Nuclear Power Generation – What, Why and How?
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Nuclear Energy is not magic and it is not a secret. Almost every country now has enough expertise to harness nuclear energy and use it for whatever purpose they desire.

This has endowed upon us a responsibility to make ourselves aware of what exactly happens inside the containment where nuclear power is generated, harnessed and utilized. Governments and authorities spend millions to make these Reactors as efficient as they can. The ultimate aim is and has always been to produce power that is cheap but clean, and more importantly, safe.

With this in mind, let's start with a tour of the different kinds of nuclear power plants and get a glimpse of how they enable power generation.

1) Pressurized Water Reactors (PWR):

Every power plant has a containment structure that houses the reactor. It is the place where all the nuclear reactions to generate heat and energy take place. As the name rightly suggests, all this is *contained* safely inside a lead and concrete structure that doesn't allow any radiation to escape or reach other components. So that's the fuel - enriched Uranium (Uranium-235) or Plutonium (Plutonium-239) contained safely inside the reactor vessel. The other absolutely essential elements that are contained within this vessel are the *coolant, moderator* and the *control rods*.

Coolant; just as any other coolant, cools. In PWRs, pressurized water is used as a coolant. The primary job of the coolant in a nuclear power plant is to absorb heat from the fuel and transfer it for steam generation. The moderator, on the other hand, provides a medium to slow down fast neutrons. The neutrons collide with the moderator atoms and lose some of their energy in the process. This brings the neutrons in an acceptable energy range so that they can interact efficiently with the fuel and produce the desired amount of heat and energy.

The final element, control rods, are rods mostly made of boron or cadmium to *control* the reaction by absorbing any additional neutrons and always keep the reactor in a steady and controlled state.

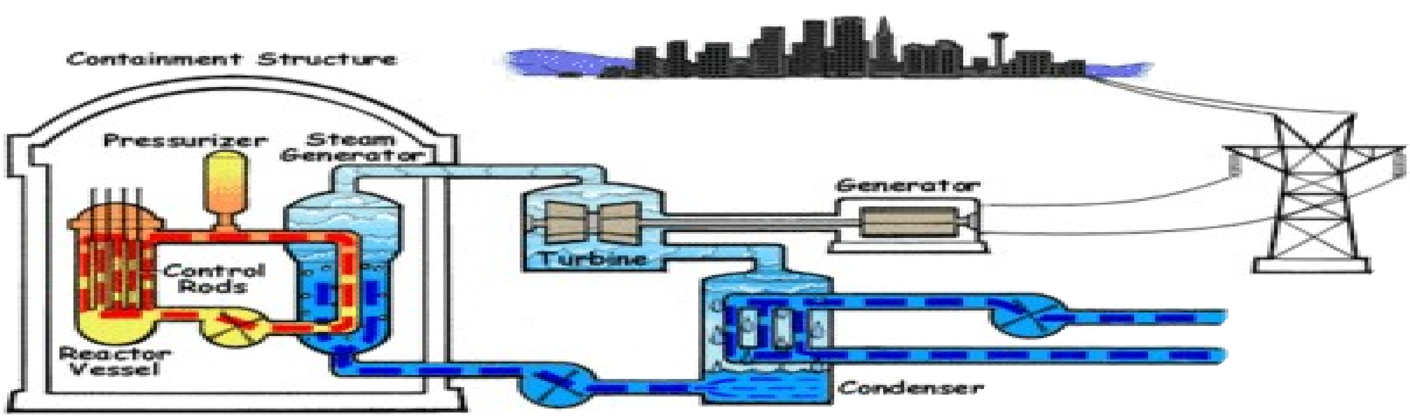

Fig.1

Like any other power plant, a nuclear power plant too has a turbine that requires high temperature, high pressure steam to run. This steam is generated by a steam generator that takes in heat from the coolant and converts water into high temperature steam. The design of a PWR requires the steam generator to also be inside the containment building thereby eliminating the possibility of any radiation leak to the outside environment. Another absolutely important part of a reactor are systems that operate pumps. These pumps ensure that there is coolant flow inside the reactor vessel at all times. It is important to remove the accumulated heat from the fuel rods so that the reactor can at any given time be maintained at a steady and controlled state (even when it is shutdown and not running).

Fig.1 gives a clear picture of how things happen inside the containment building with the fuel inside the reactor vessel, the control rods suspended inside the vessel to control the reactions, flow of coolant shown in yellow (cold) and red (hot), pumps to maintain the flow of the coolant from the reactor vessel to the steam generator and finally that steam that is free of any possible radioactivity going outside to run the turbines and produce electricity.

The United States has about 65 operating pressurized water reactor plants.

2) Boiling Water Reactors (BWR):

Unlike PWRs, here in BWRs steam is generated directly inside the reactor vessel. Boiling water acts as the coolant as well as the moderator. Fig.2 gives a schematic of the operation of a BWR. Post high temperature steam production, BWRs essentially operate in the same way as a PWR.

