Power Plant Engineering
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Lecture – 28
Nuclear Power Plants- II

Hello, I welcome you all on this course on Power Plant Engineering and today we will discuss Nuclear Power Plants.

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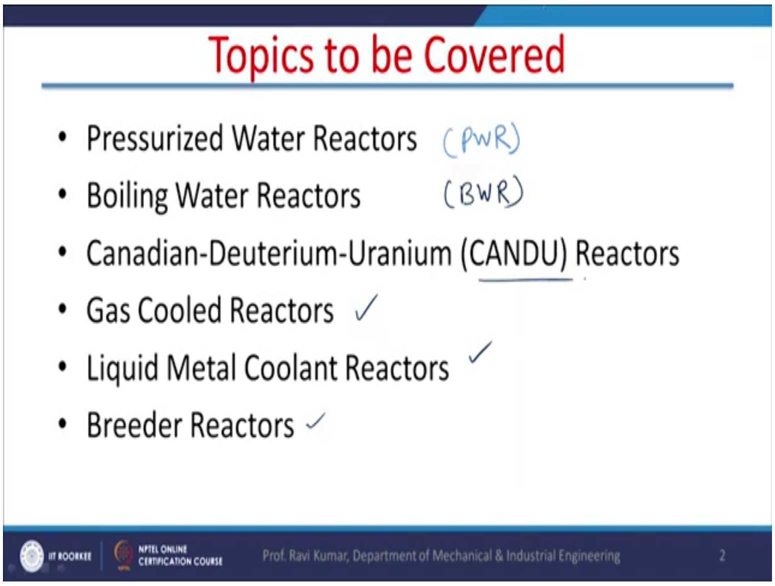

Topics to be covered in this lecture are pressurized water reactor, we will discuss pressurized water reactors, Boiling Water Reactors; BWR they are popularly called BWR. Canadian Deuterium Uranium the CANDU type of reactors, gas cooled reactor and liquid metal cooled reactor and breeder reactors. In short, I have already introduced you these reactors in my previous lecture, where now we will discuss them in details; we will start with the pressurized water reactor.

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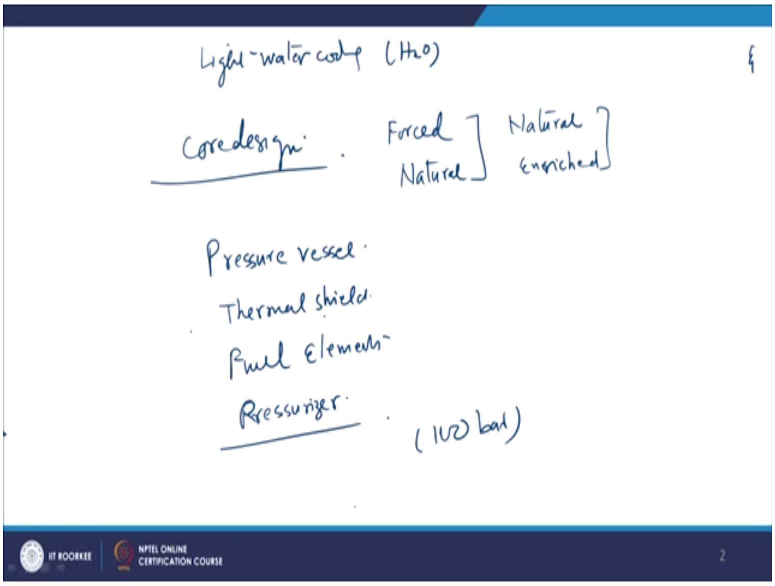

It is simple light water cooled, light water cooled means H 2 O; these are light water and heavy water. So, this is a light water cooled reactor. It is a very unusual core design this core design of this the reactor facilitates, forced and natural both type of cooling of the coal forced and natural. It facilitates both types of cooling and natural fuel and enriched fuel.

So, it is a very versatile type of reactor, it is a pressure vessel, it has a thermal shield also, fuel element, reactor pressurizer, this is a unique thing here pressurizer. Pressure is primarily very high I mean in this reactor and the pressurized up to 100 bar.

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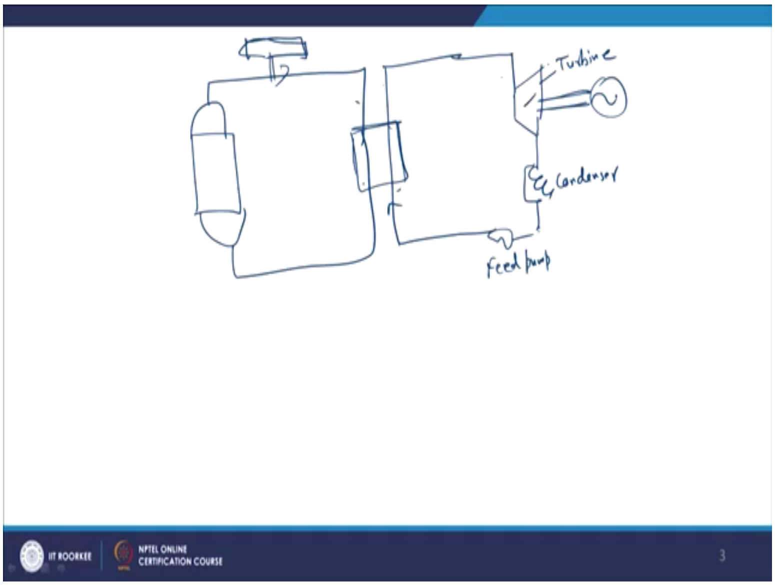

The primary circuit is pressurized up to 100 bar, if you draw this reactor suppose this is reactor core, there is a heat exchanger this we have done in the previous lecture also. Then, after the heat exchanger there is turbine condenser and then pump and this is how the water is circulated and this is a primary circuit this is heat exchanger and the pressurizer is provided here.

