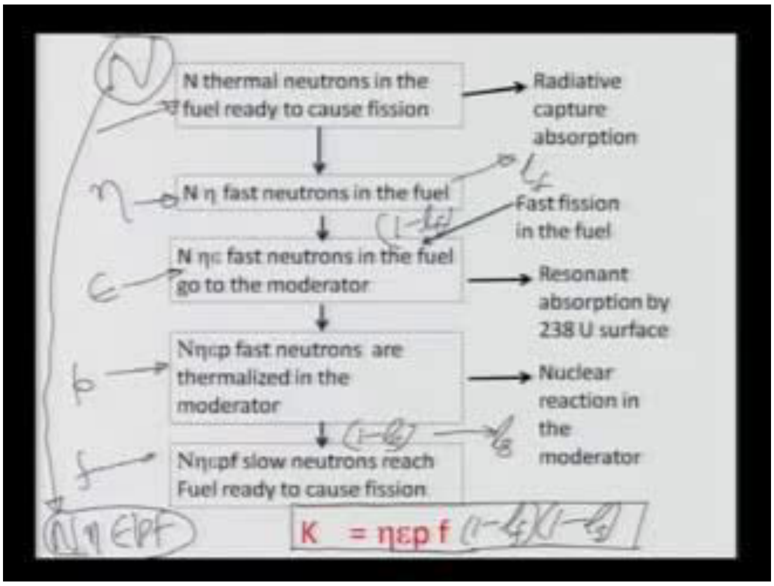
Nuclear Physics Fundamentals and Application
Prof. H.C. Verma
Department of Physics
Indian Institute of Technology, Kanpur

Lecture - 36
Nuclear Energy Programme of India

So, in the previous lecture we talked about the fate of neutrons in a nuclear reactor. You remember the design, you have fuel core which contains the fissile material and it is surrounded by moderators, the fuel rods are separated by the moderators in the reactor core. And once you have some thermal neutrons ready to fission; what happens to them that we discussed last time, just to remind you can look at the screen on which it is there.

(Refer Slide Time: 00:53)



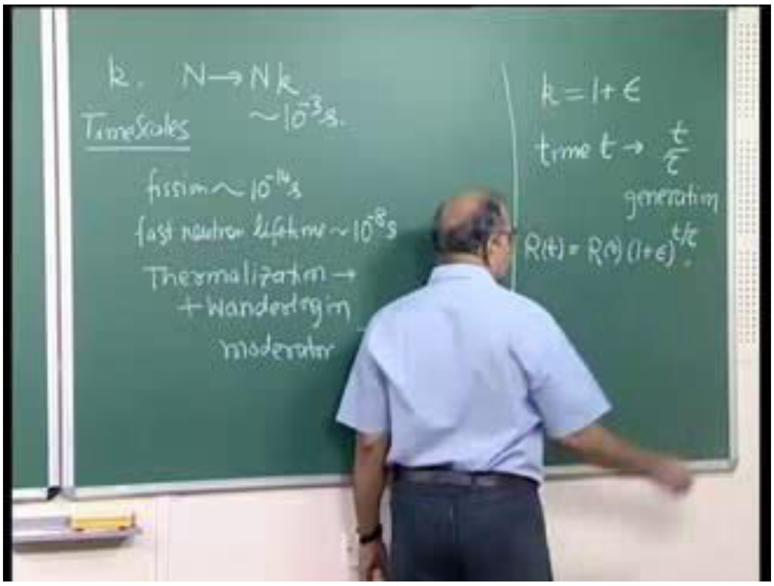
So, you have these n thermal neutrons in the fuel ready to cause fission. And of them some are radiative captured they are absorbed and they do not cause fission. Those which cause fission create more fast neutrons back factor we write as this eta. So, here it is so from n it is n times eta fast neutrons. Then you these some of these fast neutrons can also cause fission because of uranium 238. And that gives you this extra factor of epsilon. So, eta times epsilon then of these neutrons which go to the moderator some of them encounter the uranium 238 fuel rod surface. And they can get captured their through those resonance reactions. And therefore which are finally thermalized is here a factor p. And after thermalization also they keep moving in the moderator for quite some time and during that time they can interact with the moderator material itself. Some nuclear reactions can go in the moderator, and another factor f is converted is multiplied to get you slow neutrons in the fuel rods once again.

So, this is 1 complete generation or 1 complete cycle. So, in 1 generation; if you have these n thermal neutrons the next generation here you have these n eta epsilon p f thermal neutron. So, from 1 generation to the next generation the number of thermal neutrons in the fuel rod is multiplied by eta times epsilon times p times f which is known as reproduction factor. But we have missed some points all this is if you have infinitely big core in any real nuclear reactor you will have finally a finite volume. And the neutrons which are moving with fast neutrons or slow neutrons; they can just leak out of that volume that can go out of the reactor core volume.

So, fast neutrons here they can these fast neutrons which is produce some of them can go out of the of the core volume. And that is that factor is leak factor l f then only 1 minus l f that factor is going to the next channels. And similarly once they are thermalized slow neutrons slow neutrons also during their random wondering; they can move out of the core volume and that slow neutrons leak. If you write that as l s then only that 1 minus l s factor that will be surviving. So, this should be multiplied by those factors 1 minus l f and 1 minus l s. So, the fast neutrons are leaking through the core volume and slow neutrons leaking through the core volume that should be taken care.

