NPTEL

NPTEL ONLINE CERTIFICATION COURSE

Health, Safety & Environmental Management in Offshore and Petroleum engineering (HSE)

Module 1
Safety assurance and assessment
Lecture 7
Organizing safety

So dear friends today we will discuss about the 7th lecture in module 1 where we are focusing on safety assurance and assessment. In this lecture we will discuss about how to organize safety.

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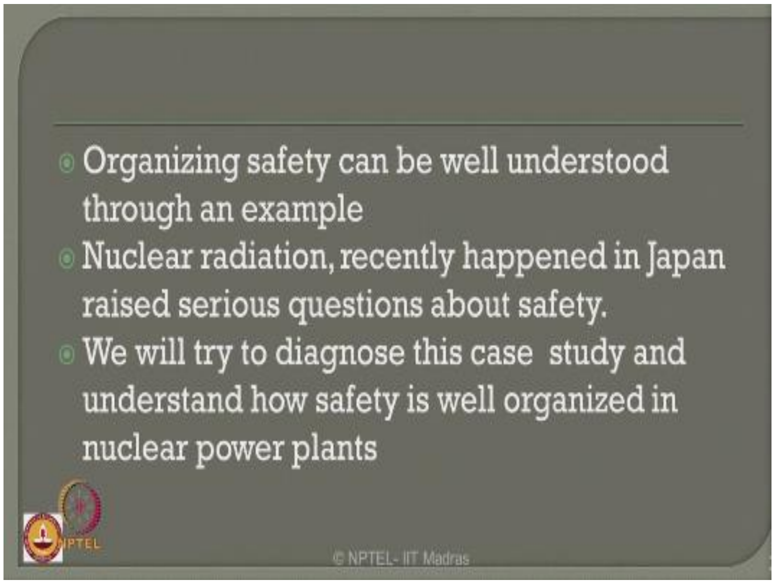

Organizing safety can be well understood through an example, nuclear radiation that has recently happened in Japan raise serious questions about safety, though the problem discussed now will not be directly applied to an oil and gas industry however an example of recent occurrence will be interesting for us to know how safety in design and operation was well practiced in a nuclear plant power plant in Japan from which we can learn good lessons.

We will try to diagnoses this case study and understand how safety is well organized in nuclear power plants in Japan.

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You can stop worrying about radiation disaster in Japan I will tell you why from this example.

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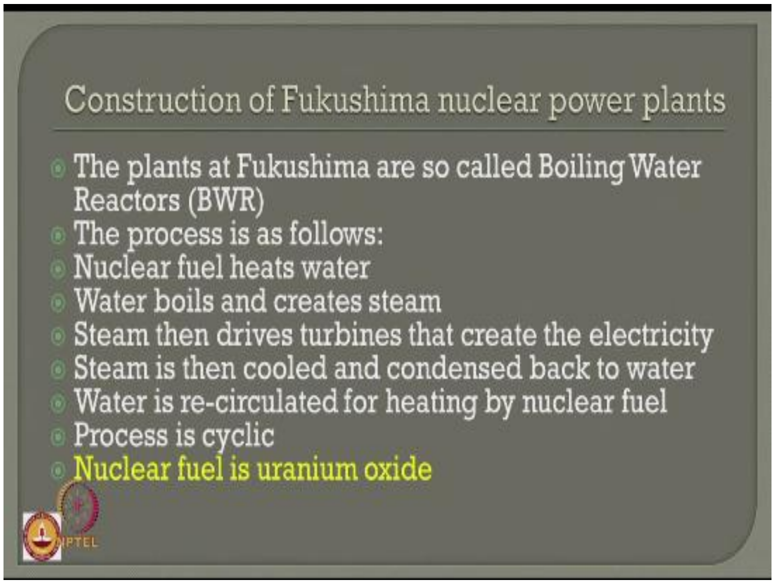

Let us talk about the construction of Fukushima nuclear power plant in Japan because to understand the design in safety and organizing safety in terms of process safety let us try to first understand the construction technology and little bit about the process of nuclear power plants. The plants at Fukushima are also called as boiling water reactors let us see type of process plant what they have for nuclear power plants in Fukushima, the process in this particular plant is as follows.

Nuclear fuel heats water, water therefore boils and creates steam, stream then drives a turbines that create electricity steam is then cooled and condense back to water, the water again is used which is getting heated up by the nuclear fuel therefore the process is cyclic. Let us quickly understand is very simple process nuclear fuel heats the water, water becomes steam, steam drives a turbine and generate the electricity.

Steam is then cool and condensed back to water it is re-circulated for heating by the nuclear fuel and the process is simply cyclic. The nuclear fuel used in this specific case is uranium oxide.

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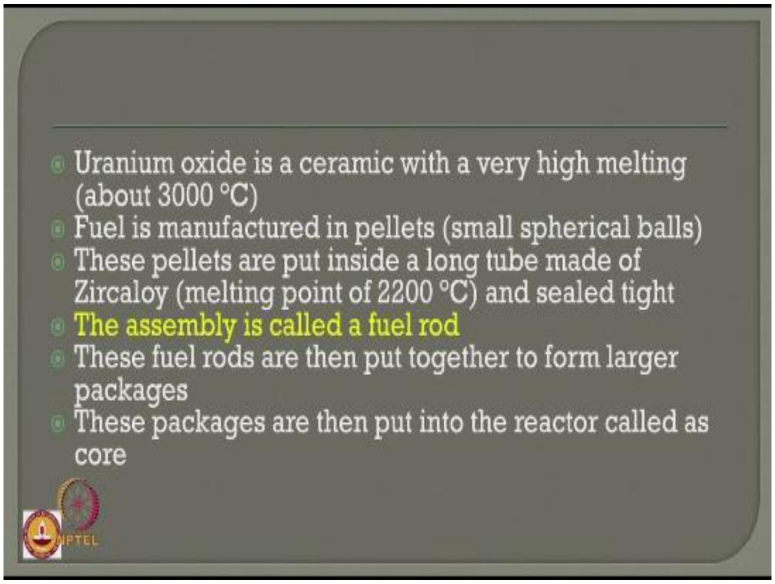

Uranium oxide is got some specific chemical properties let us see what are they uranium oxide is a ceramic material with a very high melting point it is about 3000˚C. Fuel is manufactured in pellets, pellets are nothing but small spherical balls. These pellets are put inside a long tube made of Zircaloy the melting point of Zircaloy is about 2200˚C and they are sealed in a tight packet. This assembly is technically called as fuel rod. These fuel rods are then subsequently put together in groups to form larger packages. These packages are subsequently put into the reactor and they are called as core.

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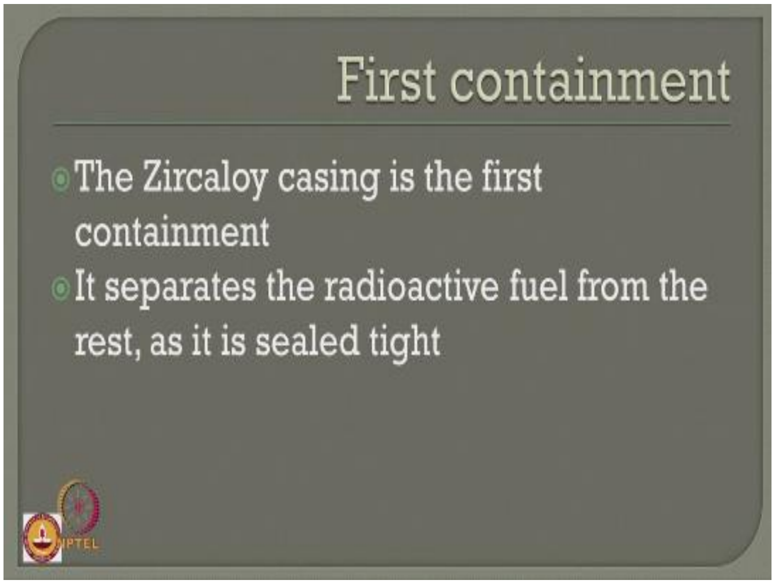

Let us talk about different containments in nuclear reactor the first containment is the Zircaloy casing it separates radioactive fuel from the rest because this is completely sealed tight.

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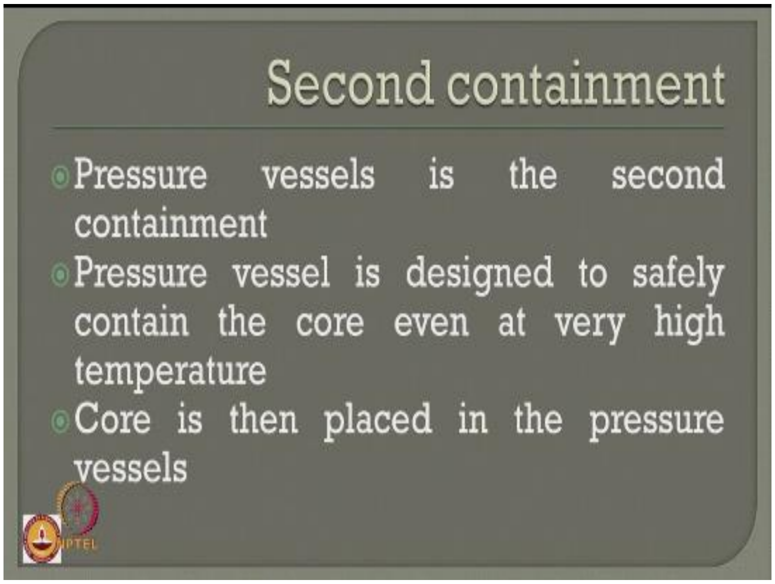

The second containment is the pressure vessel. The pressure vessel is designed to safely contain the core even at very high temperature, friends understand that core is nothing but packages of pellets which are put in group and that becomes a core the pressure vessel is usually designed to safely contain the core even when the temperature raises very high. Core is then placed in a pressure vessel.

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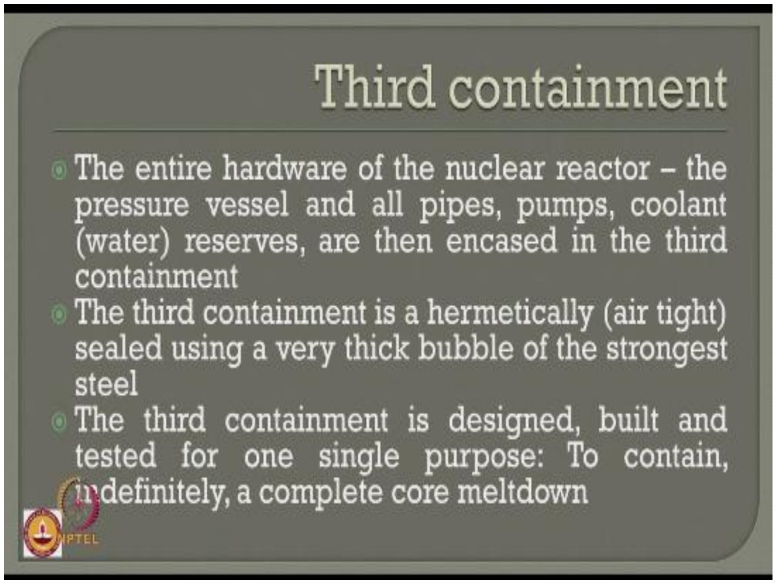

The third containment that is a third layer of cover is a third containment this entire hardware of the nuclear reactor the pressure vessel all the pipes pumps coolant essentially water are then encased in the third containment. The third containment is generally air tight which is sealed using a very thick bubble of the strongest possible steel. The third containment is therefore designed built and tested with one unique purpose and objective to contain in definitely a complete core meltdown.

Uranium oxide pellets even when they meltdown those a melting temperature is about 3000 degree centigrade even when they meltdown the third containment is design to contain then without liking them out completely even when the core melts down so there is a very high test in the design itself which is called safety by design.