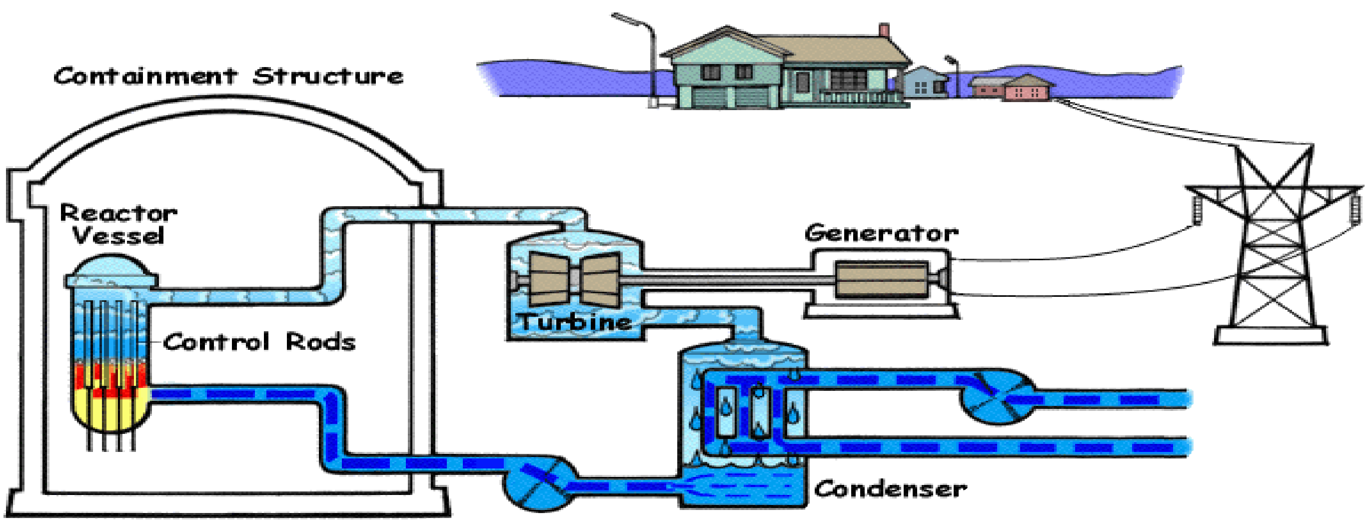

Fig.2

At present, only PWRs and BWRs are used for commercial production of electricity in the United States. There are about 99 such licensed plants which collectively generate about 20% of the country's electrical needs. Out of these, there are 34 operating BWRs.

3) Pressurized Heavy Water Reactors (PHWR):

PHWRs are generally considered the safest operating nuclear power plants. Part of the reason is the choice of fuel. While PWRs and BWRs can only operate efficiently with enriched uranium, PHWRs can safely attain a steady and operational stage using natural uranium as fuel. The reason being the use of pressurized heavy water (D_2O) as coolant and moderator. Light (or normal) water has a property to absorb neutrons while for heavy water, this probability of absorbing neutrons is greatly reduced. This enables greater availability of neutrons to interact with the fuel and attain a steady operational state. Apart from the choice of fuel and moderator, all the other parts of the power plant operate similar to that previously described.

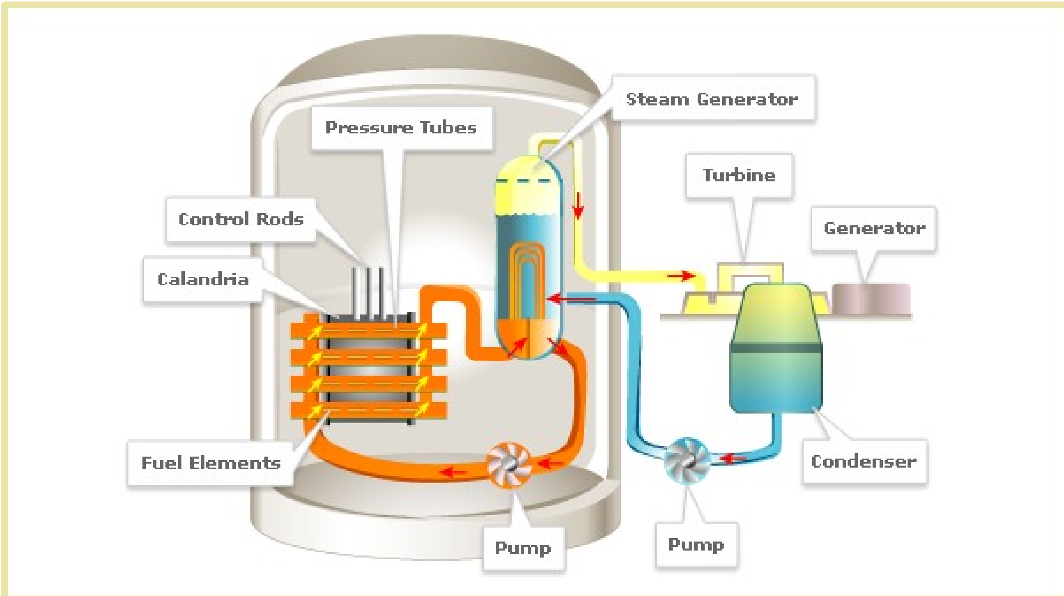

Fig.3

Enrichment of uranium requires a very expensive facility and involves extensive safety requirements so many countries have shifted to the more cost-effective PHWRs. One such country is India that has 18 operational pressurized heavy water reactor plants at present.