Then, it is the reproduction factor k. Without these leak factor sometimes people say it k infinity; assuming infinitely big core the factor will be eta into epsilon into p into f which is known as 4 factor formula because there are 4 factors here. So, this is you are going from 1 generation to the next generation; this is the factor k by which the number of thermal neutrons in the fuel rod ready to cause fission gets multiplied. Let us see something else.

(Refer Slide Time: 05:17)



So, that factor k is the factor by which the thermal neutrons are getting multiplied from 1 generation to the next generation. But how much time does it take from going from 1 generation to the next generation the time scales? So, the time scales if you look at the if the thermal ((Refer Time 05:56)) get absorbed in uranium 235 they will fission almost instantaneous some 10 to the power minus 14 seconds or so. But then the fast neutrons which are created they will take some time wandering here and there. And they that lifetime of that neutron before it gets absorbed or it causes fission or something; that is something like 10 to the power minus 8 second.

So, fission itself may take very small time but then the fast neutron lifetime in a typical case maybe something like 10 to the power minus 8 second. Then they go to the moderator and their energy is reduced because of the collisions in the moderator. And that thermalisation that will take some time and not only that after thermalisation also this slow neutrons keep moving in the moderator volume; here and there scattering from the moderator material. So, that time before they really get into the fuel rod that wondering time; if you add that also wandering in moderator that is something like say 10 to the power minus 4 to 10 the power minus 3 second milliseconds less than a millisecond. So, that is the largest time in all these. So, that finally decides the time scale going from 1 generation to another generation; it takes about a fraction of a millisecond.

So, in that fraction of a millisecond 10 to the power minus 3, 10 to the power minus 4 seconds; those capital n thermal neutrons in the fuel ready to cause fission have become capital n into k; this k times. So, N becomes N times k in this time frame 10 to the power minus 3 seconds let us say. Therefore, it is essential that the reproduction factor this factor k is kept exactly at 1 almost exactly at 1. Because if it is less than 1 then every millisecond; the number of neutrons present in that thermal neutrons present is going down.

And, whatever energy is created from this nuclear reactions it is proportional to the number of these neutrons in the core. And every millisecond if it is going down very soon it will reduced to almost 0 and the chain reaction will stop. Similarly, if this k is slightly more than 1; then every millisecond the number of neutrons will keep on increasing by this factor k which is more than 1. And in every short time the rate of reactions will be so high that it will be uncontrollable; one can work out a formula for that. If you write k as 1 plus epsilon; where epsilon is a small quantity ideally we would like to keep it at 1; so that the chain reaction sustains just sustains. So, one neutron causes fission and from that several neutrons are emitted.

And, only one neutron of that on the average causes the next fission; that is the ideal controlled nuclear reactor situation. But if it is slightly more or slightly less you can write it like this. In time t you have t by tau generations going on; where tau I am writing for this generation time scale here 10 to the power minus 3 seconds or so. So, these many generations have gone each generation it is getting multiplied by k that is 1 plus epsilon. Therefore, the rate of reaction r at time t will be rate of reaction time 0 and 1 plus epsilon that is the k t by tau power t by tau.

(Refer Slide Time: 10:57)

$$R(t) = R(0)\,(1 + \varepsilon)^{t/\tau}$$

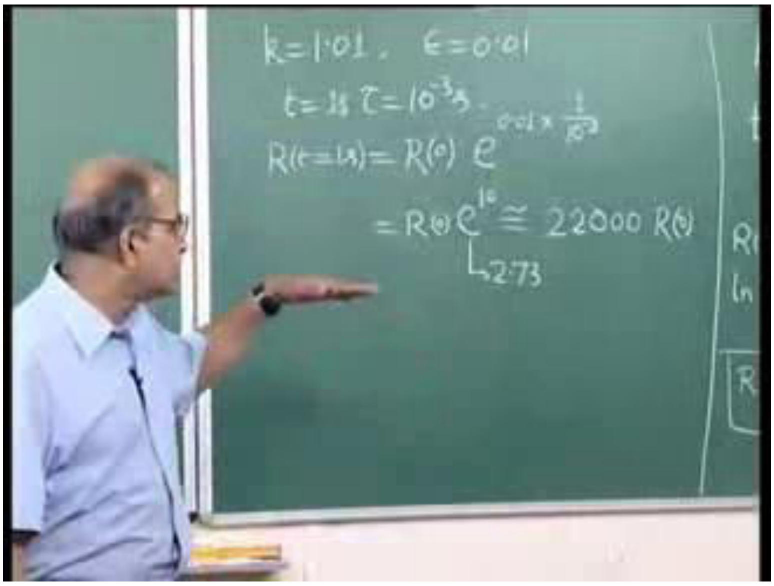
Or, $$\ln R(t) = \ln R(0) + t/\tau \ln(1 + \varepsilon)$$

Or, $$\ln R(t) \approx \ln R(0) + \varepsilon\, t/\tau$$

Or, $$R(t) \approx R(0)\, e^{\varepsilon\, t/\tau}$$

So, the rate will depend on time, the rate will increase with time if epsilon is positive through this. You can write it in a more familiar fashion you can take log of so ln (R) is equal to l n R(0). And then this will be t by tau and ln this is log on the base e; that is 1 plus epsilon here. And for a small epsilon this log of 1 plus epsilon to the base e will just be epsilon log of 1 plus x that series if you remember f starts with x minus something plus something. So, this is ln R(0) and then t by tau and then this is epsilon. And therefore if you write R that will be equal to R naught e to the power epsilon times t by tau. The rate changes exponential if the epsilon is positive it grows epsilon is negative a it goes down; but it goes exponentially and the rate changes very fast.