So, pressurize sometimes it is electrically heated to maintain the high pressure in the reactor. So, that steam does not form right. And, this turbine is connected this turbine shaft is connected to a generator to develop the power this is feed pump, this is condenser, this is turbine ok. So, there are two circuits primary circuits and secondary circuit as I explained earlier and this is and the generation of a steam, takes place in heat exchanger and this steam runs the a steam turbine.

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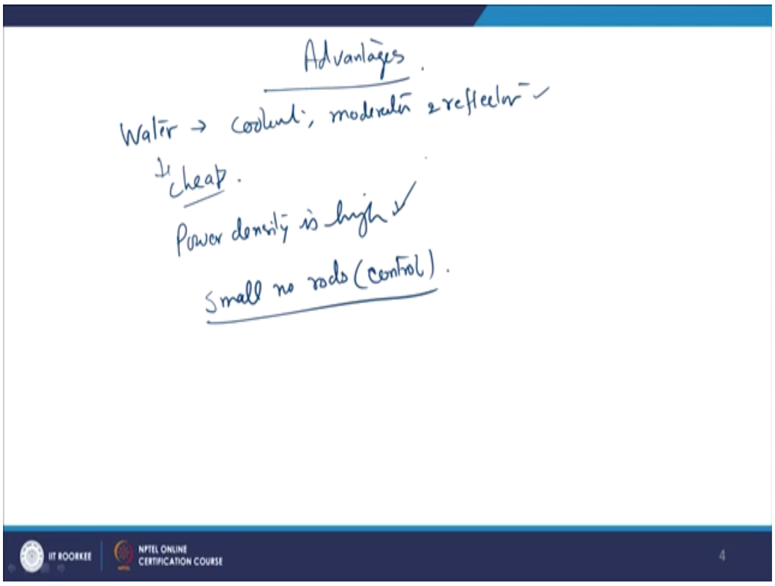

So, there are certain advantages of these reactors. Now, advantages is the water is used as coolant, moderator, and reflector. All three functions are carried out by the water and the water is cheap easily available. So, this is a cost I mean this reduces the cost of the reactor power density is high for this density is high for this type of reactor. And, fissured products they remain contained in the reactor, they are not circulated in the pipe, because they are solid fuel solid fuel is used. So, they remain contained in the reactor and small number of control rods, control rods.

Small a very small number of control rods are required in this type of reactor, if you compare with the other reactor, easy for inspection you can easily go inside and inspect the turbine because the non-radiation area. So, and per kg of fuel extraction energy is high power as I said power density is high that is also high, but per kg of fuel extraction of energy is also high in this type of reactors. It means less amount of fuel will be required for the same power generation, if you compare with the other reactors.

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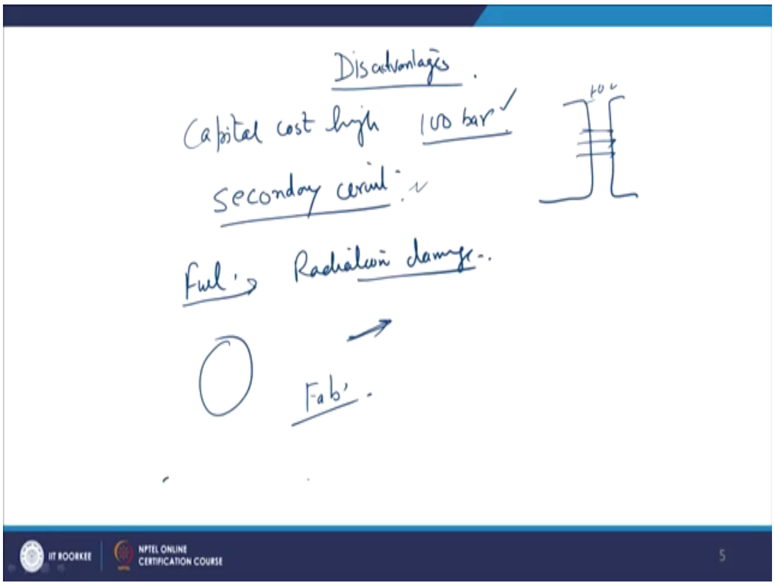

Now, there are certain disadvantage also. Capital cost is high; capital cost high, because if you remember in the primary circuit we have to maintain temperature around 100 bar. So, all the components are designed. So, that they can be their operation pressure is remaining 100 bar for the operational pressure of 100 bar. Now, secondly, it is using secondary circuit.

So, steam it has to this is primary circuit this is the secondary circuit. So, for the effective heat transfer at least there has to be temperature difference of 10 degree centigrade. More temperature difference is better, but at least it has to be around 10 for 8 to 10, approximately 10 degree centigrade.

So, definitely this affects the efficiency of the cycle on the other side right. So, that efficiency is comparatively low, there are because water is being used as a moderator and as a coolant or as a shielding material, because as a no shielding material as a reflector, the corrosion problem is there. So, corrosion problem has to be dealt with in this type of reactor.

And, the third one and the next one, which is quite serious is that when we want to change the fuel channels right, the reactor has to be completely shut down. So, it takes a gap of 1 or 2 months time. So, whenever there is a replacement of the fuel or the channel has have to be replaced the reactor has to be shut down for 1 or 2 months time. The fuel suffers the fuel in the reactor suffers the radiation damage, because it is confined to the reactor core insertion of control rod is also difficult this is such a compact design of this reactor, that insertion of fuel rod is also difficult in this reactor.

