium pressure injection and it is a some in the basement for the low pressure injection ,so they pump the water and get it back to the ECC heat exchangers these are the ECC heat exchangers which are again cooled by raw water or service water and this continues and this low-pressure phase can continue for as much as three months.

So this is how we do the emergency core cooling of the pressurized heavy water reactors in our country now all sorts of systems.

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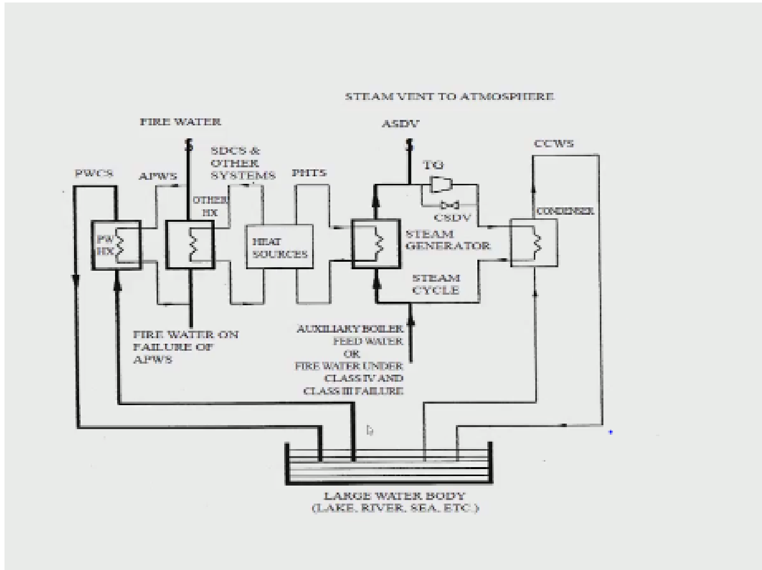

Which I have talked about on the primary side secondary side are all picture all given here so that you can see how we do and this is that large body emergency water system ,which I could it relies incase my emergency core cooling system fails to cool the reactor and remove the decay heat then the containment.

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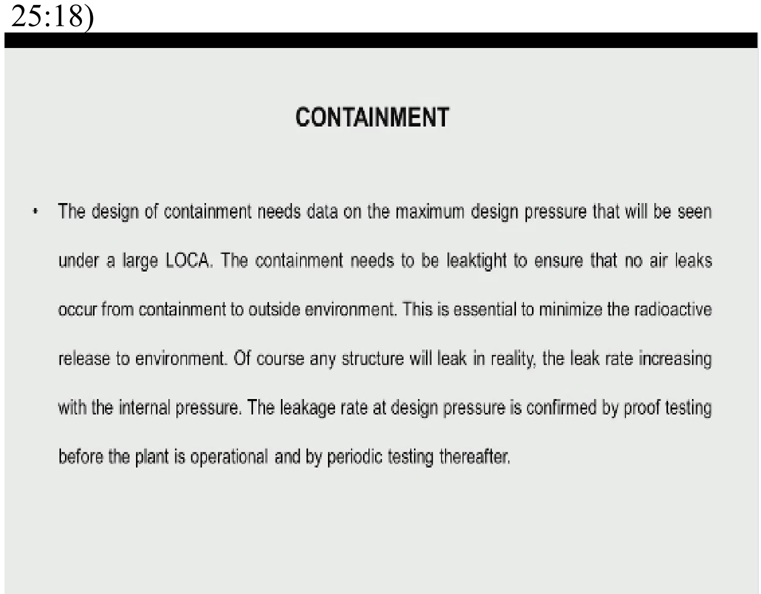

We said core first is surround cool contains around cool contain so contain so now the containment what happens let us say there is a large LOCA your water is going to flash hey water even though it is going to flash when it flashes into steam the pressure will be built up in the containment building. So we need to find out what is the maximum pressure. Which can be expected in case of a loss of coolant accident in fact if you just recall the when, I was talking about the design basis events and then how we what happens in case of a LOCA in case of the taiga to 20 megawatt reactor so we will recall that the pressure increased so this pressure increase needs to be considered so your design pressure will be fixed by this pressure increase this is a large LOCA.

Where there is a large amount of water then this containment needs to be licked tight as I mentioned no LOCA should be there wherever there are penetrations as I said we minimize the number of penetrations of electrical or process but then we cannot remove them and wherever there are penetrations we try to seal them and test them and every year we normally LOCA test so that to ensure that the leakage is very minimal now pressure is getting built up.