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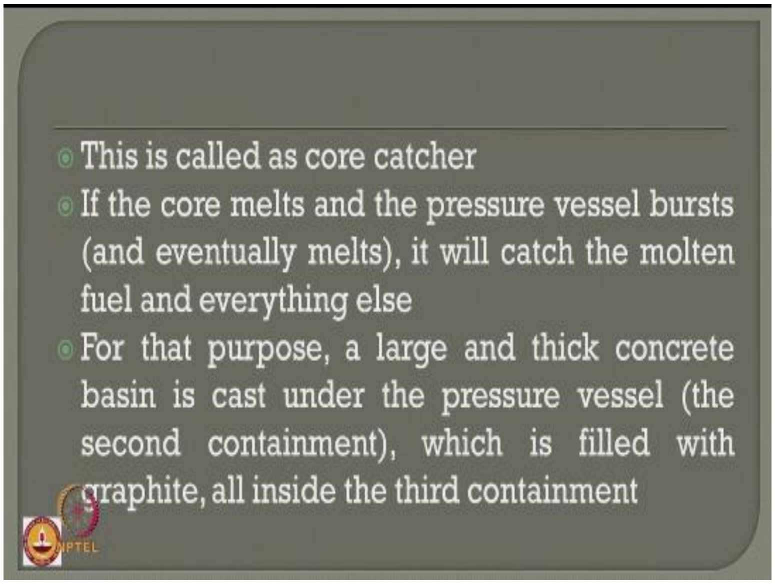

Now we call this assembly as a core catcher now why this is called as catcher. If the core melts and the pressure vessel bursts eventually it will catch the molten fuel and everything else that is what is called core catcher for this purpose a large and thick concrete basin is constructed under the pressure vessel. The pressure vessel as we all know it is a second containment a larger and thick concert basin is cast or constructed under the pressure vessel which is subsequently filled with graphite all inside the third containment this where the core is catch.

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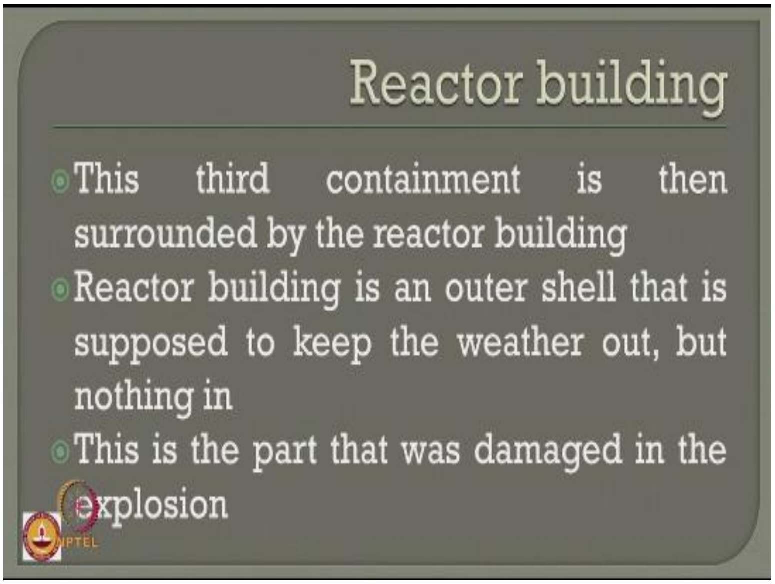

Now let us talk about the reactor building the third containment is now then surrounded by what we call as a reactor building. Reactor building is an outer shell that is suppose to keep the weather out but nothing in, this the part that was damaged in the explosion in the nuclear power plant in Japan.

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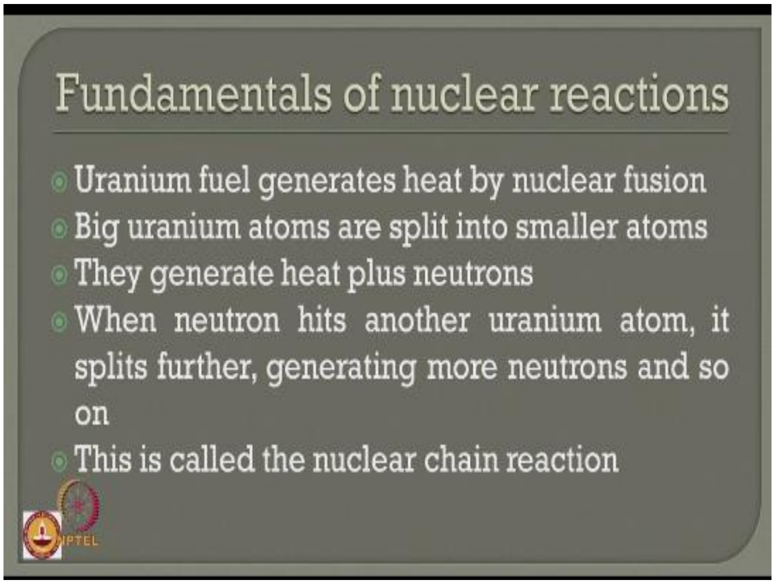

Before we understand how safety in design and how safety in operation was practiced in the specific power plant let us try to understand fundamentals of nuclear reaction as process because if do not understand this at least in a very primate level we not be able appreciate the safety level management what they employed in the nuclear power plant in Japan. Let us see what are the fundamentals of nuclear reactions the uranium fuel which is used as in pellets generates heat by nuclear fusion. Big uranium atoms therefore will be split into small atoms. They will generate heat plus neutrons.

When neutron hit another uranium atom it splits further generating more neutrons and so on this is called the nuclear chain reaction.

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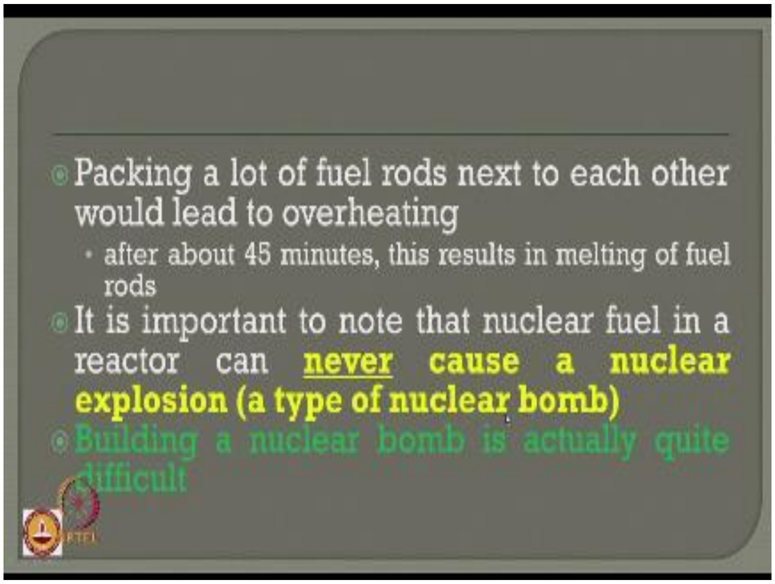

Packing a lot of fuel rods next to each other would lead to overheating because that is what it generally do after about 45 minutes this can result in melting of fuel rods itself it is important to note very important to note that the nuclear fuel which is uranium oxide in this specific case in the reactor can never cause a nuclear explosion I mean there is no possibility that the nuclear fuel can become a nuclear bomb, in fact to be very specific building a nuclear bomb is actually a quite difficult process it is not very easy therefore please understand friends that the nuclear fuel use in this reactor can never become a nuclear bomb.

So there has been a mis-concept or miscommunication. So there is no possibility that this could have become a nuclear explosion at all. Then how this happened?

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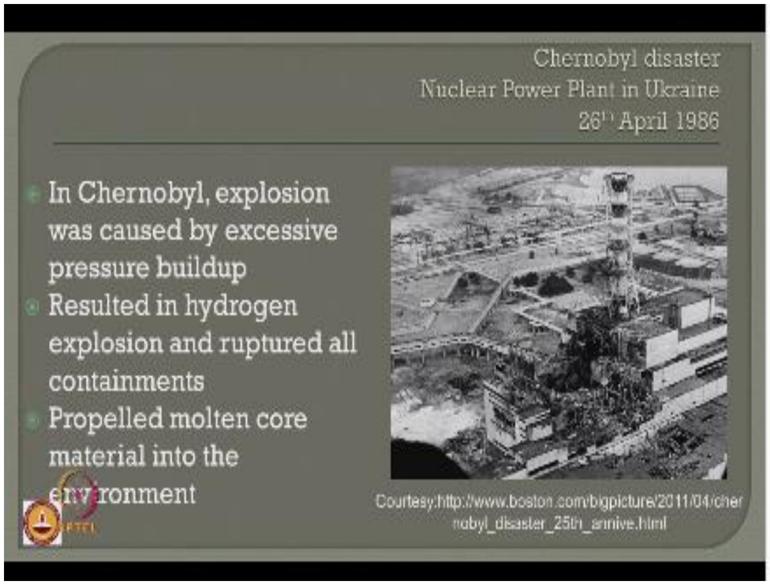

To understand this let us take a parallel example which is Chernobyl disaster of a nuclear power plant in Ukraine which happened on 26th April 1986, the power plant is photographer is shown on the right, in Chernobyl explosion was caused by excessive pressure build up resulted in hydrogen explosion and ruptured all containments, after the containments have ruptured it propelled the molten core material into the environment that is how this became a disaster.

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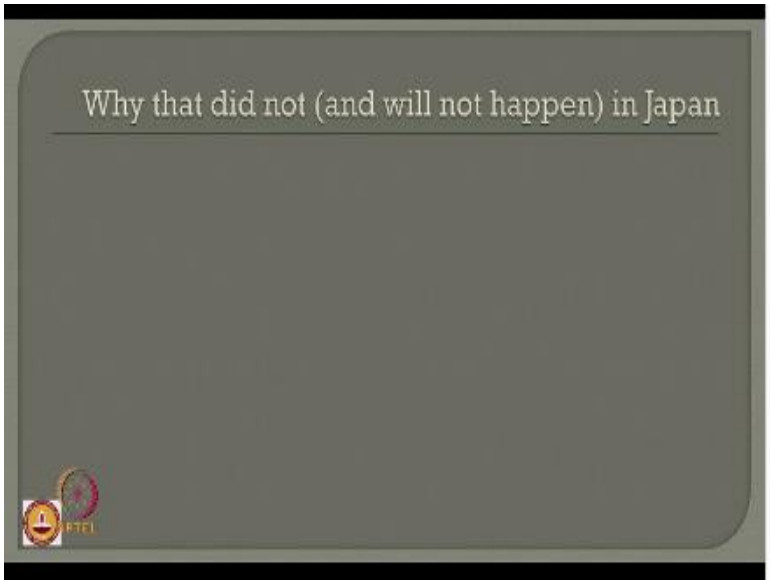

Now one can ask a question, why this not happen in Japan or possibly this will never happen in Japan, let us see how this is where I am emphasizing safety we design and safety be operation.

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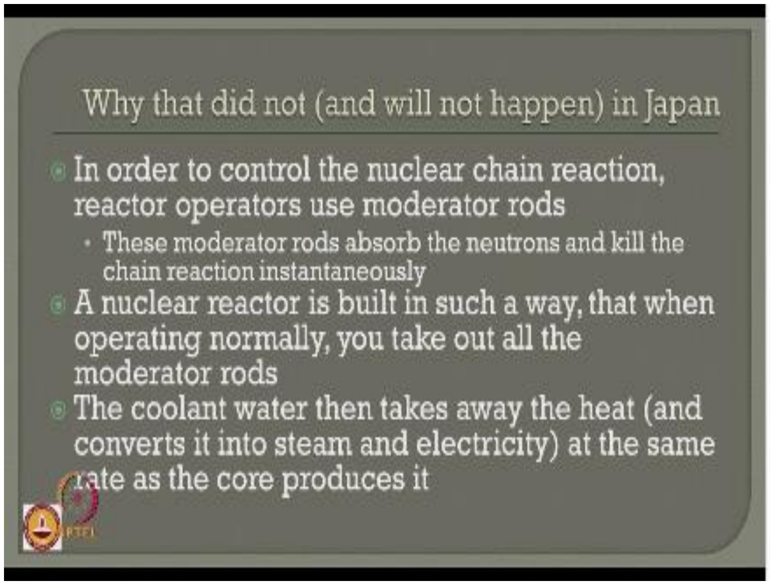

Now in order to control the nuclear chain reaction just now we saw in the previous slide what is meant by nuclear chain reaction, in order to control this reaction reactor operates use moderator rods then what is the moderator rod? The moderator rode actually absorbs a neutrons and kills the chain reaction instantaneously, so if you use a moderator rod this will intercept the chain reaction it will abundant the chain reaction instantaneously.

Therefore in nuclear reactor is generally built in such a manner that when operating normal you will take out all the moderating rods. The coolant water then takes away the heat and converts it into steam and electricity at the same rate as the core producer it. So all these process happens simultaneously in the normal operator and procedure the moderator rods will not be kept inside the container.