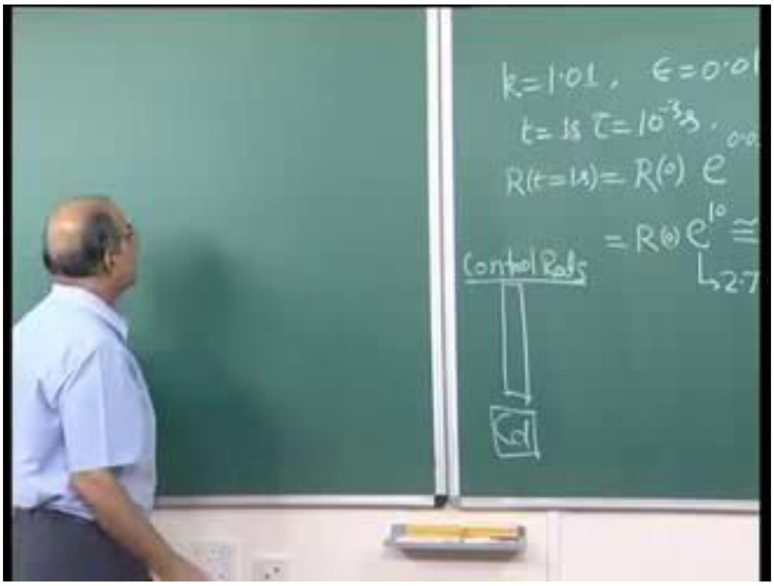
(Refer Slide Time: 12:24)



A typical example we can take suppose k is 1.01; so that epsilon is 0.01. And in 1 second what happens to the rate? So, 1 second if t is 1 and if tau is 10 power minus 3 second; t is 1 second. Then this will be r at t equal to 1 second will be equal to r at 0. Then e to the power epsilon which is 0.01 and that is multiplied by t by tau that is 1 second; and divided by tau is 10 power minus 3 here. So, it is here. So, that will be 1000 and this will be 10. So, it is r into e to the power 10; e is remember it is around 2.73 or so. So, you can work out or your calculator how much is this e to the power 10? And that will turn out to be approximately 20000.

So, you rate is increased approximately by this factor 20000 in 1 second. So, every second the rate is increasing by more than 20000 factor. So, even a small increase in this reproduction factor k can lead to a very high energy output in very short time; and it can be difficult to control and the things can go up. And therefore it is it must be maintained almost exactly at 1. How does one do that for that one uses this control rods.

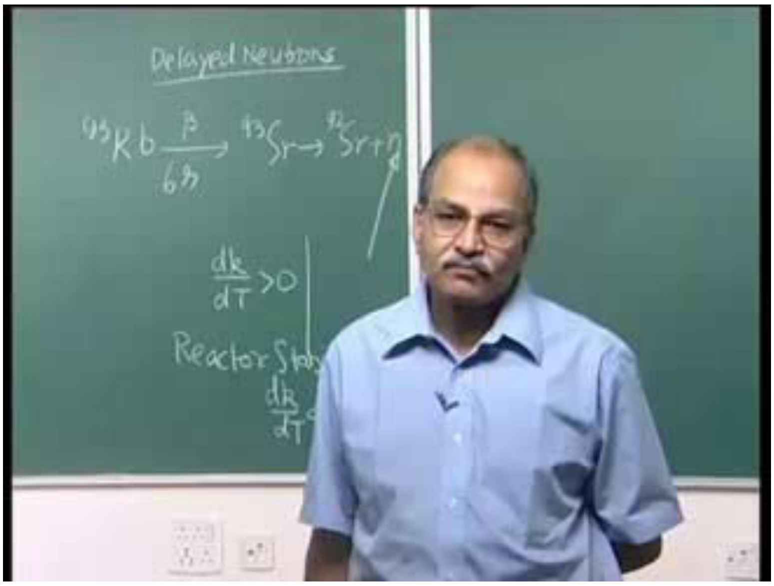
(Refer Slide Time: 14:30)



Control rods are some rods made of materials which absorb neutron; cadmium is the most popular choice cadmium absorbs neutron. So, these rods are put in the core and the fuel rods are separated and these control rods can just go in between. So, when you want to slow down the reaction; these control rods are pushed inside. So, that they start absorbing more neutrons and the rate goes down and if the rate has to be increased; if k has become less than 1. And you want to make it k equal to 1 that is called critical; the reactor is critical. When k is one reactor is critical and if it is less than 1 it is called subcritical and if it is more than 1 it become supercritical dangers.

So, if it is subcritical and you want to make it critical; you want to increase the rate of this fission reaction these cadmium rods are lifted up. That means, up or whatever so that less amount of less fraction of those rods are inside the core. So, that is how it is controlled but if it is controlled by this mechanical moment of these rods. Then these mechanical moments cannot be or it is very difficult to control that at this millisecond time scales 10 to the power minus 3, 10 to the power minus 4 second time scales. In that time scale it has to mechanically go in or mechanically go out that will be very difficult. So, how that is done?