And, the fuel element fabrication of fuel element, it is also difficult in such type of. So, there are certain limitations or we can say disadvantage of pressurized water sorry this type of reactor. So, this is we are done with the pressurized water reactor right, the next is boiling water reactors.

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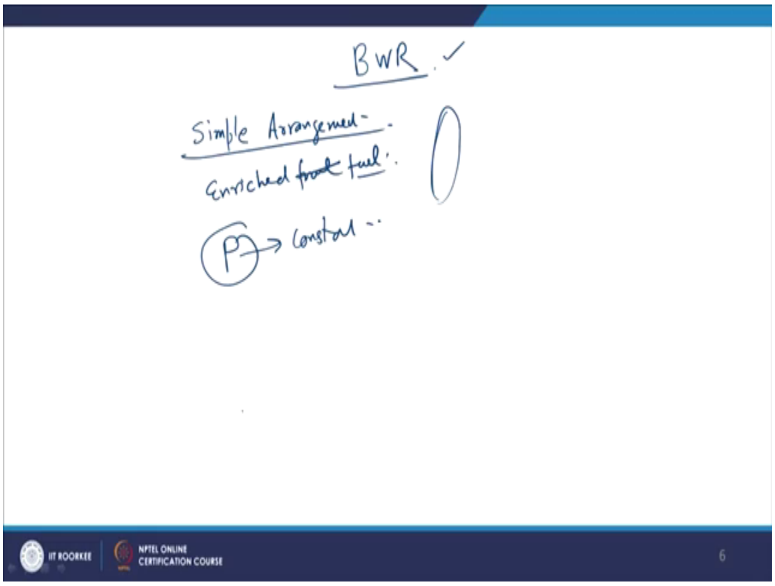

Now, the boiling water reactor as it is clear from the name itself, the water boils in the core right. And, this water directly is directly used for running the turbine there is no heat exchanger. The efficiency is certainly better than the pressurized water reactor. So, this simple arrangement, it is very simple arrangement and enriched fuel is used is used in the this type of reactor natural circulation is possible boiling water reactor natural circulation is possible.

And, here in the boiling water reactor the pressure has to be maintained constant ok, pressure has to be remain constant. So, suppose there is a power load there is a sudden decrease in the load, in that case a steam bypassing is done. So, when we are bypassing the steam, the same amount of fuel is used, but the less power is generated.

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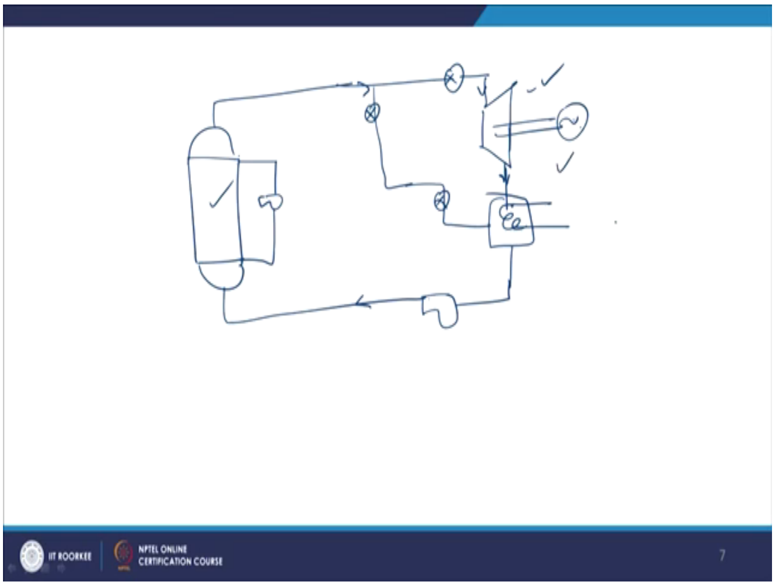

So, if we look at the arrangement of this boiling water reactor and this is a pump here, which is used for forced circulation it can be a natural circulation also, it directly goes the some walls you can show some walls and here there is a turbine connected to generator. And, here there is a condenser, which is used for taking away the heat and there is a feed pump right.

Now, there is a certain degrees in requirement of the power we lead this power. So, but the reactor core continue to generate a same amount of a steam and steam is bypassed steam is bypassed and it goes to the condenser directly bypassing the turbine, bypassing the turbine, bypassing the turbine right. In that case the efficiency is reduced drastically.

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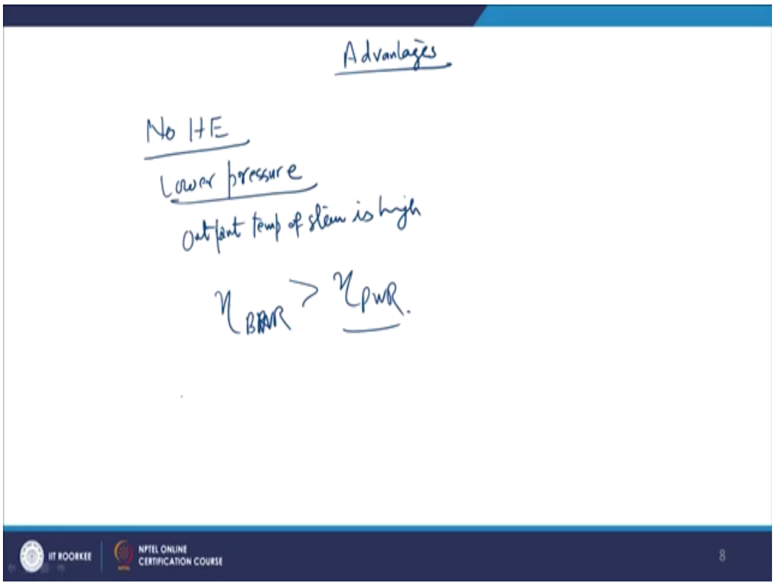