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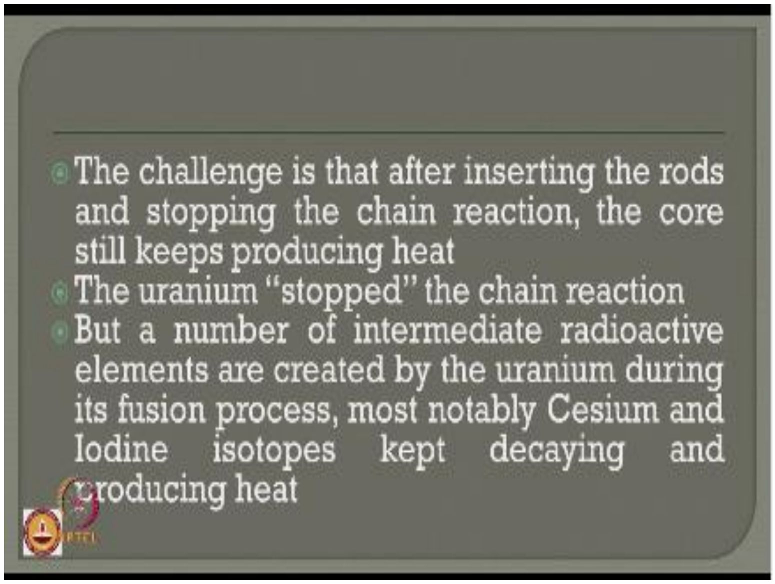

Now the challenge is that after inserting the rods and stopping the chain reaction the core will be still keep on producing heat because we cannot stop that heat production from the core okay the moderator rods have disconnected the chain reaction but the core is still keep on producing heat actually there is no reaction happening when heat is there, this heat is got to be exasperated, the uranium stop the chain reaction but a number of intermediate radioactive elements are created by the uranium during its fusion process.

Most notably cesium and iodine isotopes they kept decaying and producing heat of course this take some time even though after the chain reaction is abundant there are some radioactive elements which are creatively uranium for example cesium and iodine isotopes they will be decaying of course and while the decay process they will produce heat.

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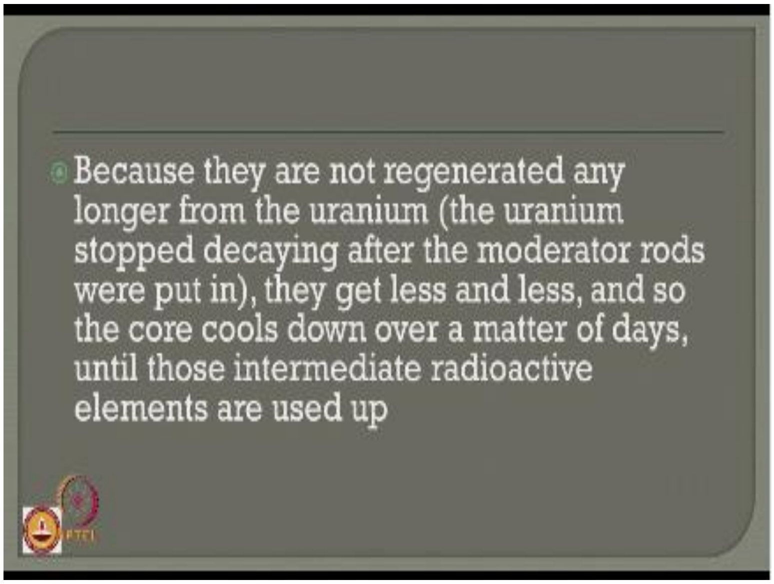

Because they are not regenerated any longer from uranium because uranium reaction has been stopped after the moderator rods are inserted in they get less and less and therefore the core cools down over a matter of days until those intermediate radioactive isotopes are used up, so the cooling process will take some time but it will cool up because the uranium has stopped from its reaction.

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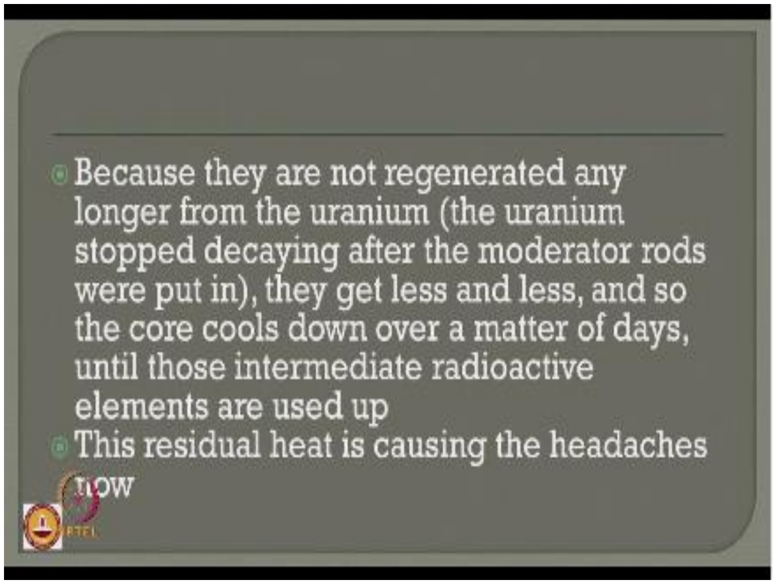

This residual heat is causing headache generally.

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Let us see how this has been taken care of the design in the Japan power plant.

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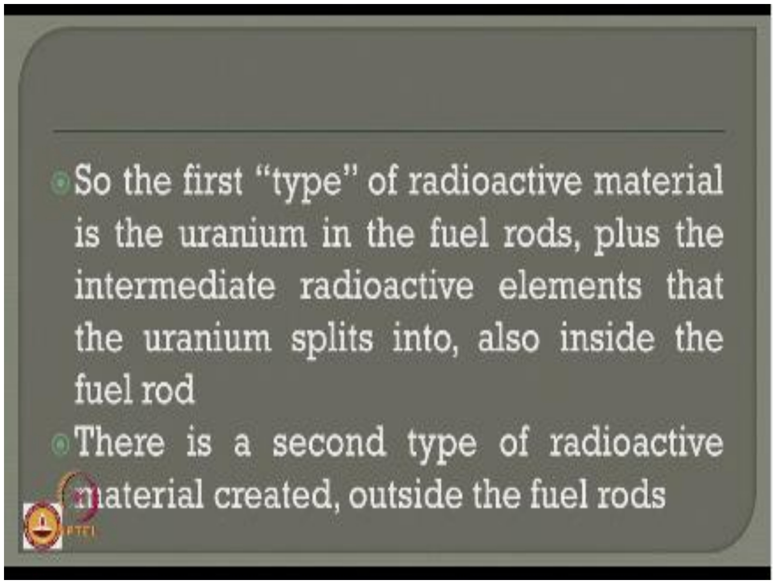

So the first type of radioactive material which is uranium in this case which is a fuel rode plus the intermediate radioactive elements that are uranium splits into are also inside the fuel rod, there is a second type of radioactive material created outside the fuel rod, so there are two types now.

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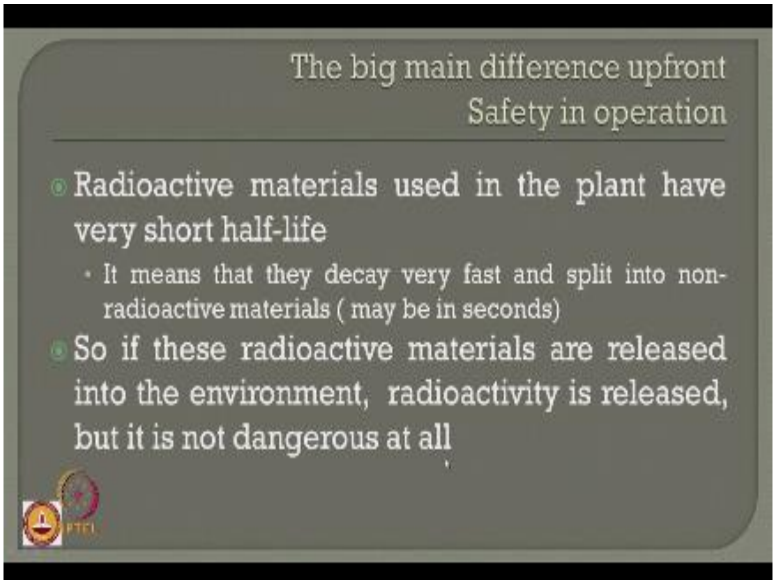

One is inside the rod itself one is outside the fuel rod, let us see what is the main difference in the upfront in the design and safety in the operation, the radioactive material used in the plant have a very short half life what is it means that they decay very fast and split into non radioactive materials may be in seconds so we need not have to bother even in the discharge in atmosphere. So if these radioactive materials even when they are released into environment radio activity is released but it is not dangerous at all, we must understand this first.

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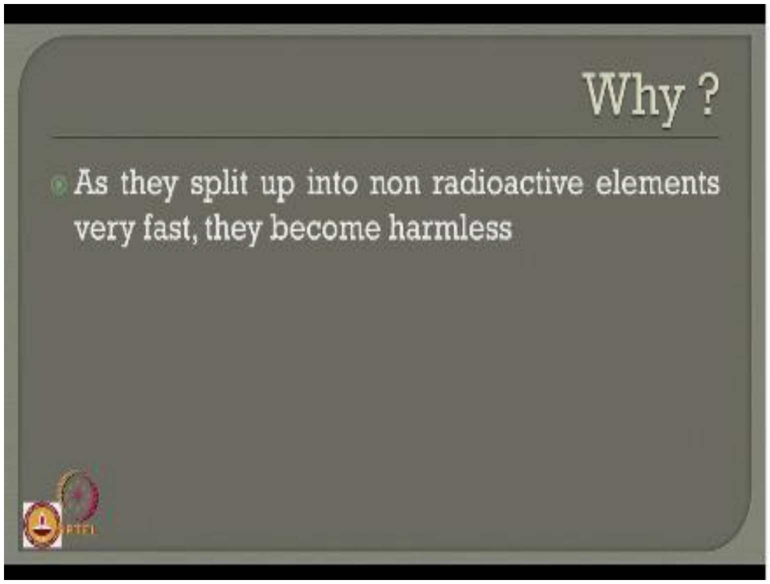

Why? As they split up into non radioactive elements very fast, they become harmless because there is a tendency that these elements will get split up in the non radioactive elements very quick may be within seconds and therefore they become harmless.

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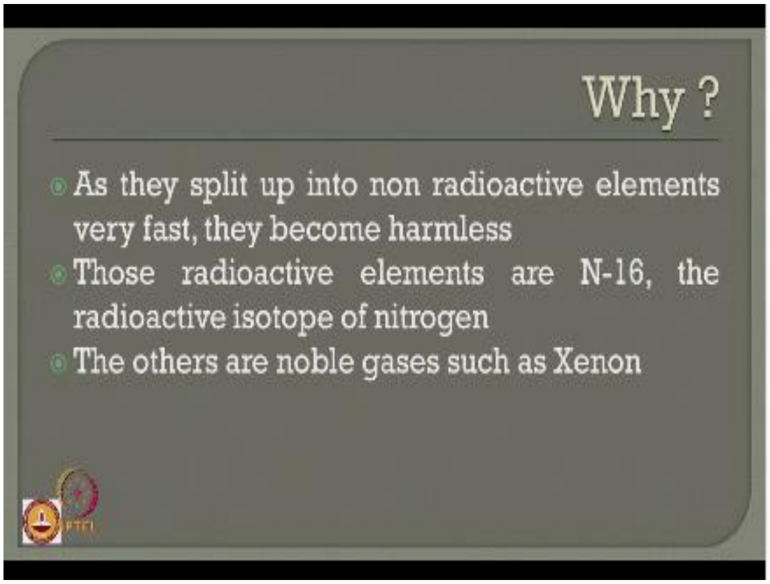

Those radioactive elements are generally N-16 the radioactive isotope of nitrogen , the others are noble gases such as xenon.

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Another question comes where these elements come from? When the uranium splits it generates a neutron most if these neutrons will hit other uranium mattes and keep the nuclear chain reaction going on, but some will leave the fuel rod and hot water molecules or air that is present in water then a non radioactive element can capture the neutron it becomes radioactive, so there is a catch here even though when the uranium splits and generates neutron.

But some of them which leaves the fuel rod can hit water come in contact with non radioactive element and now they can become a radioactive element. But this will quickly get red again to the neutron to return to its former within seconds, even though the reaction is semi active but still they will become harmless because they will further split and become non radioactive very quickly may be within seconds.