(Refer Slide Time: 16:29)



That we are help with a phenomenon which is known as delayed neutrons I talked about it earlier. In a fission reaction some neutrons are immediately emitted those are known as prompt neutrons; and we had talked about prompt neutrons in this 4 factor formula and all that. But then some of these fission fragments they emit beta rays to reduce their n by z ratio; and the product nucleus of this beta reaction that emits neutron. So, that is also possible. For an example, if you have fission fragment say 93 rubidium. So, this 93 rubidium that beta decays with a half life of 6 seconds and beta decays to 93 strontium. And this 93 strontium then emits a neutron and it becomes 92 strontium.

Now, this neutron that is here; it has come on the average 6 second later than the main fission event which has emitted which has created this fission fragment. So, this neutron has to wait because it will come from 93 strontium. And 93 strontium will be created from 93 rubidium through this beta decay process which has a half life of 6 seconds. And therefore this neutron will come with a delay of this order of time. So, these are known as delayed neutrons. We had talked about these delay neutrons earlier they are about 2 percent of the prompt neutrons but that 2 percent gives us the handle. The whole design is made so that only on prompt neutrons the reactor it is slightly subcritical.

And, then only when these delayed neutrons are taken into account it becomes critical. So, if that be the case only these delayed neutrons are needed through make it critical and these delayed neutrons are coming after few seconds or 10 seconds or 6 seconds or 2 seconds or 5 seconds or 20 seconds. Then we get enough time to control that mechanical moment to follow the variation in k. So, that is how it is controlled. Another aspect of this chain reaction sustained chain reaction is that this reproduction factor depends on the temperature. Because reproduction factor has all those absorption cross section and different reaction cross sections and so on and these depend on the temperature. So, finally, this k also depends on the temperature.

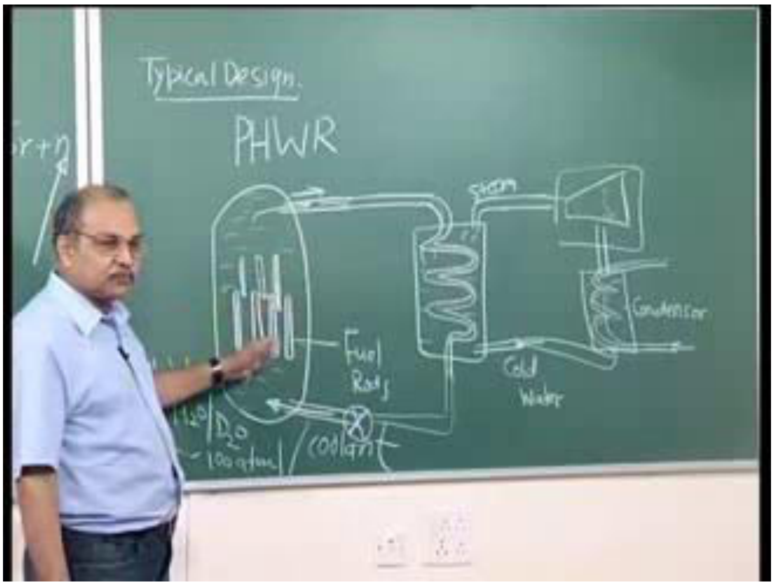
So, if the temperature goes up k can increase, k can decrease depending on the material, depending on the geometry and depending on the design. Now, if this k happens to be increasing with increasing temperature then the situation will be difficult to control. Because if the rate of reaction by any chance goes up and if the k is also increasing with temperature. So, in that case so that means d k d t this is greater than 0 and by the chance this temperature increases in the core. Because of anything less coolant flow will talk about the coolant and all that due to factor if this temperature goes up and k also increases. Then the rate of reaction will further be increased. It has increased because of some factors which we were not able to control.

And, then the reaction rate also increases because of the increase in temperature. And as reaction rate increases the temperature will rise further and as the temperature will rise further the reaction will rate will again increase. So, it is something like unstable equilibrium in mechanics; where you are sitting at the top of the of this potential function. And if you slightly displace it further get displace and displace and displaced. Similarly, here if by any chance temperature increases due to some factors reaction rate increases. And reaction rate increases temperature increases further; the temperature increases further the reaction rate again goes up because of this positive factor. So, this is dangerous type of situation. So, for reactor stability what we say reactors stability.

For reactor stability this d k d t this should be negative. The choice of materials, the choice of design all that should be such that k as a function of temperature should give you d k by d t negative. In that case if the temperature goes up because of some factors the k the value of k decrease. So, the neutron multiplication is not that high and the rate of reaction will decrease; and that will be some kind of self correction. If the temperature has increased the rate of reaction has decreased and the temperature has also gone down. So, this is for stability for reactor stability this d k by d t that should be less than 0. So, there are many things in reactor design I am only telling some essential parts in it.

Now, what is the output of this reactor in what form the output is? And in what form we need that output? The output of nuclear reactor is in the form of this thermal energy generated. Even this fission takes place then all this kinetic energy of the fission fragments and the neutrons all that is absorbed. Finally, in that core volume itself and that increases its temperature. So, we say that heat is generated, a thermal energy is generated. That is the primary output in the core volume itself. After that what use we have to make the most common use is power generation electricity generation. So, there are there the other users can also be there to drive submarines to get some kinds of neutron beams for research and so on. But let me talk of the electricity generation using this nuclear reactor. So, the heat that is created in this reactor volume that has to be taken out and then put in some use.