So, if you look at the advantages of a boiling water reactor advantages. Now, first of all there is no heat exchanger, no heat exchanger. So, when there is no heat exchanger definitely it helps in getting the efficiencies. So, efficiency improves lower pressure vessel, here we do not have to maintain very high pressure of the order of 100 bar. So, lower pressure vessel with the lower pressure vessel definitely there is a cost cutting in the material which is used for the fabrication of the reactor output temperature of a steam is high, because the inlet temperature is high.

So, definitely output temperature is also be high credibly high. So, it is efficiency of this boiling water reactor; water reactor is greater than the efficiency of pressurize water reactor right, but there are certain disadvantages also.

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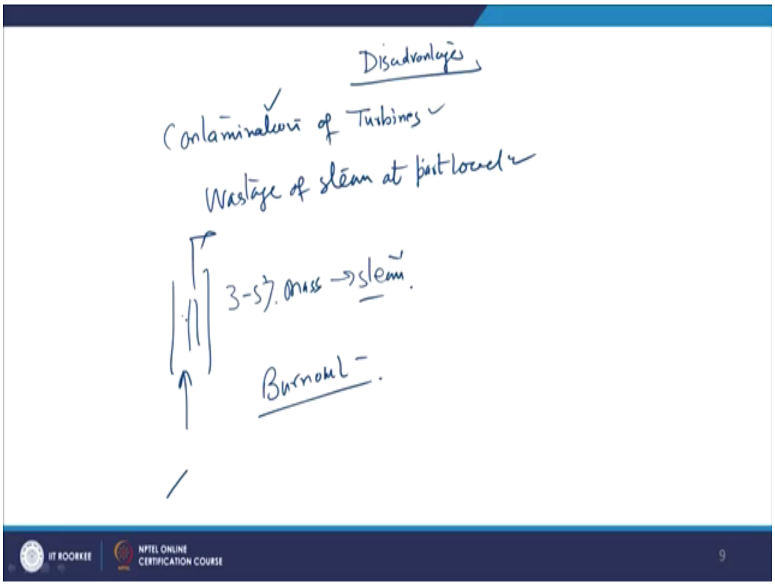

First of all disadvantage disadvantages, first of all contamination of turbines of turbines, because the coolant it goes to the core and then from the core it directly enters to the turbine, there is no heat exchange. So, this water which enters the turbines it contaminates the turbine. So, if there is any failure of the fuel element. So, the fissured material will also enter the turbine that is a dangerous situation right. So, this is the major disadvantage. So, more precautions are needed in case of the boiling water reactor. And, as I said earlier there is a wastage of a steam, at part load, at part load right.

And, it is power density is also limited, because in a boiler water reactor with the water enters from this side and leaves from the other side only 3 to 5 percent of mass it is converted into steam right. So, that is also a limitation of the boiling water reactor and another thing is the possibility of burnout, possibility of the burnout is more in the case of this reactor, because the coolant is indirectly contact with the fuel rod. Now, what is burnout?

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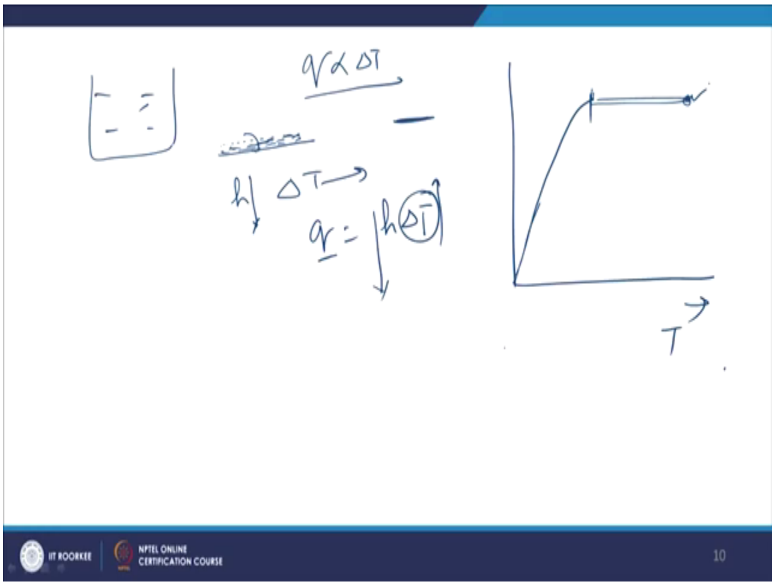

Now, if you take any pool of water right and keep on increasing the temperature and you keep on temperature in the temperature the heat flux will also increase, because heat flux is directly proportional to temperature difference right, it will keep on increasing it will reach a certain value. So, initially the nuclear boiling will take place and when the when there is a intense heating, in that case on the surface will start covering with a thin vapor film right.

So, the fuel will no longer remain in contact with the surface. In this situation and this situation because the heat trans steam out of heat has to be transmitted the delta T shoots exorbitantly, because the heat transfer coefficient reduces drastically and q is equal to h delta

T. So, when q is same because a constant heat flux due to formation of film thin film of the vapor I am just telling it in a nutshell ok.