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Now let us apply this concept to Fukushima accident.

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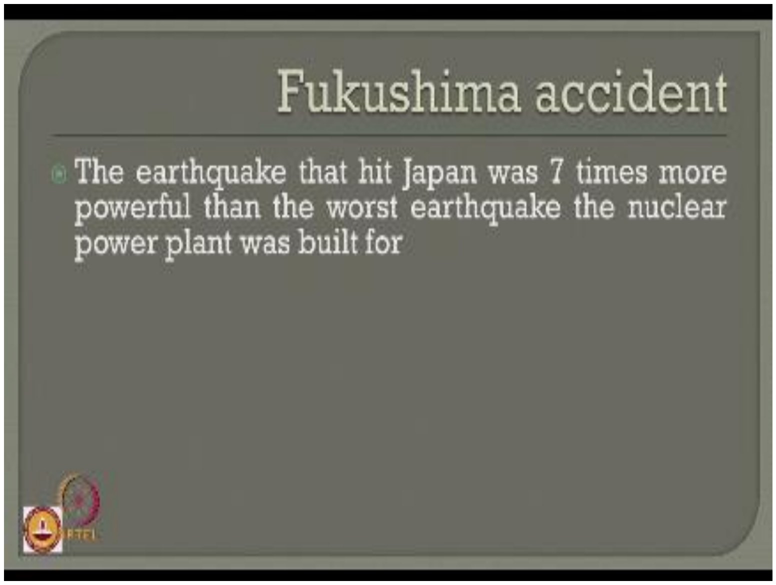

Now how this accidents actually happened? It is very interesting to know that unfortunately in this power plant three disaster subsequently happened, one is the earthquake followed by which is the tsunami, followed by which even the electrical standby failure is also occurred let us see how there has been third line of defense being planned in the design which was successful in saving this plant or atleast saving the society from a major risk.

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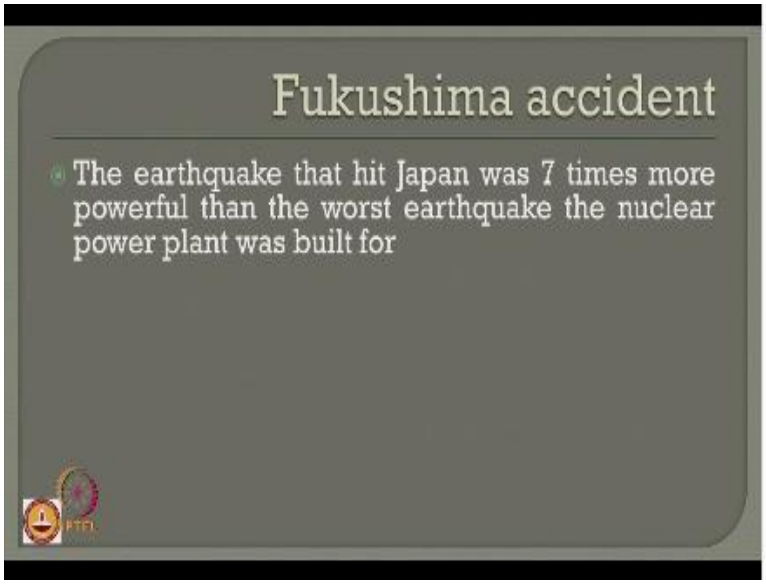

The earthquake that in Japan was 7 times more than the power which was expected than the worst earthquake that ever hit any nuclear power plant even built in Japan, so it is very unfortunate that the catastrophic reaction of this earthquake was 7 times very high compared to any earlier natural disaster earthquake occurred in Japan in the nearest vicinity where this power plant was constructed.

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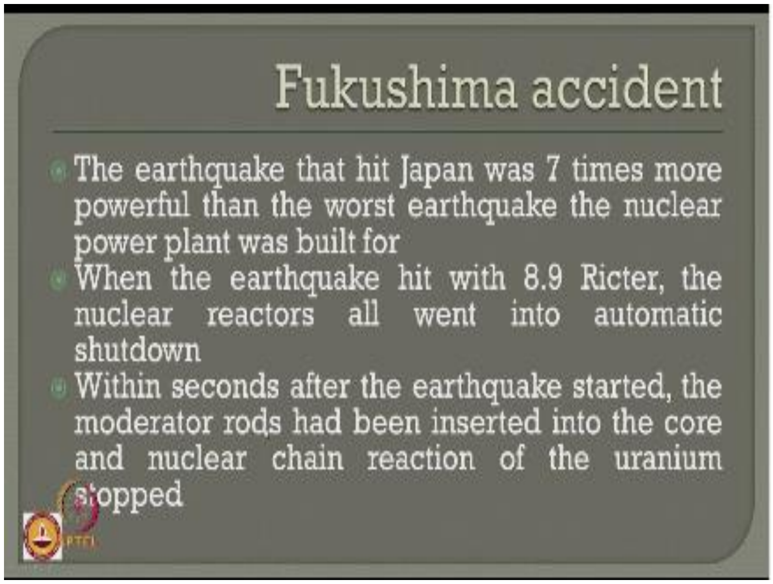

When the earthquake hit it was actually having a mind rid of 8.9 Ricter, the nuclear reactors all automatically went into shut down mode, so the reactant went into shut down mode within seconds after the earthquake started the moderator rods have been inserted, please understand this is safety by design and operation because even within seconds after the earthquake occur the moderator rods has been inserted, please understand moderator rods will always try to or attempt to kill the chain reaction and make the power plant automatically cool down, but cooling down of the plant is not instantaneous, it will take some take some time.

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So within seconds after earthquake occurred moderator rods has been inserted into the core as a nuclear chain reaction of the uranium was stopped, so one can say this is the first line defense of safety by design.

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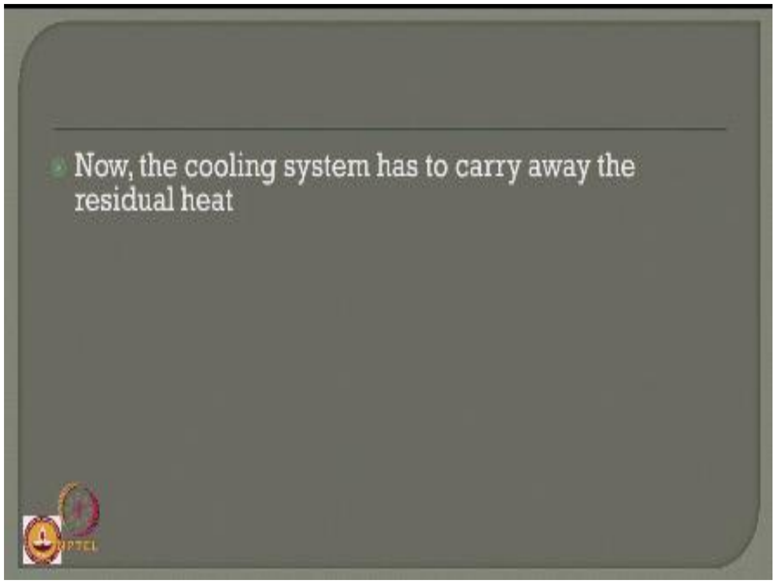

Now the cooling system has to carry away the residual heat, because the reaction has stopped, but the heat is present, this hest as got to be regenerated and it is got to be cool down. So the cooling system which is present in the design itself has to carry away the residual heat which generated inside the core.

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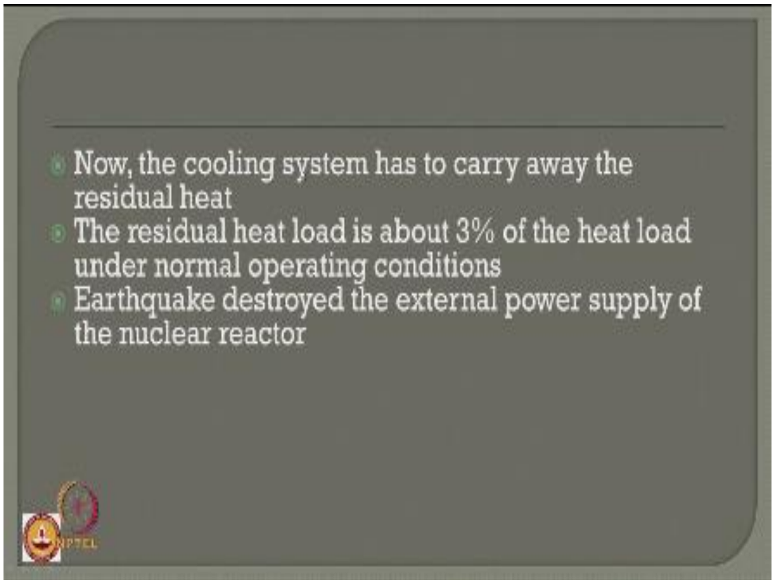

This residual heat is about 3% of the heat load under normal operating condition that is the general anticipated value. But unfortunately to operate the cooling system you need power but earthquake destroyed the external power supply completely nuclear reactor so there is an external power supply possible to the reactor therefore, the cooling system which was the part of the design was not in operation because earthquake destroyed the external power supply which goes to the reactor, so cooling cannot take place.

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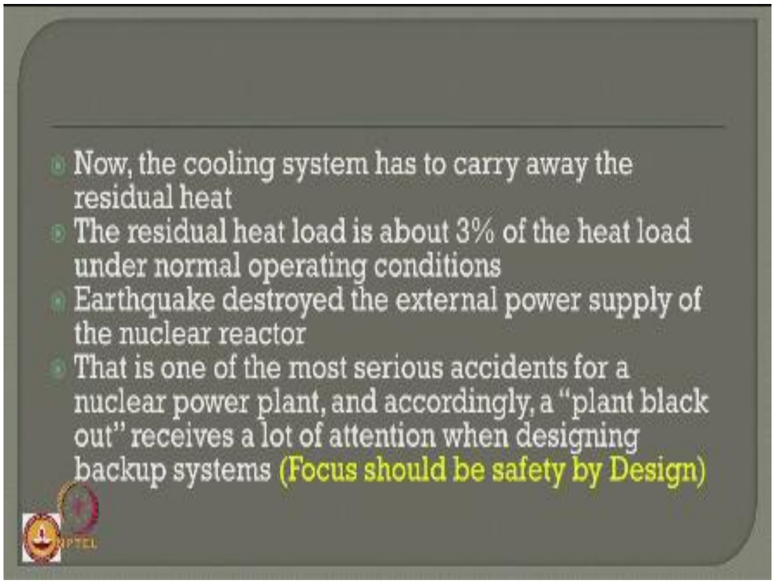

That is one of the more serious accidents for the nuclear power plant because the cooling supply system was disturbed and accordingly a plant blackout has occurred which received lot of attention when designing backup systems. Therefore, ladies and gentle men please understand the focus generally should be.

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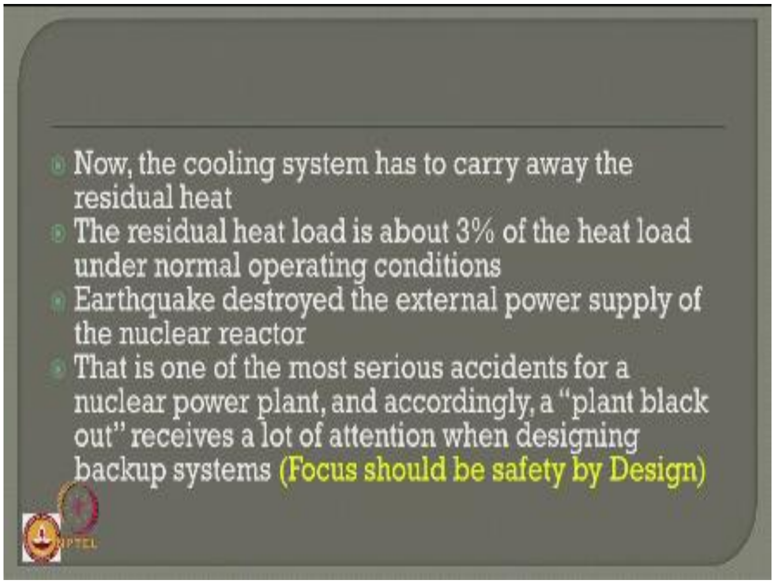

Safety by design, safety by operation will follow only when there is a success in safety by design so first you must evaluate your design for safety procedures. There are methods by which you can always evaluate the design what we call as FMEA failure mode effect analysis which is one of the interesting design concepts for risk management which will discuss in a successive module. But importantly here one should understand that focus should be always.