(Refer Slide Time: 24:30)



So, for that a typical design which most of Indian nuclear reactors have is what we call pressurized water reactor PWR. And in place of water if you use heavy water then it is PHWR pressurized heavy water reactors. Most of our 20 nuclear reactors in India which are commercially producing electricity 16 are of this type. So, what is that? In this that reactor core; say this the reactor core which contains all those fuels and control rods. Let me schematically say that these are the fuel rods and these are those control rods. So, the control rods can be inserted in can be taken out and in this we put water or heavy water at very high pressure. So, this is water H2O or D2O at very high pressure and pressures are of the order of say 100 atmosphere.

And, this is sent into this at high pressure some pump is there, some tower in there; from there this pressure is maintained. And this water is pushed in and that this water goes out of this through another outlet. So, it goes out and at this higher pressure the boiling point of water goes up and reaches something like 300 degree Celsius or so. And therefore it remains in liquid form although the temperature increases to say to 250 degree or so much above the normal boiling point. So, the heat of this core is taken out of this core through this coolant this is coolant; this water acts as coolant one can have another types of coolant depending on the design. But for this PWR or PHWR it is cooled by this high pressure water maintained at high pressure, water sent at high pressure and then taken out. Not only acts as the coolant to take the heat out. It is also the moderator the same water is also the moderator.

So, the fuel rods are surrounded by moderators so that water is acting as moderator. And the same water is taking away the heat is getting heated because of this coolant cooled water is coming from here. And then hot water is going from here; it is a heat is taken from here. Now, after that the heat is use for steam generation to run a turbine; it will go in some kind of heat exchanger. You can have different designs of heat exchangers one design would be to take tubes take this water through tubes and so on. So, hot water is coming like this at some 250 degrees or so at very high pressure. It will finally be recycle this will go here when it becomes cold it will go here. And here one can send say cold water at relatively low pressure.

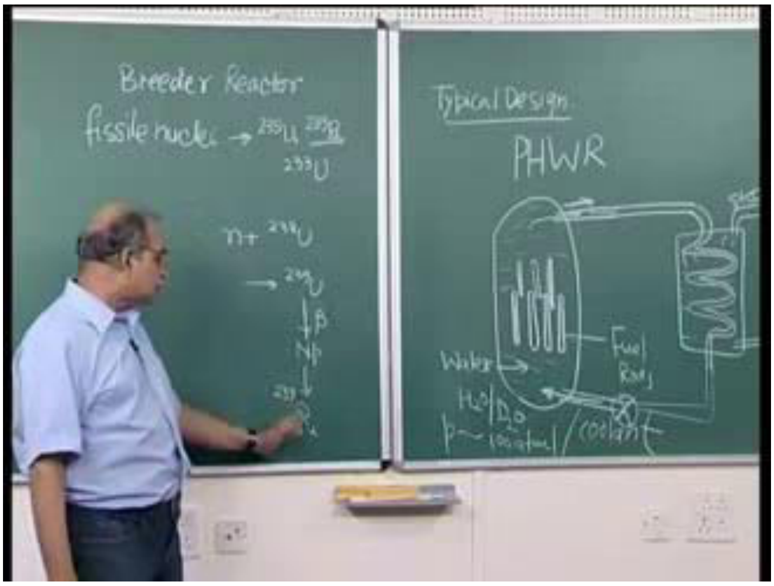
So, that heat is given by this hot water in the tubes to the cold water in this chamber; and this water boils because it is not at that high pressure. And therefore it boils and makes steam. So, here it makes steam and that steam can be taken to that turbine chamber. So, that turbine chamber to run that turbine and then that steam can go to another heat exchanger. And from here that steam can you can call it condenser. So, you sent this cold thing here. So, this steams becomes water condenses here and then it can that coldwater can go to this. So, the coolant and the moderator both functions are done by this water or heavy water. What is the difference between water and heavy water? Moderator has to be a low z material.

If it is low z material it will reduce the kinetic energy of the neutron very effectively. And therefore water which contain hydrogen the lightest nuclei would be ideal from that kinematics. But then the neutron absorption is also very important; this proton or hydrogen nucleus proton that can capture a neutron to make a stable isotope deuteron. So, there is a reasonable cross section for that. So, the neutrons get absorbed significantly if you if one uses light water. In that case to keep the reaction at reasonable rate one has to use enriched uranium. So, uranium has 0.7 percent of uranium 235. And this uranium 235 is the main nuclear fuel in this type of reactors. So, it has to be enriched some 3 percent, 4 percent and 5 percent then light waters can be used as moderator.

But if heavy water is used in moderator then that absorption cross section for neutron is small. Although deuteron can also absorbed neutron to make that triton 3 h and worse it is radiative; deuteron is not radiative this triton is radio actor. But then the cross sections are small the probabilities of that adoption is much smaller than the probability of proton absorbing a neutron and making deuteron. So, with heavy water as moderator coolant one can use natural uranium without enrichment.

So, it is a trade off; heavy water is costly one has to make heavy water from light water that involves its own complications. But then this enrichment of uranium that is that can be saved a unnatural uranium can be used. So, that that is the difference between PWR and the PHWR. Now, another type of reactors are called breeder reactors; in fact Indian nuclear program is called 3 stage nuclear program. So, let us first talk what is breeder reactor?