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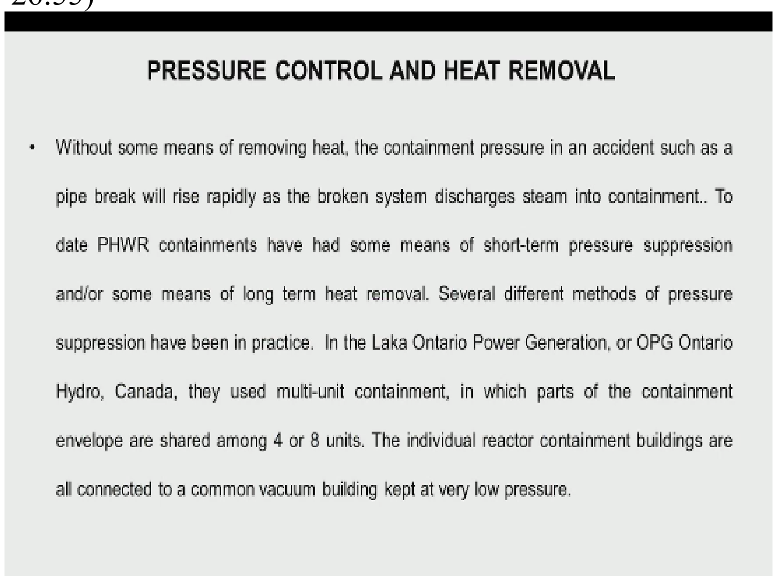

Within the containment so if I am able to remove that heat the pressure would come down and how do you remove the heat you put water and quench the steam so there are different methods of quenching one way is if suppose you have three or four units what we do we discharge the stream we have a connection to a common building or a common containment building we put which all the things are linked so the steam goes to the that common containment building which is kept normally under LOCA, normally they would not be linked but in case of a loss of coolant accident we will link the vacuum building common vacuum building with the containment of that building of the reactor so what happens all the steam would flow there.

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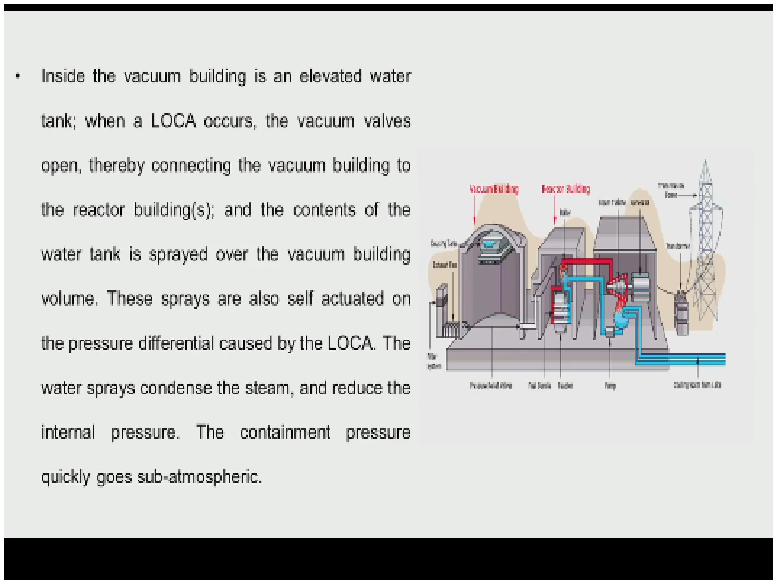

Then we in that building we have a dowsing tank as shown in this figure and this dowsing tank water will spray and quench the steam and bring down the pressure so this way the pressure would-be maintained low and this would be actually actuated based on. The pressure differentials and the pressure rise would be taken care of very easily so this is the reactor building this is the steam turbine building. Now in case this is for as I said for a multi unit this thing you have you can afford to have one containment building this also helps in another way that the hydrogen.

Which is generated due to the reaction of the water with the clad that also comes out of the reactor building to the common building and can be handled here but if suppose you have a single unit as we have for example we have two units only not multi-units so we have a dowsing tank within the reactor building at the topmost level as you see here and there is a spray from the top which quenches this team dowsing starts when the pressure comes down to certain level and when the pressure has gone down the dowsing is stopped of course it is a of much nuisance value whenever there is a dowsing because the whole building is full of water.