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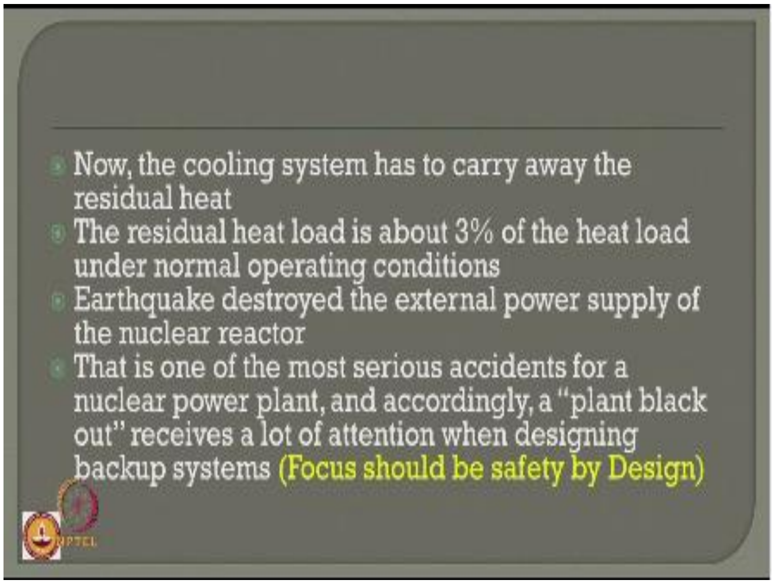

Safety by design first, if this is achieved then only safety we operation can be implemented. So the plant has gone into total black out there is no power supply to the reactor earthquake has destroyed the power supply system the power supply system has not interrupted the cooling system which is now require to cool down the system because though the reaction is stopped, because moderator rods where introduced.

But the cooling is not happening because the heat cannot be controlled as there is in a power supply.

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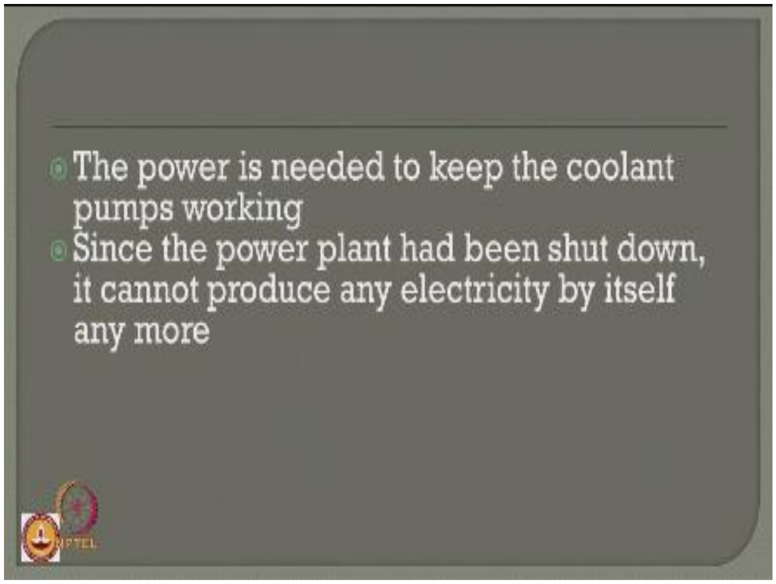

Now the power is acquired to keep the coolant pumps working, you have no external power. Since the power plant had to be shut down it cannot produce any electricity by itself, so there is no supply of electricity also from the nuclear power plant because nuclear power plant is stopped.

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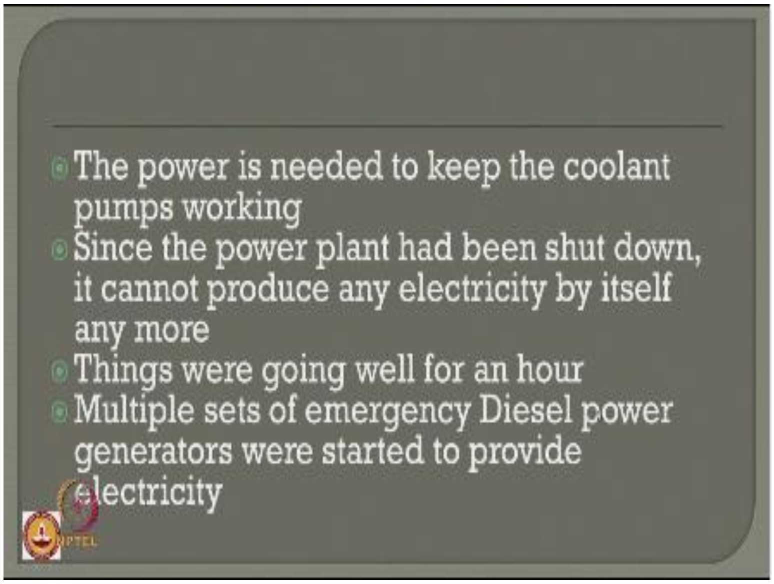

Things were going on well for an hour, okay. Subsequently multiple sets of emergency diesel power generators were started to provide electricity. So that is the second made of decency now generator which are diesel power driven or switched on to provide external power which is artificial source of power to the cooling supply system which is now they acquired to bring down the heat. Now remember the reactor they stopped, by inserting moderator rods. Now cooling system cannot be automatically on because there is no external power supply plus power supply was damaged because of earthquake.

Now within an hour people have switched on the multiple emergency source of diesel power generator where started the provide electricity. Now here one can understand what would have been the delay, what would have been the procedural violation to switch on the diesel power maybe not an hour maybe up to 30 minutes. So there can be a studied and here.

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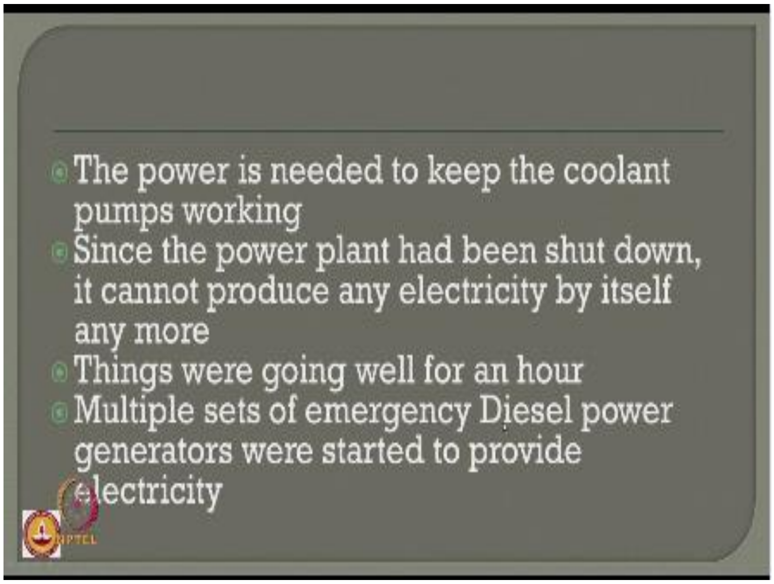

To understand the post that in scenario so that this delay or the phase delay created between start of the diesel power plant or the diesel power source with respect to the power shut down from the plant can be minimized. So one can do a safety process assessment here which can be done either doing a hazard analysis or using a FMEA again, now let us understand the scenario there is no external power electricity disconnected nuclear reactor has stop heat this on there is no radiation to be controlled, there is no power supply external power supply is now switched on is equal to diesel power.

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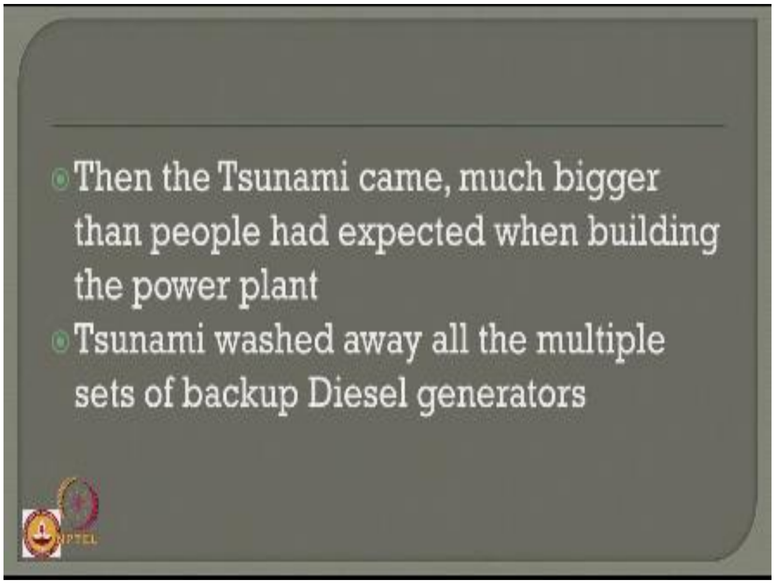

Then came the second line of attack from the nature. Then came the tsunami earthquake stop tsunami came and the tsunami was much bigger than people expected when the building the power plant. So now this again second disasters subsequently happen. Now unfortunately friends tsunami washed away all the multiple set back diesel generators kept on source, so now you cannot generate power from plant to that plant is stopped.

Though the plant is stopped heat is still on the cooler system cannot be on because there is no power supply, earthquake spoil the power supply and tsunami washed on the artificial power supply also. So you see safety by design can work only to some extent. Safety we operation then takes place that is what I want emphasis here. Though we have all second line and third line of defense in the design when all of them fail how safety by operation can rescue the people around the plant that is what we are going to see in this example.

Now tsunami came diesel power systems were also washed away.

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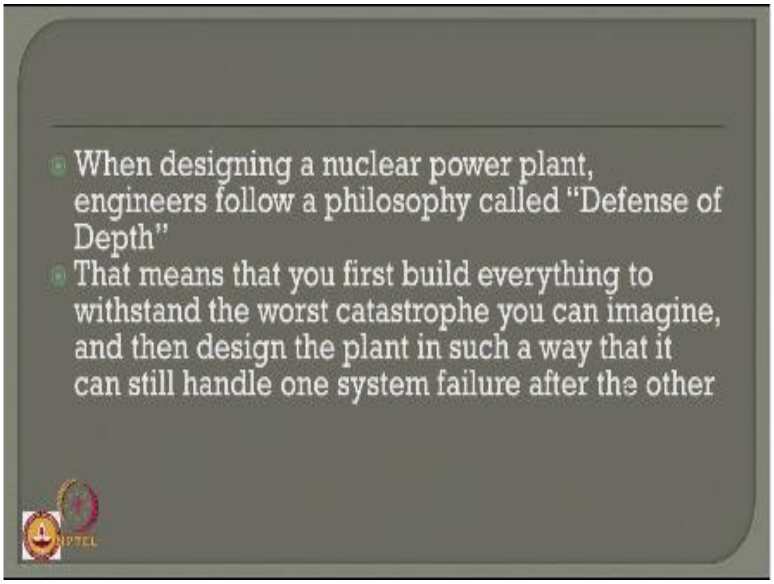

Now in designing a power plant in general people will agree with me there is always a philosophy called "Defense of Depth". Now let us see what is defense of depth this means that you first build everything to withstand the worst catastrophe you can imagine. So build everything withstand the worst catastrophe you can imagine and then design the plant in such a way that it can still handle one system of failure after the other. Remember, the defense of depth is possible only then the system failure occurs in sequence.

But in this case earthquake and tsunami which are natural disasters of very highest possible order occurred simultaneously or more or less followed by one another which was not expected, so therefore the defense of depth was in place in the design.