(Refer Slide Time: 32:56)



Breeder reactor is where you breed the nuclear fuel. You know the fissile material uranium 235 and plutonium 239 and uranium 233 fissile which can be used in a nuclear reactor where neutron goes into it and makes the fission. Now, let us take this as a typical example uranium plutonium 239. How this form? It is formed by the absorption of neutron in uranium 238 that gives 239 uranium and then it beta decays. And after beta decay it gives you neptunium and that gives you finally plutonium 239. So, it can be produced plutonium 239 can be produced if neutron is bombarded on uranium 238. Now, in a normal power reactor thermal reactor where we use natural uranium has a fuel or even enriched uranium as a fuel; there is a lot of uranium 238 available. For natural uranium you have 99.3 percent uranium 238.

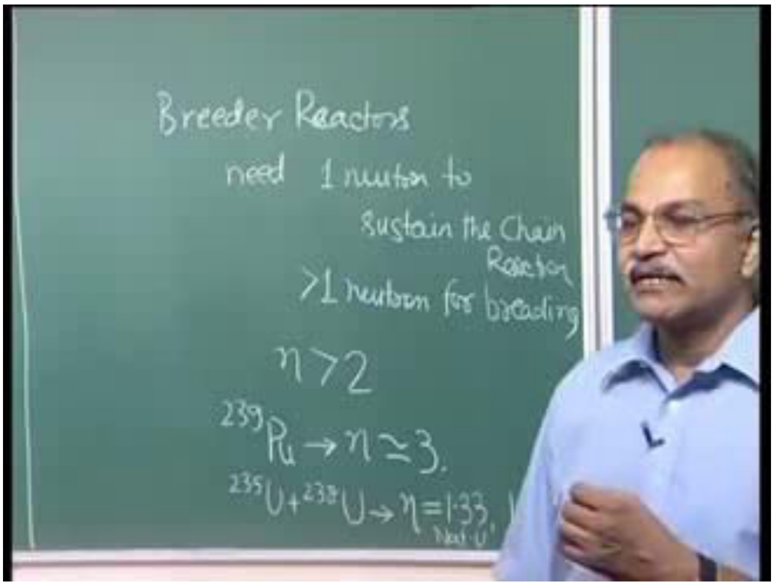
And, even if you enriched the uranium to some 4, 5 percent of uranium 235 you have lots of uranium 238 available. Even the spent fuel rods where the uranium 235 is now over or it is so small that it is it cannot be used any more for power production it is uranium 238 in plenty. Now, of the fast neutrons which are created in fission event 1 neutron can go to this uranium 238 and make it plutonium 239. You will be producing new fissile material. So, if a reactor is designed in such a way that from fission you have say 2.5 neutrons and 1 neutron is needed for sustaining the chain reaction still you have 1.5 neutrons; if it can be designed that out of that 1.5 one is directed towards uranium 238.

Then, you are producing one fissile nucleus from when you consume one fissile nucleus of uranium 235. So, this type of reactor although with 2.5 neutrons it will be very difficult to do this. But this type of reactors which consume a fissile material to produce electricity your power or whatever. And then from the neutrons which are being lost radioactively captured this that. If 1 neutron can be assured to cause this conversion of uranium 238 to plutonium 239; we are just producing the same amount of fissile material. And if it can be more than 1 on the average then we will be producing more fissile material then what we are consuming. Such reactors are called breeder reactors. So, you have seen that these neutrons which are produced in fission reaction.

If it is uranium 235 you get something like on the average nu equal to 2.5. And if it is mixture of uranium 235 and uranium 238 which will always be the case with lots of uranium 238. The average number of fast neutrons which come out from one fission reaction in a natural uranium or enriched uranium will be much less than 2.5. For natural uranium it is 1.33 and for 3 percent enriched uranium it is 1.84. Why? Because uranium

238 which is plenty in that mixture in that fuel that is not given the fission that is only absorbing the neutrons. So, in that sense the factor is not 2.5 the eta that we use in that 4 factor formula is 1.33 or 1.84 and that cannot be used for breeder reactions. For breeder reactor you do need eta more than 2 because 1 neutron is needed to sustain that chain reaction at a constant rate. And at least 1 neutron is needed to produce this new fissile material. So, 2 are needed and all kinds of absorption and leaking and all those things will be there. So, this nu has to or eta has to be much more than 2. So, breeder reactor is built with plutonium 239 as the fuel.

(Refer Slide Time: 39:22)