And you need to really do cleanup and there have been incidents of spurious signals and dowsing happening once or twice it has happened so that also sometimes a nuisance value but then when such a large accident has happened it is most important that we have such systems to see that the containment integrity is maintained.

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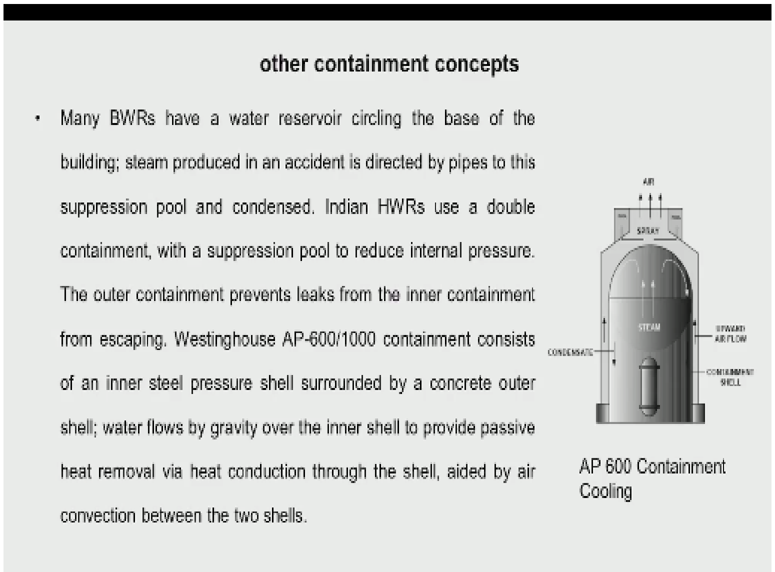

Now let us look at some other containment concepts in our Indian heavy water reactors we have double containment we have one containment with another containment and the gap is filled with the inert gas this is to see that the heat flow is not there to the other containment and of course we have a dowsing tank within now in some of the new designs, they have in the inters pace we have passage for air, so whatever steam comes here as you see here steam comes here and there is an upward airflow and along with that there is a spray of water from a pool which is a cylindrical pool at the top which sprays and cools this boundary.

So that your water can condense back into steam now this is the inner steel vessel and the outer is the concrete so you see how with air cooling and water spray over the thing they are able to remove the decay heat this is a picture of what is in the AP 600 concept.

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Containment Isolation

- In normal operation, containment is not a sealed system. Many fluid lines penetrate the building (e.g., steam lines, feedwater lines, service water lines, instrument lines). For PHWRs, the building is normally ventilated for atmospheric temperature control, especially since personnel access to parts of the building is required during operation. All these penetrations are pathways for release of radioactivity if an accident should occur; so on an accident signal, many of them are automatically isolated. There are two dampers in series on each ventilation line which are closed very rapidly on a containment isolation signal high containment pressure or high radiation in containment. Other lines penetrating containment are also closed on the same signal.

Then when a loss of coolant accident has happened you know activity can come so we need to isolate the containment because there are lot of lines coming into the containment and activity can go so containment needs to be isolated and the venting will be there for the building because we are having personal coming in and going out so all the penetrations need to be isolated automatically in the case of such a LOCA and they act on the LOCA signal and based on the high pressure signal in the containment building they also have another signal from the radiation levels.

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Other Containment Functions

- Containment also acts as a barrier to protect reactor systems from external events (tornadoes, turbine missiles, aircraft crash). These may impose additional design requirements on the structure. Hydrogen can build up in containment after an accident. After a LOCA, hydrogen is formed slowly by radiolysis of the water. Also LOCA plus loss of Emergency Core Cooling can produce hydrogen early on due to the chemical reaction between the hot cladding and the steam in the fuel channels. The large building allows some mixing of the hydrogen due to natural circulation. Air cooler fans provide forced mixing. In addition there are igniters placed in various rooms to burn a local hydrogen concentration before it can detonate. Turning on the igniters is done automatically by the containment isolation signal.

Now we said the containment is the final barrier before the public and the reactor so we need to really protect it under all conditions say tornados turbine missiles aircraft crash not a passenger I cut about a military aircraft crash so these are some of the things which we take care but remember after the accidents you would have heard hydrogen bubble bust fire and the containment has breached where is his hydrogen as I mentioned hydrogen is generated when the temperature of the water is high beyond about 350 to 400degree centigrade and the zirconium reacts with water to produce the conium hydride.