So, the edge goes down drastically this increases delta T and delta T may increase up to such an extent that the surface may burnout, that is it is also known as this flux is known as critical heat flux, but burn out means physically the surface physically burns out and in this scenario, if this happens in the in this a boiling water reactor, the fuel will come out and it will get mixed with the coolant and this will lead to a very dangerous situation ok.

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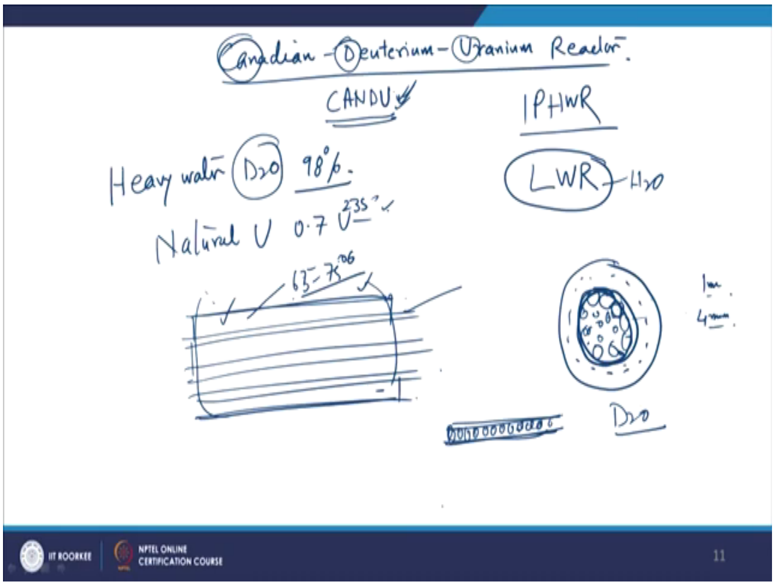

Now, the next type of reactor we are going to discuss is Canadian, deuterium, uranium reactor, this is known as CANDU type of reactor, Canadian, deuterium, uranium, CANDU type of reactor. And, in India many of the reactors which are work which we have in India, they are modification of CANDU type of reactor and they are known as pressurized heavy water reactor, or Indian pressurized heavy water reactor.

Now, in this reactor the heavy water is used as coolant, a heavy water that is D 2 o with the concentration of 98 percent with the concentration of a 98 percent natural uranium as a fuel use 0.0235. So, this is type of reactor is useful for the country, which do not produce enrich uranium because enriching uranium is also I mean it is a costly exercise, if you artificially, if you want to enrich uranium. So, those country which do not have the facility or which do not do the enriching of the uranium right, this type of reactor are suitable for those country. It differs from light water reactor, there is a the number of light water reactors.

In light water reactors the water H 2 O works as a coolant. Here it is differs from light water reactor in that manner only and here the heavy water used as a coolant, but the beauty here in this reactor is that only coolant has to be pressurized not the entire reactor only coolant has to be pressurized. So, in case of any accident in case of LOCA, the severity of the damage is very less right, if, you look at the arrangement of a typical CANDU type of reactor.

So, there is a voluntary shell. In shell there are number of channels maybe 300, 400, 200 depending upon the design of the reactor. So, there are number of channels right. And, each channel suppose I take 1 channel, each channel has a zirconium tube of let us say it depends upon the power generation, but normally the thicknesses is of the order of 1 millimeter or 1.2 millimeter, zirconium tube.

And, concentrically a zircaloy tube was also used this is a zircaloy tube off thickness around 4 mm, close to the 4 mm depends I mean crossly it is 4 mm. And, this tube has number of pins, fuel pins. Fuel pins are nothing, but the zirconium tubes of half approximately half is diameter and the uranium fuel pellets us are filled in the zirconium tube right. And, each tube is known as fuel pin and there can be a number of fuel pins in a grid right. Maybe 20 30 40 or 50 pins in a grid.

Now, in the void space between these pins the heavy water flows that is D 2 o, which flows in the void space between these pins. And, because the fission is taking place the fission heat which is generated in these pins is transmitted to the heavy water and part of the water is converted into this steam. Now, this is steam which is generated is collected in a header.

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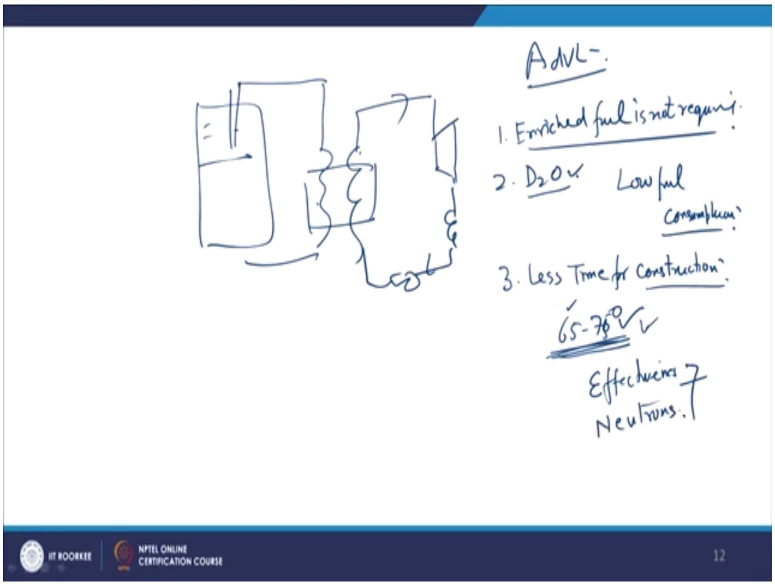

There is a steam header in the top part this steam is and the for the top this steam is taken and there is a heat exchanger again and through heat exchanger the heat is transmitted to the working in this fluid that is H 2 O water, and again it goes to the turbine, and condenser, and then pump, and again back to the heat exchanger right.