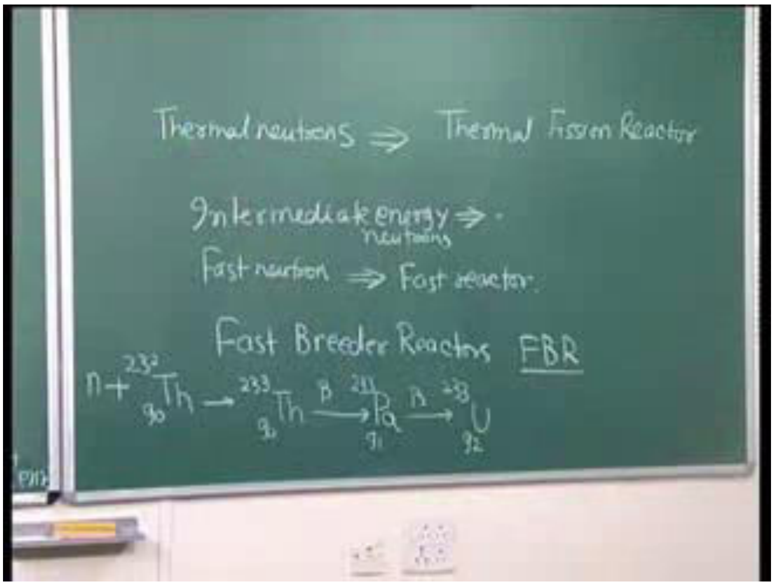


So, breeder reactors 1 neutron to sustain the chain reaction and more than 1 neutron if it is as to breed. So, if it has to produce more nuclear fuel then it is consuming; this should be in fact more than one neutron for breeding. And therefore that eta must be greater than 2 not only greater than 2 is reasonably greater than 2. So, that after all those radiative absorption and leaking through the core. And all those things absorption in the moderator still you have these 2 neutrons or more than 2 neutrons available. One for sustaining the reaction and one for breeding the fissile material. And plutonium 239 is reasonably or perhaps is the only good choice because for this you can get eta around 3; with uranium 235 plus uranium 238 the usual fuel in the nuclear fission reactors that will give you eta say 1.33 for natural uranium. And 1.84 for 3 percent enriched uranium this cannot be used.

Now, this thermalisation low kinetic energy of neutrons moderation all these things where for uranium reactor. Because the cross section of fission for uranium 235 is very high 500, 600 barns at these thermal energies. So, to utilize that all that moderator was needed and other things. So, that neutron can be taken out of that fuel rods, fast neutrons they there kinetic energy is reduced and then sends to the fuel rods again.

So, that large cross section of fission for this uranium 235 can be utilized. Plutonium 239 does not need that; it can fission with fast neutrons itself. And therefore no moderators are needed in breeder reactors. In breeder reactors is just then fast neutrons which are produced from fission; they themselves fission go for the next generation fission. And so the moderators are not needed; coolant has to go from outside the core. And normally liquid sodium is used as coolant in this breeder reactors. And they are known as fast breeder reactors that is another classification of reactors.

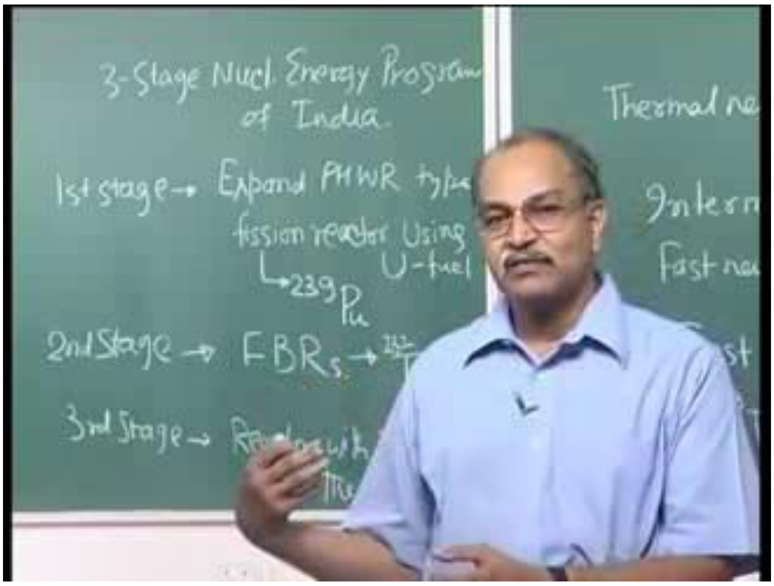
(Refer Slide Time: 42:57)



If the reactor is using thermal neutrons if thermal neutrons are causing the fission; that kind is known as thermal fission reactor. Another is intermediate energy moderation is there but intermediate energy that is another possibility; you can call it intermediate fission reactor. And then the fast neutrons; if fast neutrons are producing the next generation fission then you call it fast reactor. So, breeder reactors in the present designs are all fast reactors because the fast neutrons which are produced in fission of plutonium 239 they themselves cause the next generation fission. So, they are generally termed as fast breeder reactors FBR. Another breeding reaction that is important or possible is with thorium. Thorium 90; z is 90 and A is 232. This thorium this is also available in fact India has large reserves of this thorium. This is not fissile material as such but if a neutron is absorbed in it. It can create 233 thorium and this can beta decay to Protectium Pa and that can again beta decay.

So, this will be 233 here and it can again beta decay and this will become 92 that is uranium and 233. So, this is a fissile material the 233 uranium. So, a breeding reaction is possible if you have 232 thorium which absorbs neutron and then from there it can finally give this. So, but this 232 thorium this itself is to be placed properly there. So that the neutrons from this fission reactions get absorbed into it. So, what we have in India it is called 3 stage nuclear program of India. And what are those 3 stages let us see.

(Refer Slide Time: 46:30)



So, 3 stages nuclear energy program of India; the final vision is to use that large availability of thorium in India; the uranium reserves are limited. But the thorium reserves are in much more better conditions. So, keeping that in mind the first stage is to expand these fission reactors PHWR or PWR using uranium fuel as usual. This is the usual variety all fission reactors in the world most of them are of this variety. So, expand presently 20 such reactors are use; 16 use this heavy water then to boiling water reactors. Boiling water reactors means the coolant and moderator; that water that is going that boils there itself the pressure is not that high. So, it boils in that core itself and the steam is from there itself taken to the turbine; that is boiling water reactor 2 of them. So, expand this built more reactors not only that we need electricity from that.