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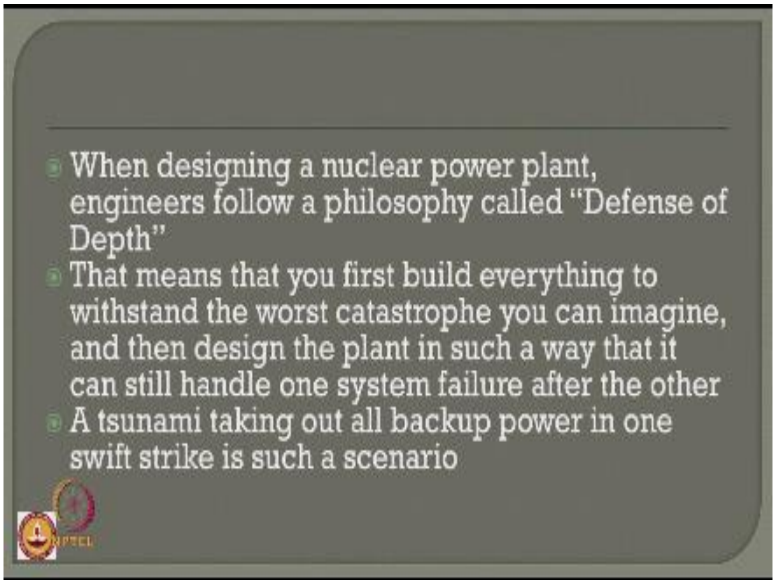

But not very effective, therefore a tsunami taking away all the power backup in one swift is now an important scenario.

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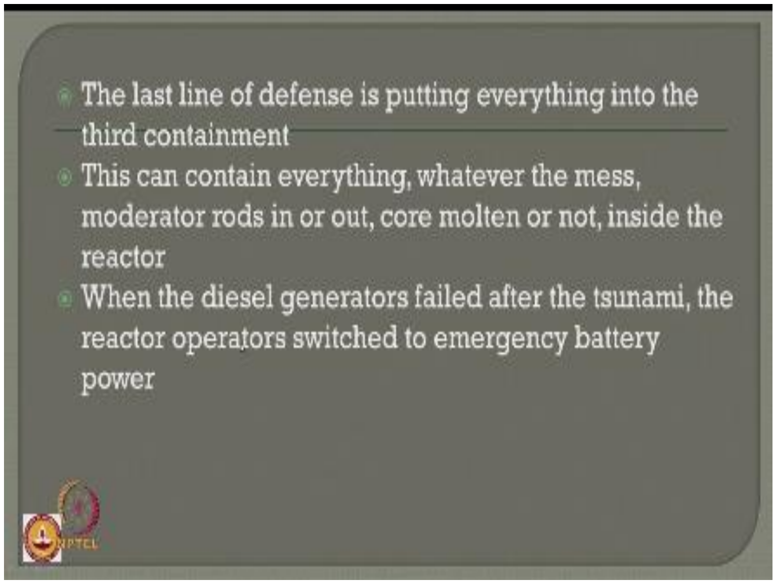

The last line of defense is putting everything into third containment, because now the third containment is an external cover is now at risk. This can contain everything whatever the mess is the moderator rods in or out, core molten or not inside the reactor. If this third containment cracks it becomes a serious problem. When the diesel generators failed after tsunami the reactor operators switched to emergency battery power, this is where I say safety way process, okay.

Now the reactor operators who were personal working in the reactor should an emergency response planning guidelines and training given to them so that even at that moment of failure they were able to switch on the emergency battery power that was the last line of defense they had.

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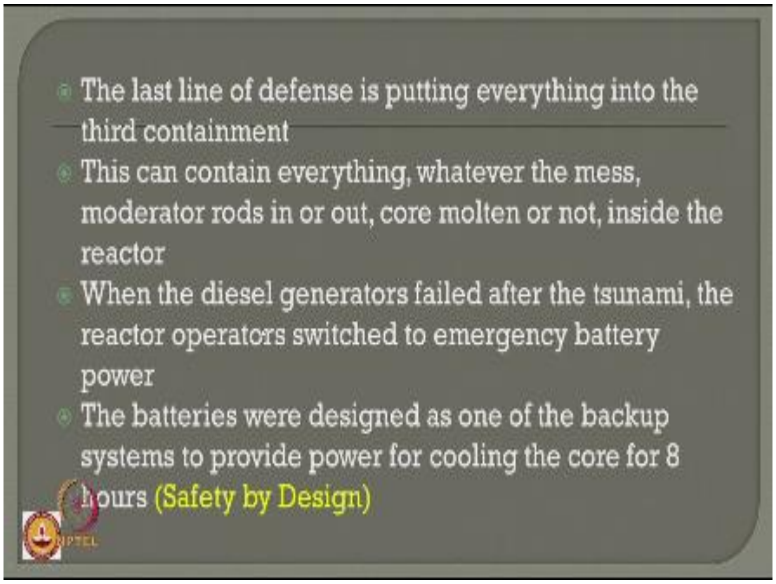

So the batteries were designed as one of the backup systems to provide power for cooling the entire core for 8 hours. So one can easily say here this is one of the intelligent design done by the Japanese which I say safety by design and this was the one system what they had they have trained the operator such a manner safety by process and safety was an important line of defense in this example.

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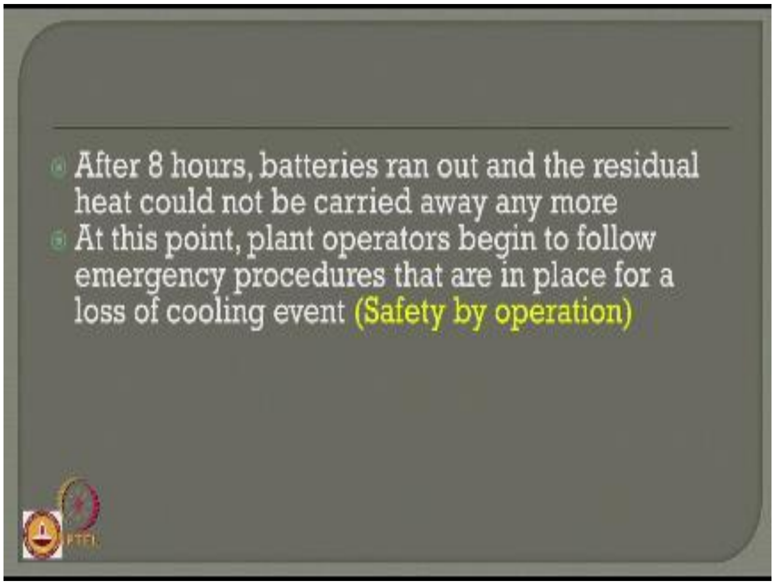

After 8 hours when the battery also ran out the residual heat could not be correct a way any more is not possible at this point the plant operators begin to follow emergency procedures that are in place for loss of cooling event again safety be operation see intelligently the people who have been working in the plant even though the battery will also ran out that is exhausted after 8 hours we are trying to operates a emergency procedures.

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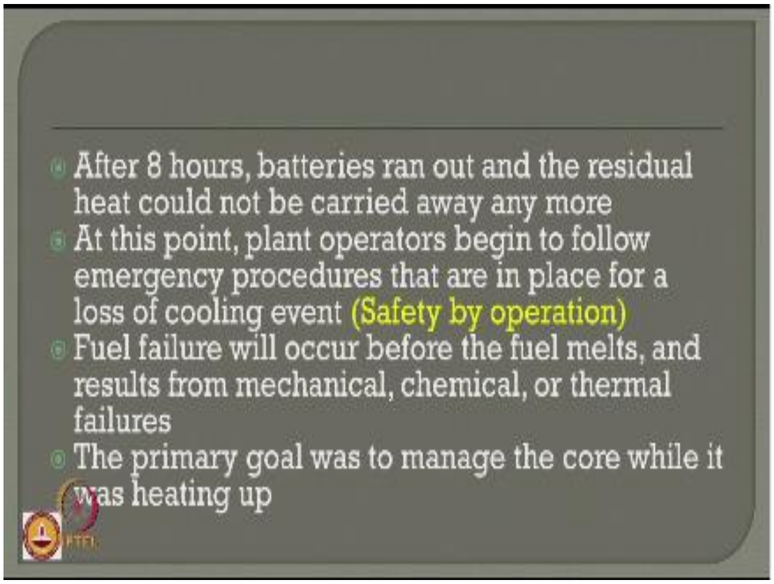

It means if you are not in imparted with necessary training are all emergency planning you not able to act in such situation so safety be operation safety be process it is very important in such situation the fuel failure will occur before the fuel melts and results from mechanical chemical or thermal failures the primary goal now adjust movement is to manage the code while it is heating up because it is heating up and it do not want the heating to continue I want this to cool down.

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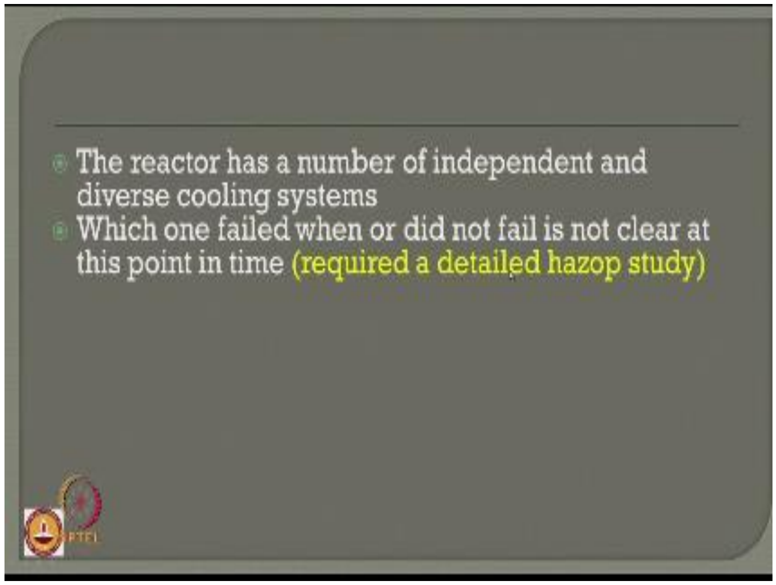

The reactor has number id independent and diverse cooling systems safety be design again which one fail which did not fail is not clear at this point of time therefore friends it is important that a detail HaZOP study should have been conducted or I think must have been conducted they should tell me what is the sequence of the failure if one fails following the other so I do know this report is not available.

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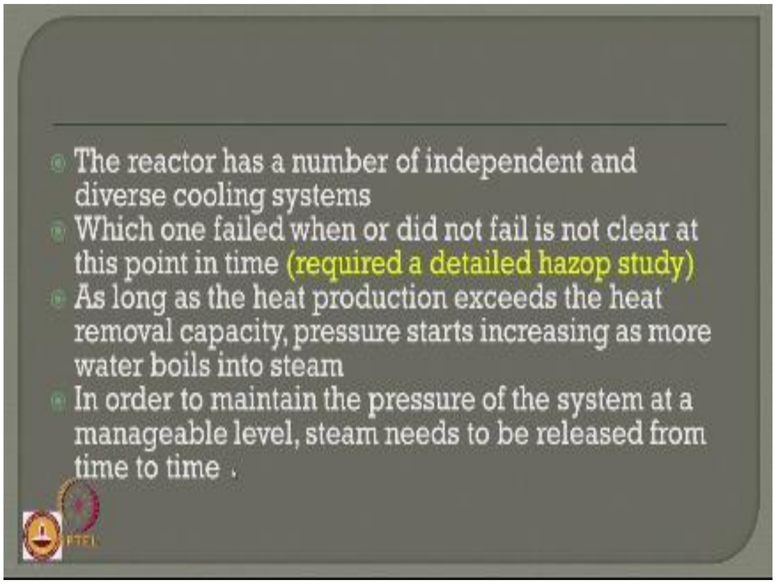

In the public domain and do not know whether a detail HaZOP study was for this particular power plant after the failure or before the failure but still I believe that a detail HaZOP study would have at least imparted a good knowledge about the sequence of failure in such situations now as long as the heat production exceeds the heat removal capacity pressures starts increasing there is a problem here if you are not able to reduce the heat production compared that of heat removal capacity what you have.

In terms of cooling system this will result in pressure increase and that will again start boiling water into steam and steam will again no problem because in such situation the heat explosion therefore in order to maintain the pressure of a system at a manage your level this steam which is being produced needs to be released from time to time.