4) Breeder Reactors:

Breeder reactors are a revolution in the nuclear power generating community. These reactors have the capability to significantly change the state of art by not only generating clean and safe power but also producing additional fuel to be used by other reactors thereby putting to rest the ever troubling question of fuel availability. This advantage however comes at the cost of a more complex design.

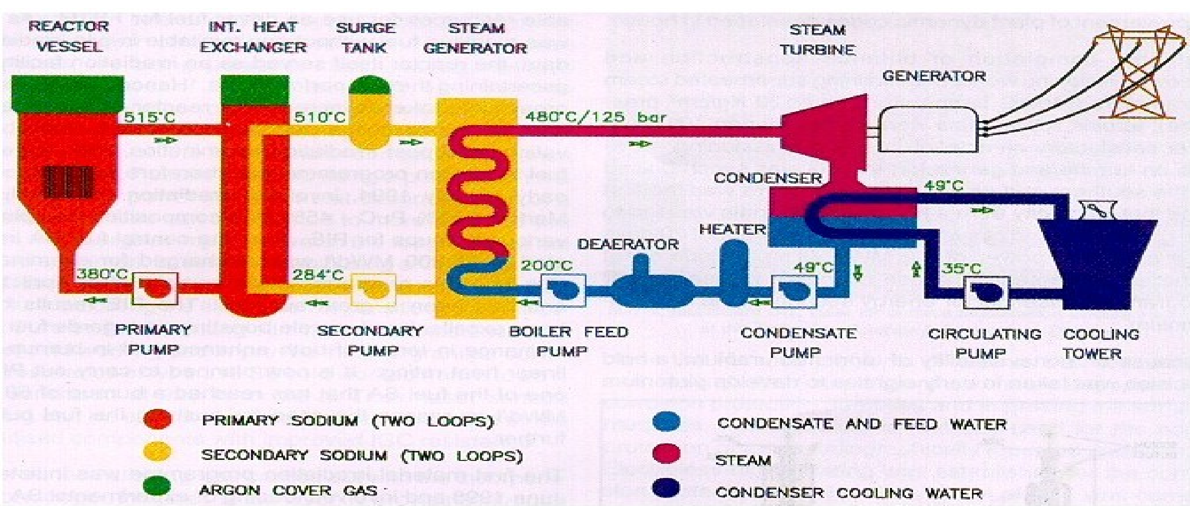

Fig.4

Shown diagrammatically in Fig.4, breeder reactors have a considerably different design as compared to the other kind of reactors. The fuel used is still natural uranium but instead of using light/heavy water, breeder reactors use liquid sodium as a coolant. Sodium being a metal has a very high conductivity i.e., it can remove heat much more efficiently than water. Also, the other reason of not using water here is that in breeder reactors, we do not want the neutrons to be slowed down. So, we need something that can qualify as a coolant but not act as a moderator. Hence the choice of liquid sodium. The use of sodium demands an additional safety requirement. Sodium is highly reactive and can have an explosive reaction if it comes in contact with air or water. So it has to be kept under an inert blanket of Argon cover gas. Argon, being an inert gas, does not interact with sodium and also serves as a shielding to prevent the contact of sodium with air.

The breeding material (usually natural uranium (U-238) or thorium (Th-232)) is kept in a blanket outside the primary fuel. The fast neutrons, after interacting with the natural uranium fuel, reach the blanket and gets captured to produce enriched isotopes (Pu-239, U-233) that can further be extracted and used in PWRs, BWRs and PHWRs.

Heat removal mechanism is a two-step process here. To limit radioactivity from reaching the steam generator and turbine area, an intermediate heat exchanger is used. Liquid Sodium is pumped in two different loops; primary sodium that is directly in contact with the fuel and is hence radioactive and the secondary sodium which is in a different loop (shown by yellow in the figure) and is not radioactive. Primary sodium takes up heat from the fuel and delivers it to non-radioactive secondary sodium which in turn goes to the steam generator and produces high temperature steam to run the turbine.

United States had about 7 breeder reactors with 4 of them being experimental/test reactors but none of them are in operation at present and are shut down. Russia, Japan and India are the three countries that have breeder reactors operating either at the experimental or the prototype stage.

Breeder reactors are in every sense the rising future of nuclear power. With the ever increasing population and growing energy demands it is only sensible that we make use of a technology that not only meets our demands but also produces the raw material needed.

In the wake of the current energy demands, it is time to make the paradigm shift and nuclear power is the only power that has the potential to handle the increasing burden and perform gloriously.