And hydrogen now this hydrogen is coming out and getting into the containment building so if this hydrogen concentration becomes to a particular level something like nine percent it can four to nine percent it can gets lightest spark it can get cat fire and burn and explode hydrogen explosion could be there that is what happened in the Fukushima reactor. So this hydrogen it needs to be seen that the hydrogen concentration does not cross a particular level normally we have fans circulating fans which continuously take the atmosphere.

Which is within the containment to outside and then not outside mean to the public and then through a closed system purify it and coming back also we have igniters from time to time we put on those igniter so that should there be hydrogen it will burn out so that it does not become an explosion and these are all done automatically.

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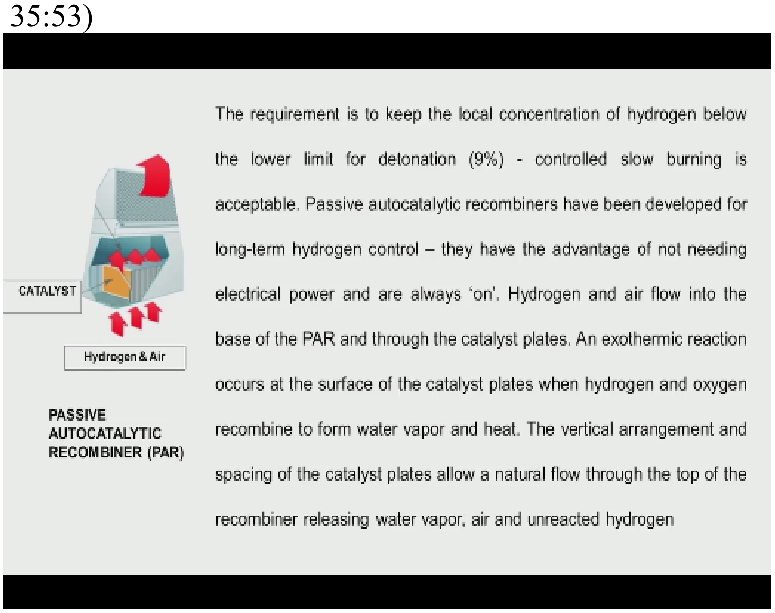

But then why this happened in case of Fukushima so there is an approach nowadays to have what is called as passive autocatalytic recombine errs recombines means the hydrogen is taken the atmospheric air is taken the oxygen in the air and the hydrogen mix and become water so that there is no chance of hydrogen existence of hydrogen and this has been developed to a large extent lot of work has been done in Canada and now in all the reactors, this passive auto Caltech degree combiners are being put in all our present designs under different conditions, we have compartmentalized the compartments in the containment.

Such that under no condition the hydrogen concentration would reach the magnitude where it can ignite so how do we do it this passive autocratic combiners they do not need electrical power so the hydrogen and air are flowing through this catalyst and this catalyst promotes the reaction between hydrogen and oxygen and water vapor comes out at the top of course any of the unreached hydrogen also comes no drops and that can be ventilated.

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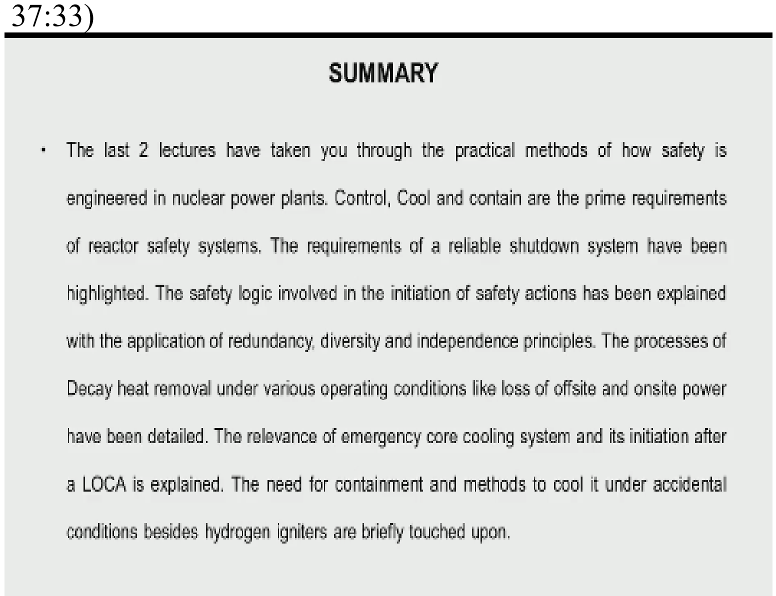