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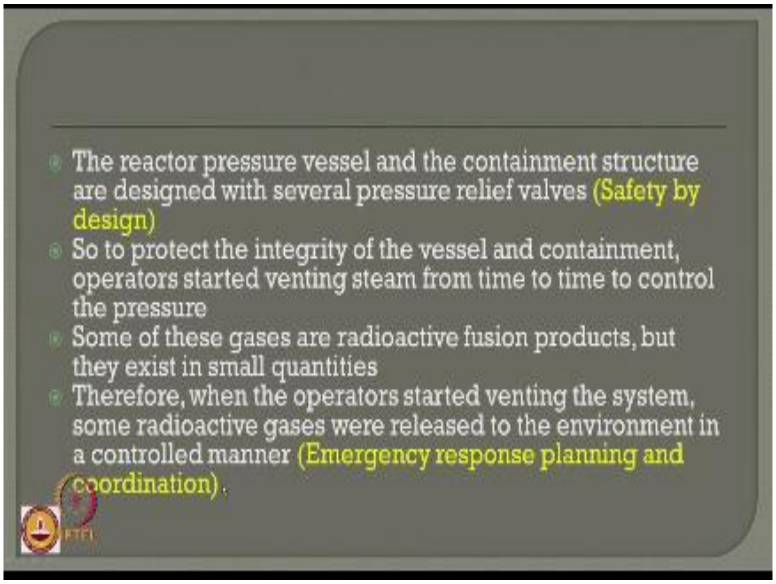

So the reactor pressure vessel and the containment structure or design with several pressure relief valves but you call as PRV's so this is the point to be noted friends it is safety be design again so to protect the integrity of the vessel in the containment operators started venting steam from time to time to control the pressure so this is by safety by training an operation and process some of these gases are radioactive fusion products but they exist in a very small quantity of course I will still strongly believe with you and agree that yes.

Some of the venting steam are few contain some radioactive gases there is no doubt about it but it is believe that they were in a small quantity therefore when the operators started venting the system some radioactive gases where released to the environment in a controlled manner this what we call emergency response planning and coordination which is a very vital part on safety be training.

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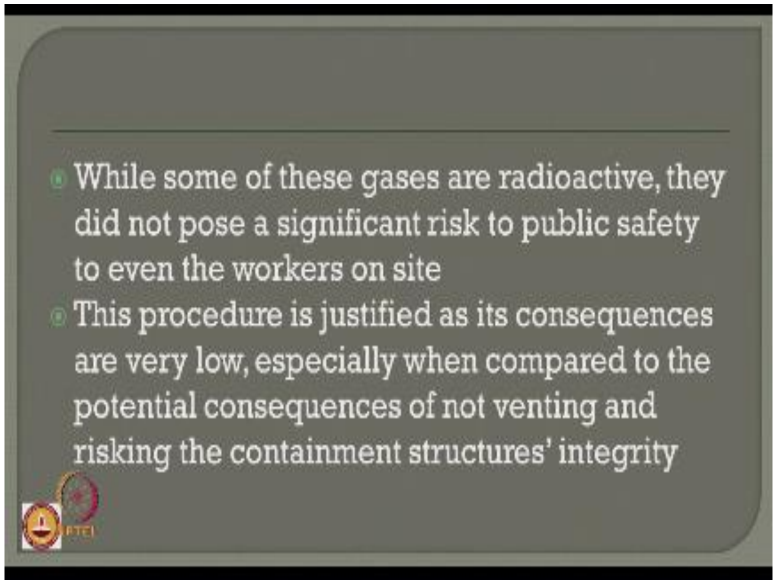

Now friends while some of these gas are radioactive they did not pose significant risk to the public safety to the workers on site I will tell you how in the last slide this procedure is justified however as the consequence are very low remember risk as we all now understand is a product of magnitude and consequence now can say large amount of gases.

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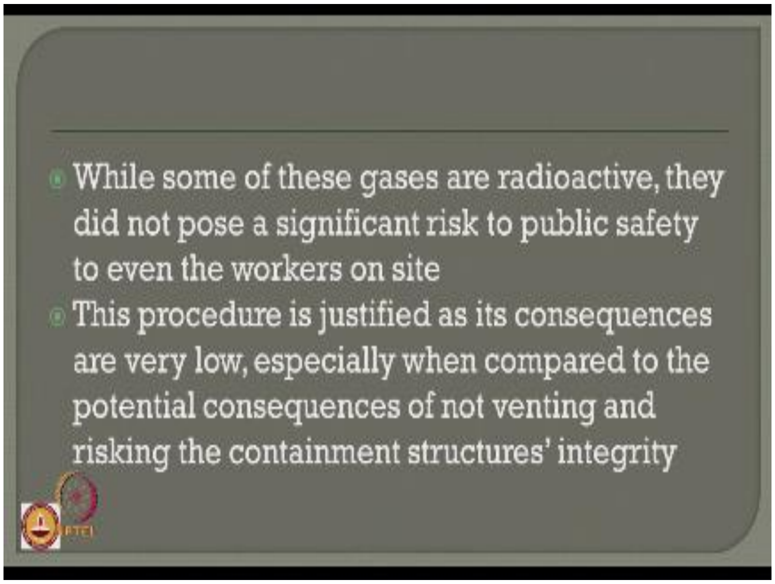

Have been radioactive been released even in that case the consequences cost with this releases very low therefore the risk put to the public safety is not very high and therefore it was justifiable especially when compared to the potential consequences of not venting it all because if you do not vent it out it will result in pressure raise and that will lead to explosion however unfortunately the Japanese case even explosion occur I will tell how because instead of sharing the containment structures integrity at least operators in presently release the PRV's and therefore.

They made the steam to escape in an environment however yeah agree with you yeah these gases contain some radioactive components but when compared to the consequences of the disaster of the containment itself I would strongly agree that, that was a intelligent decision remember such decisions can come only when you have been trying for safety or have an important education on emergency response planning guidelines.

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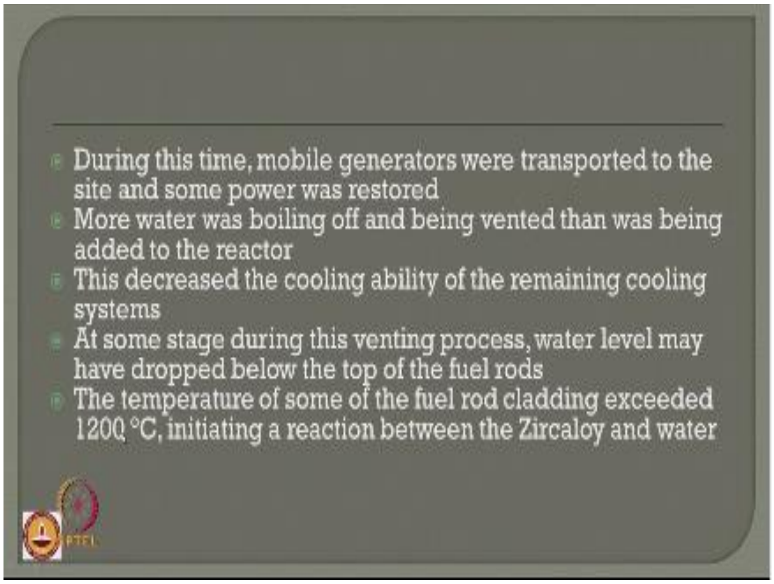

So during this time mobile generators were transported to the site and some power were restored more water was boiling of and being vented that has being added to the reactor to cool down the reactor this decrease the cooling capacity or the cooling ability of the reaming cooling systems of course the reaming cooling systems which are only partially working where again relief of because external water was being pumped.

No there is a problem here you need lot amount of water the amount of water required to cool the reactor is enormously high at some stage during the venting process the water level may even dropped below the top of the fuel rod and fuel rod is now very high temperature as high has close to 2200 centigrade so they need to be cool down the temperature some of the fuel rod exceeded even 1200 initiating a reaction between the zircaloy and water zircaloy remember is a second level of containment.

Even that started melting because a temperature is not coming down therefore they wanted more water to cool down the reactor.

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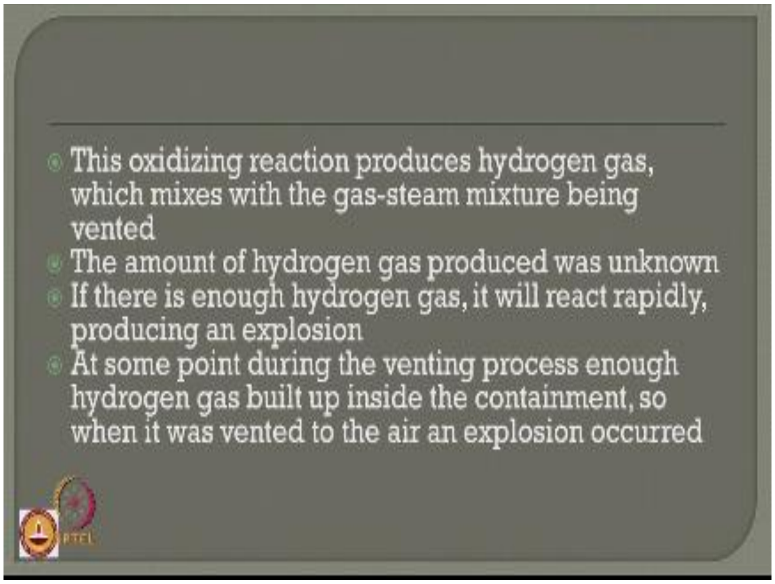

Intelligently this oxidizing reaction produces hydrogen gas because we are pumping water which mixes with the gas steam mixture being vented and the amount of hydrogen gas produced for really not known but however if there is enough hydrogen gas present this could have result in the explosion and that happened so in a some amount of external water being pumped in the reactor resulted in this process of casing an explosion so at this point during the venting process enough hydrogen gas was built of inside the containment so this was vented out to the air an explosion occurred.

So you can see this serious of fault occurred earthquake started earthquake damage the reactor it resulted in a power shutdown reactor was stopped moderate rods introduced there is no cool and supply available the external power was brought in Tsunami came the external power was damaged there is no power backup available after fw hours people brought up battery supply even battery supplied drained out but they could stop the reactor but they cannot stop the heat they pump and water.

They want to disable or relief of the cooling system this water produce hydrogen gas hydrogen gas release pressure result in the explosion you see these are all sequence of problems occurred at one plan though we are very unfortunate to know this happen in one part of the world which was very advance country but still I am happy to know that this as at least give a good education system to understand how safety we design safety be operation safety in process what is practice Japanese to the code so they could contain this the greatest possible extend without causing disaster to the society around the plant.

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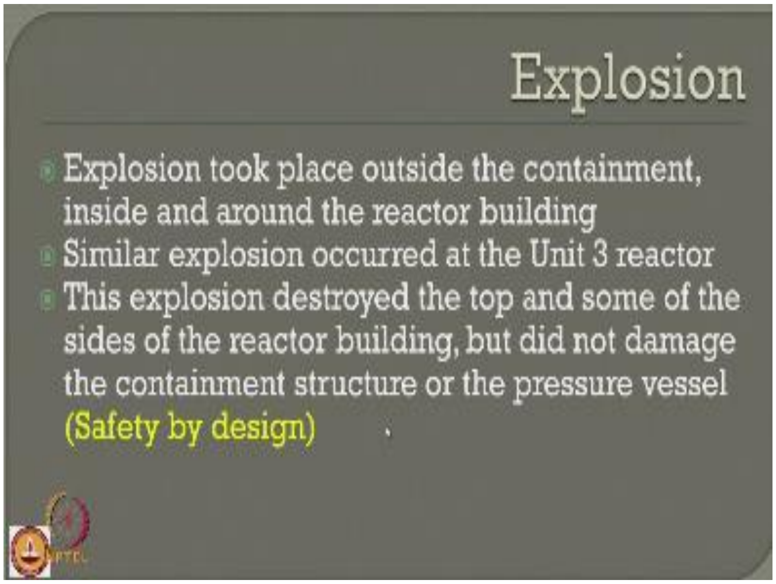

Now explosion resulted explosion to place outside the containment and inside and around the reactor building similar explosion occurred at unit 3 reactor as well this explosion unfortunately destroyed the top and some of the sides of the reactor building but he did not damage the containment structure or the pressure vessel remember this a very important appreciation I want applaud to the Japanese because is a very interesting and very through designed.

And therefore I would occurred this a safety by design interestingly understand even after all different system of regular occurred even then the pressure vessel.