So, the beauty of this CANDU type of reactor is the pressure high pressure is there, but high pressure is there only in this pressure tube inside the pressure tube right. And, this part is covered is filled with the inert gas to in order to prevent the heat transfer and the entire assembly there can be a let us say 300 channels. So, 300 channels assembly of 300 channels is placed in a vessel which is known as calandria vessel.

Now, the advantages; advantages of this type of power plant first of all enriched fuel is not required. First of all enriched fuel is not required natural rename can work. So, and D 2 o is used as a moderator and only D 2 o is pressurized which is used as a moderator. So, sorry D 2 o is also used as a moderator not only as a coolant it is also used as a moderator. So, when as a used D 2 o is used as a moderator, it is multiplication factor is high D 2 o has a high multiplication factor and which results in low fuel consumption, right.

And, this calandria vessel the calandria vessel where the tubes are fixed it is not it does not work on a high very high pressure, it is works with the normal pressure. So, that material cost is also saved second thing is the ambient temperature is maintained between 65 to 75 degrees centigrade is between this range right. And, this because this vessel is also filled with the water.

So, it also acts as a I mean it also serves as a purpose of the safety also in this case, because we have several number of safety barrier. First of all fuel pin is filled with fuel and it is filled in the pin, which has also certain thickness, then there is a pressure tube, then surrounded by the calandria tube, calandria tube is surrounded by the calandria, sorry pressure tube calandria tube and calandria vessel.

So, level of the safety is more in case of CANDU type of reactor. Less time is needed for construction, construction ok. And, I said earlier the moderator which can be kept at as a 65 to 70 degree centigrade in this range right. So, we can extract more work out of the or we can. So, moderator can be kept and another point is moderator can be kept between the temperature of 65 to 75 degree centigrade, which increases it is effectiveness. It increases it is effectiveness and it slowdowns the neutron the neutrons are also slowed down.

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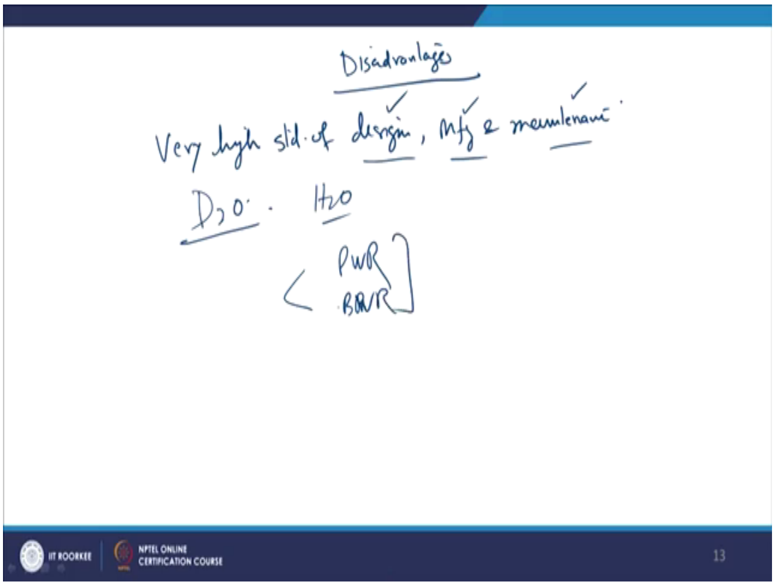

Now, there are certain disadvantages also, now very high standard of design, manufacturing and maintenance. These things of very high state of the art design is required for a CANDU type of reactor, state of the art manufacturing is required, because the several joints like roller joints are also have to be provided at the ends of the channel and high level of maintenance is required in the CANDU type of reactor.

The coolant and the moderator are D 2 o, which is also itself is costly if you compare the cost with the light water. There are certain leakage problems are also there in the CANDU type of reactor. And, it has low power density if you compare the power density of CANDU type reactor. So, it has low power density if you compare with the pressurized water reactor and boiling water reactor. So, for the generation of the same power more space is required by the CANDU type of reactor.

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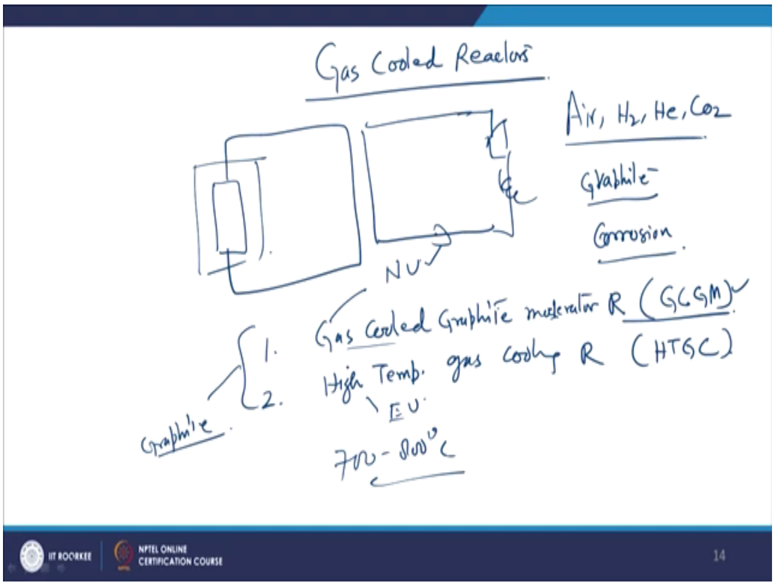

The next is gas cooled reactor. Now, in the gas cooled reactor all the reactors have, if you draw the schematic, all the reactors have this type of the schematic. Now, this most of the reactor have this type of the schematic now here condenser pump. Now, here the gas is used instead of liquid gas is used as a coolant.