Now let me summarize what we have gone through in the last two lectures of course it is engineers method of how to overcome the obstacles practically and to make the planes plant safe control cool contain that means around cool and contain this we have seen we have seen a very reliable how to achieve a reliable Shannon systems redundancy diversity independence these are the mantras this mantra we should never forget. I also gave you a small example of how, I chose the first floor in a in my flat apartments.

Then decay heat removal again follow the same principles we also talked about the relevance of emergency core cooling and not only that we also looked at how emergency water system which is directly having a diesel driven pumps are which are feeding the core to cool the reactor in the first case are there so we touched upon the igniters also the autocatalytic recombine errs by which we can take care of the hydrogen problem.

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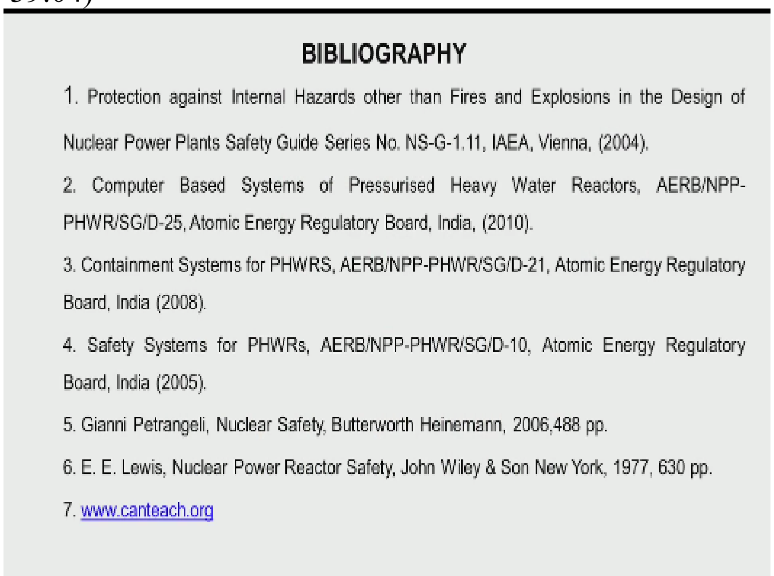

This is a small bibliography in which you can find out the publications of IAEA and the Atomic Energy Regulatory board in India of course you can find some more things of the reactors earlier reactors from the book by Lewis and Petrangali and this website can give you a lot of information about your reactors.

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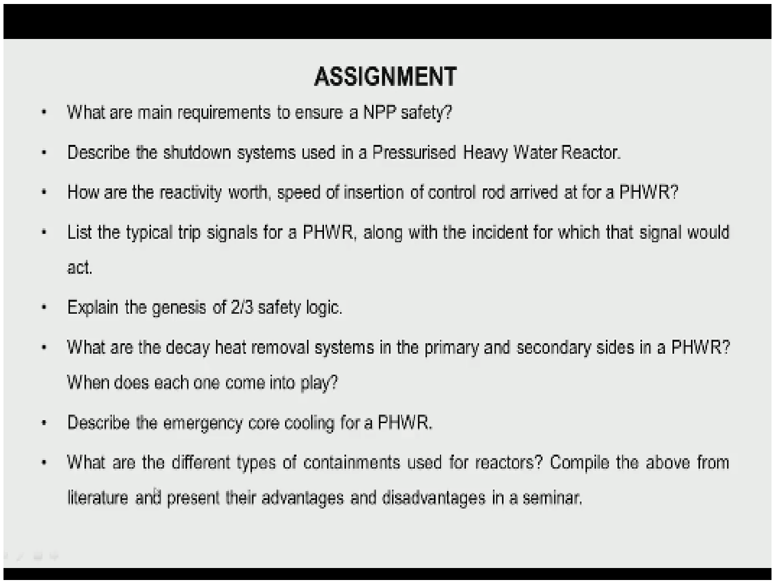

And this is a small assignment for you which would help you to see whether you have really understood this lectures or not and thank you for your attention you.

Online Video Editing /Post Production /Camera

R. Selvam
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