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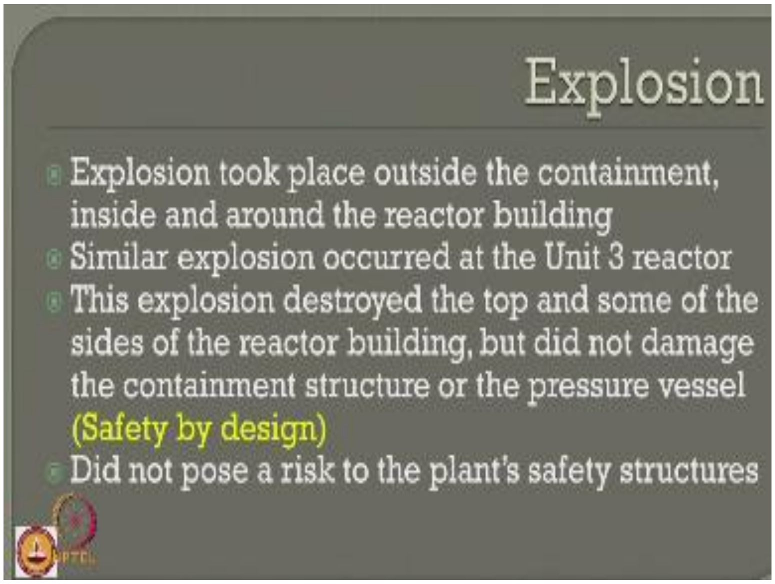

Did not damage so one can appreciate really how the design was so strongly tested for it safety even at the stage of explosion. Therefore this did not pose a risk to the plant's safety structures at all.

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We can see the picture where the thick smoke has been generated and they are not able to control the heat you can even see the blowing flames here they are not able to control this is after 13 hours of the earthquake and tsunami occurred.

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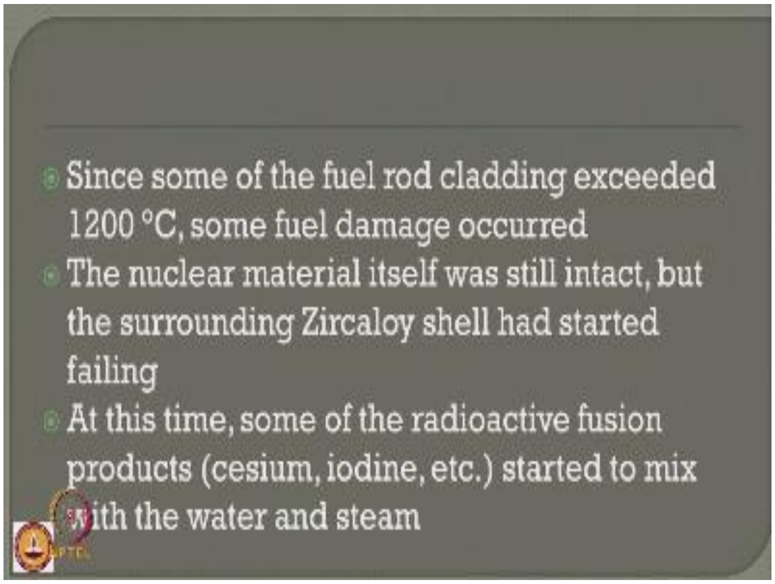

Let us see subsequently what happened since the fuel rod exceeded a 1200 degree centigrade some fuel damage occurred, the nuclear material itself was still intact but the surrounding Zircaloy had started failing at this time some of the radioactive fusion products like cesium, iodine etc, started to mix with the water and steam.

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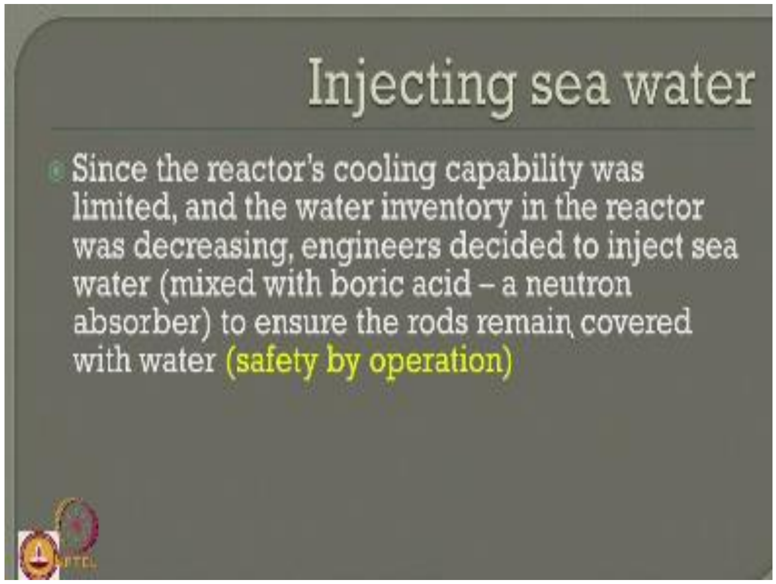

To control this injected sea water since the reactors cooling capability was limited and water inventory available in the reactor source was also limited engineers decided to inject sea water mixed with boric acid of course a neutron absorber they ensure the rods remain cover with water because if they are remain covered with water can come down the heat. Because a rods of now at a very high temperature of close to 1200 degree centigrade.

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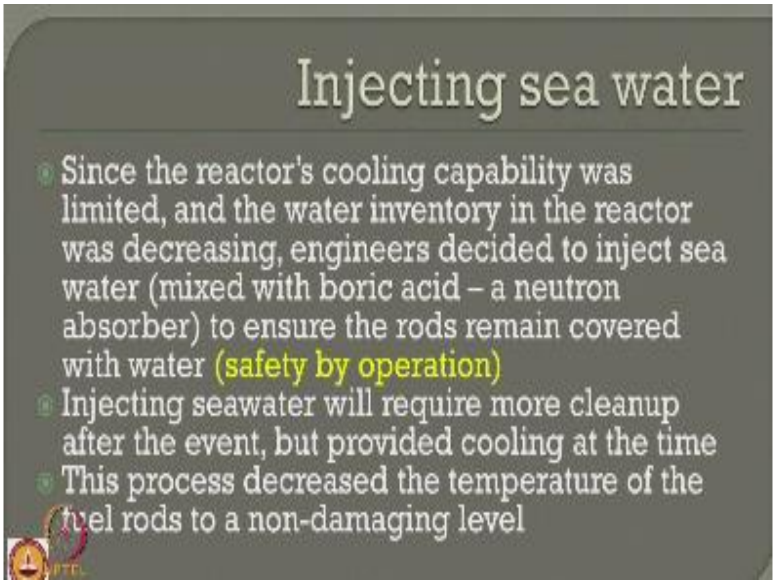

Now I would say this as safety by operation because that is not from the sea water directly they mix sea water with boric acid which is neutron absorber and then pump in, but even then injecting sea water will require more clean up after the event but provided cooling at the time to control the heat in the reactor. Of course fortunately and successfully this process decreases a temperature of the fuel rod to a non -damaging level.

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So this was the pumping sea water to the plant to control the heat.

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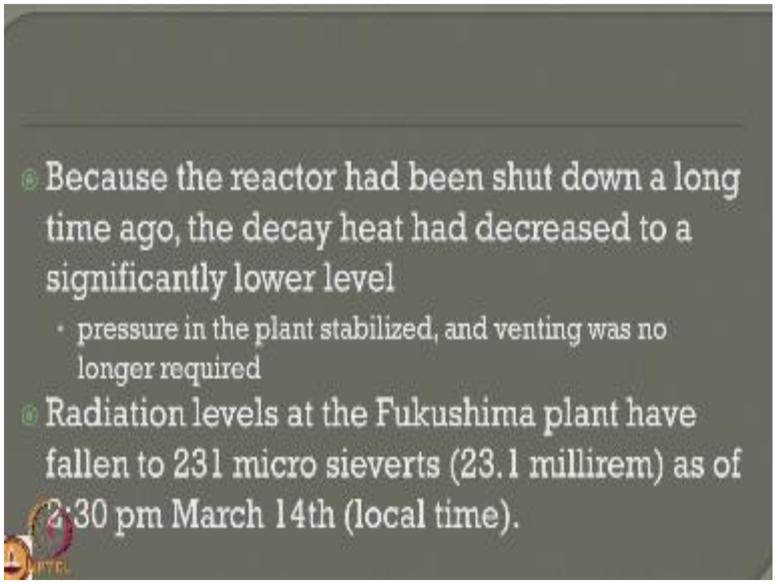

And because the reactor has been shut down a long time ago the decay heat as decrease to a significant lower level pressure in the plant stabilized and venting was no longer required that is how this was put to an end by the Japanese intelligence, radiation levels at the Fukushima plant have fallen to 231 micro sieverts which is equaling to 23.1 millirem as of 2.30 pm March 14 local time.

So interestingly friends we have understood the different lines of depends what this plan design had the different levels of safety and design and operation what they are practiced how the design was successfully done thought this product or this case study is not related directly to oil gas industry being a process industry understanding safety from such very interesting example I am sure what I emulate a new how safety by design safety by operation safety by training emergency response planning guidelines would easily help people to act or to react in such emergency situation.

So that the plant safety can be at least broad down to an acceptable level, now one interesting question to most of you is that what we understand by the micro sieverts.

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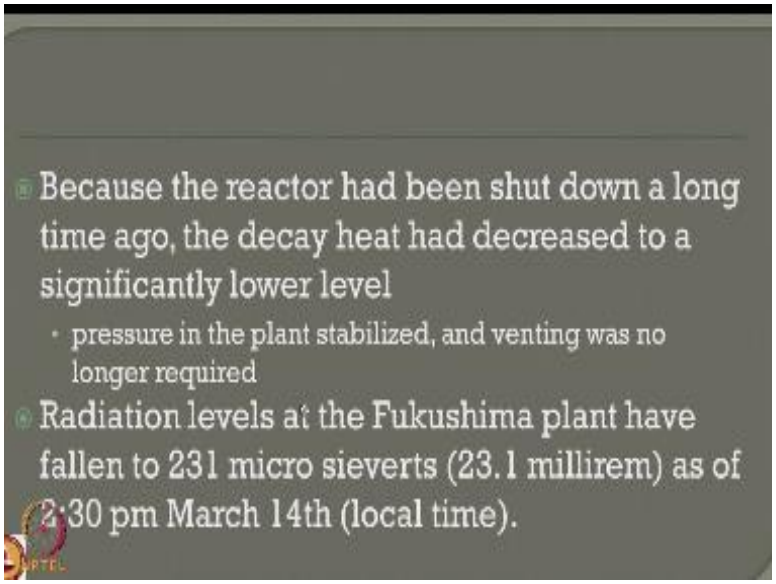

Is a unit to measure the radiation level let us see what is this because that gives the completion for the lecture.

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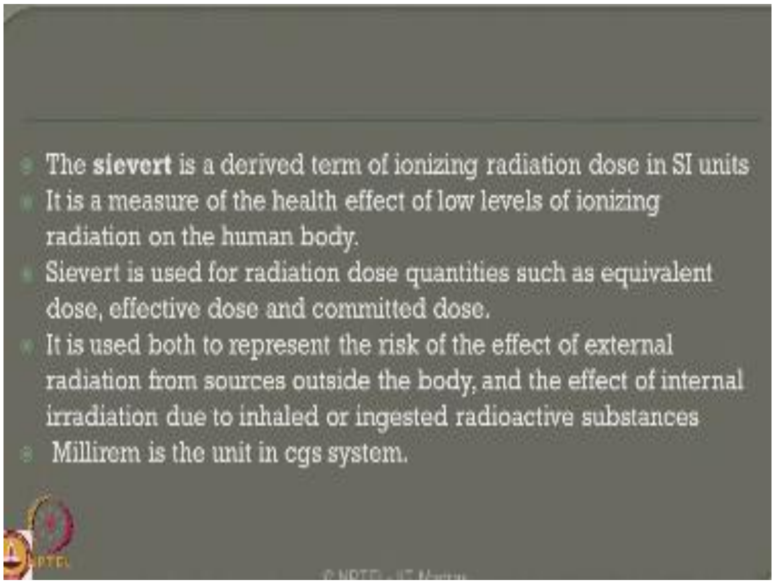

Sievert is a derived term of ionizing radiation dose in SI units, it is a measure of health effect of low levels of ionizing radiation on human body that is how the radiation effect on human body for ionizing radiation is measured actually sievert is used for radiation dose quantities such as equivalent dose effective dose and committed dose. It is use both represented the risk of the effect of external radiation from source of outside the body as well as effect of internal radiation due to inhaled or ingested radioactive substances. The other unit millirem is an equal unit of sievert in cgs system.

I hope friends we have enjoy this lecture because it gives a very interesting case study that discussion what we had with colleagues in IIT Madras which is help us to have the clear understanding of post accident scenario, ladies and gentleman my emphasis in the selected is that how would safety by design safety by operation can be easily plant and how hazards study can be executed so that advance safety features or failure of safety measures can be anticipated and the design can be modified using FMEA FMECA hazard study and safety by operations, thank you very much.

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