But the another output is that from this we will get lot of plutonium 239 because in that natural uranium; those uranium 238 is there which are getting irradiated by the neutrons in an natural way in the reactor. Plutonium 239 is being made there and from that it can be separated chemical. So, by expanding this nuclear reactor base we will be getting more plutonium 239. So, that is plus electricity of course; then the second stage. So, this gives this us as an output plutonium 239. Now, use this plutonium 239; second stage fast breeder reactors FBR; fast breeder reactors will need plutonium 239 as fuel. And if we go for large amount of breeding number of FBR then we will need corresponding amount of plutonium 239 as fuel. And for that we need the first phase reactors; normal uranium reactors which will give us that plutonium 239 fuel.

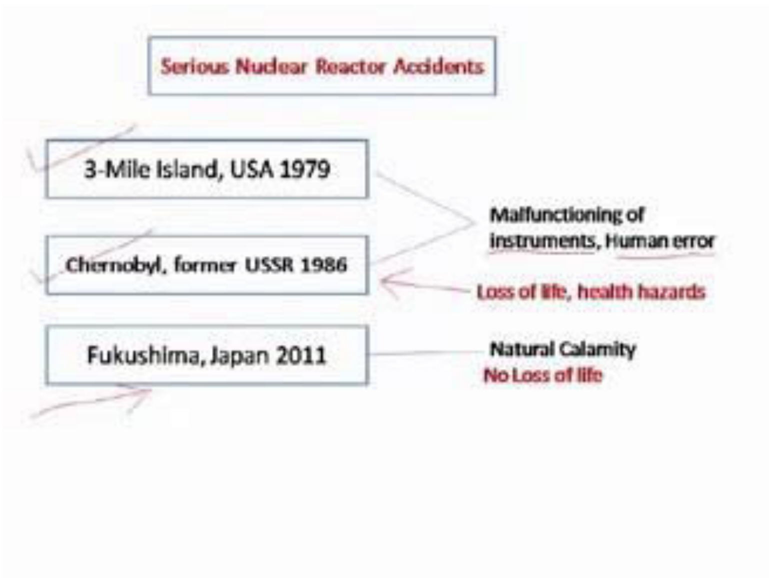
So, this will be used here to construct to run these FBR. And in these FBR this thorium 232 will be irradiated then that will give us 233 uranium. So, once those fast breeder reactors are in place with plutonium 239 as fuel. In those fast breeder reactors we can breed uranium 233. We can put our thorium fuel their not fuel thorium material there and irradiated with these neutrons breed that. And then from using this reaction here we can get this fissile material uranium 233. And then the third stage is to build reactors with this 233 uranium as the fuel. So, we are at first stage at present but one FBR in fact FBR fast breeder test reactor is running for quite some time 1985 or so. So, we have all that technology all those things ready and one small reactor at kalpakkam is also running at uranium233.

So, all technical aspects are all well tested. And it is only a matter of doing it for first stage, second stage and third stage. Now, one more aspect must be talked when we are talking of nuclear reactor and that is safety aspect. Because when these fission reactors reactions take place they create lot of radioactive material. All these fission fragments are radioactive, the beta decay they emit neutrons and so on. Some of them have small lifetime, some of them have large lifetime, thousands of years or even more. So, we are producing that much of radioactive material which has long lifetime as well. So, to keep that radioactive material isolated from water mass, from air mass, from human population that is very important.

So, in any nuclear power plant lots of radioactive materials are being produced; the spent fuel rods there are all radioactive emitting radiations. So, to keep them we are running the reactors; we are piling up all these spent fuel rods. So, to keep all that radioactive waste from fission reactor is big challenge. And if something goes wrong and if this radioactive material goes into the human populations through whatever means that will be disaster.

So, that is one thing containment of this radioactive material and their final disposal. Finally, what will happen? We can keep this in our reactor complex in an isolated building and so on but if it is piling up at the end of it 100 years from now, 500 years from now, 1000 years from now. What will be its final disposal? That is one issue. Another issue is accidents; with all the good designs and everything accidents do occur; in the history of nuclear fission reaction we had 3 big accidents. Let me give it on the screen those 3 famous big accidents.

(Refer Slide Time: 54:09)



So, you can see that three serious nuclear reactor accidents so far in the whole history. What is known as this 3 mile high island in USA that was in 1979? And in this there was some malfunctioning of instruments, some wall got stuck something happened and the operators could not respond to that well; and so both malfunctioning of instruments and human error that cause explosions and melt down of the of the these fuels and all that. So, that was 1979 then the worst is Chernobyl former USSR in 1986 there also it was essentially some malfunctioning in some human error. And this was the one in which some loss of life was there. And also health hazards increase in cancer cases and other things this the worst. And very recently as everyone knows in Japan Fukushima two thousand eleven no human error here and no instrument failure here. But it was a natural calamity when this 15 meters of tsunami waves entered the complex, destructed the power supply, the cooling could not be done. Although the reactor was shut down automatically from the design itself but even if it is shut down the radioactive decay continues.

And, that creates heat and that could not be cooled and everyone knows that this entire complex is now unusable for any anything. So, but this was a natural calamity. So, far no loss of life has been reported or even the radiation exposure is not very highly alarming to the workers and people there. But this chainable surely it is created lot of problems and some 50, 56 or something is reported casual it is human life, casual it is and so on. So, this f t aspect has to be kept in mind when we talk of reactors and expansion of nuclear programs and all those things. All these 3 accidents had have thought us to deal with such situation, and we hope that no more nucleus accidents in future.