So, air can be used as a coolant, hydrogen, helium, carbon dioxide, they can be used as a coolant. Here the moderator is graphite. In these type of reactor, the moderator is graphite, but the benefit is the problem of corrosion, which persists in the case of where the water is used. Here, because air or the gases are used, the corrosion problem is not there. This problem is not there, if accident happens they are relatively safe the level of safety is high, thickness of reactor shield is much reduced, there are 2 types of gas cooled reactors.

The one is gas cooled graphite, moderator, reactor. Graphite cooled, gas cooled, graphite moderator reactor. And, another is high temperature gas cooled reactor high temperature gas cooled reactors. Let us say GCGM and HTGC. So, there are two types of reactor gas cooled graphite moderator reactor and high temperature gas cooled reactor, both type of reactors has graphite as moderator. But, this reactor is uses natural uranium and this uses enriched uranium that is a difference.

So, this natural uranium is used in gas cooled graphite reactor and this uranium is used in high temperature gas cooled reactor. The pressure is 50 to 30 bars and the temperature goes to 700 to 800 degree centigrade right.

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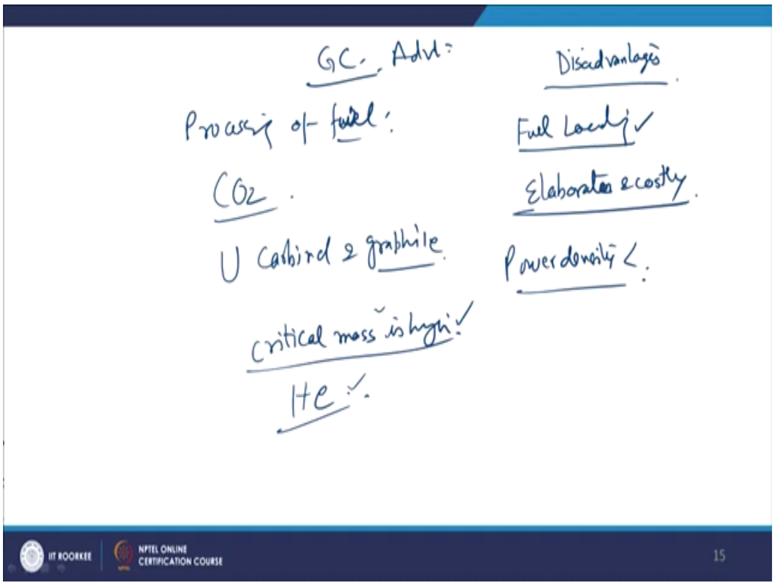

Now, advantages of gas cooled reactors gas cooled reactors advantage, but the advantage is the processing of fuel is simple; process of fuel is simple as I stated earlier there is no problem of the corrosion inside of the reactor and graphite remain stable under high temperature. It does not disintegrate.

And, if we are using C O 2, it eliminates any possibility of the exposure in the reactor also right. And this uranium carbide and graphite they are able to resist high temperature so, temperature. So, these type of reactors can be operated on high temperatures. Now, there are certain disadvantages also, fuel loading. Now, fuel because here we are using gas the density of gas is lower than the solids normally.

So, the fuel loading is elaborate and costly right, power density is low; power density is low right. Because, critical mass is high for this reactor criti so, high mass has to be loaded initially because critical mass is high, if critical mass is low initially low mass is required, but because here the critical mass is high mass is required is high mass of the fuel loading is required initially and the another thing is if you are using helium.

So, helium diffusivity is high for the helium. So, they are biggest problems if you are using helium coolant is gas. So, more power more bulk of the volume has to be handled by the pump. So, more power has to be consumed by the pump in these type of reactors. And, controlled in coolant is also complicated and because a negative coefficient of helium and it does not absorb the neutrons. And, gas cool next is liquid metal cooled reactors. In previous lectures also I draw I have drawn the schematic of the liquid cool where there are two heat exchangers.

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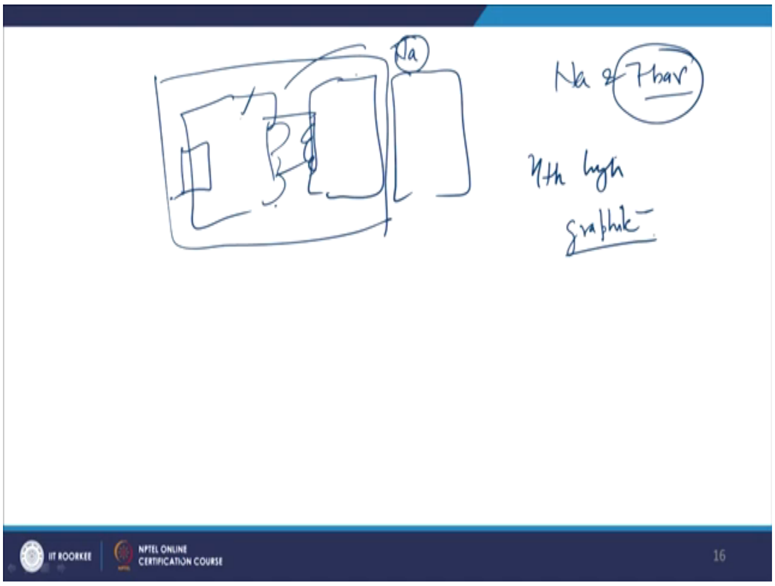

Where there are two heat exchangers right. So, in these liquid metal type of a reactors sodium is used at 7 bar, sodium boils around 800 degree centigrade temperature. So, the very high temperature can be maintained in such type of reactor. So, sodium can be pressurized or without pressure also even, we do not pressurize sodium in that case also this reactor can be can work efficiently. Thermal efficiency is high, definitely if a reactor is operating on a high temperature difference in source and sink is high. So, thermal efficiency is going to be high.

And, graphite moderator is used graphite moderator; even low cost graphite moderator can be used in such type of reactor. And, is this smaller in size; smaller in size and super heating is possible in such type of reactor, because they are operating very high temperature. But, the disadvantage is the sodium react very violently is water. So, in any case in the remotest of the possibility the mixing of sodium and water has to be avoided.

Otherwise very violent reaction will take place, thermal stresses because it operating very high temperature, thermal stresses is also an issue in these type of reactor. And, the heat exchanger in this type of reactors have to be leak proof, because if there is a leakage again there will be a reaction of sodium with the moisture with the atmosphere or with the liquid which is circulated in the secondary circuit.

So, that is why shielding of first and second stage is done right. So, the major disadvantages of this reactor is the leakage of sodium is very dangerous.

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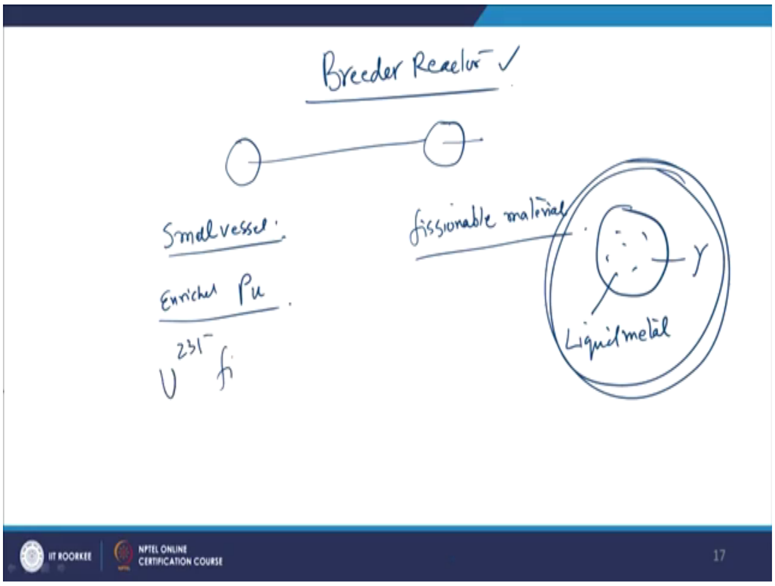

Now, the next one is the breeder reactor. Now, it is as it is clear from the name itself, the breeder reactor can also be used for generating fluid. In the breeder reactor the mass of the fuel or the fuel which is consumed and the end product is more fuel is more fuel is generated at the same time power is also generated.

So, it is used for the breeding or the generating the fuel and breeder reactor is also used for the power generation. So, it has a small vessel and some amount of enriched plutonium is kept with moderator, enrich and there is a fissionable material, which absorbs the neutron surrounding the vessel, which absorbs the neutrons surrounding the vessels the core is pulled by liquid metal.

So, liquid metal is a an additionals is because here the gamma radiations are also there. So, additional shielding is a very robust shielding is provided surrounding the reactor when uranium 235 is fissioned, when uranium 235 is fissioned enormous.

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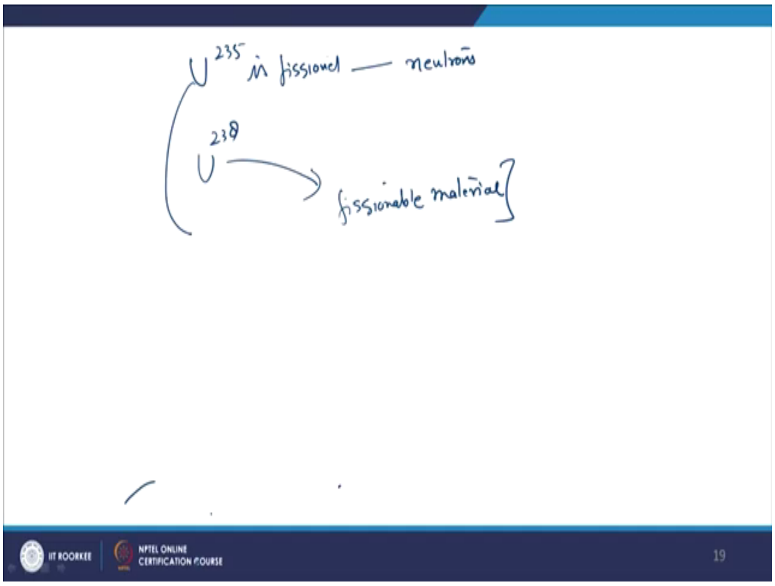

Heat is liberated and at the same time neutrons also or also liberated. If, U 10 38 is kept in the vicinity or a part of the reactor after the reaction it can produce. So, after reaction with 2 235 this uranium 238 can be converted into the fissionable material this is how the first breeder reactor work. So, it consumes the fissionable material and end product is more fissionable material and at the same time heat is also liberated which can be used for the power generation that is all for today.

Thank you very much.