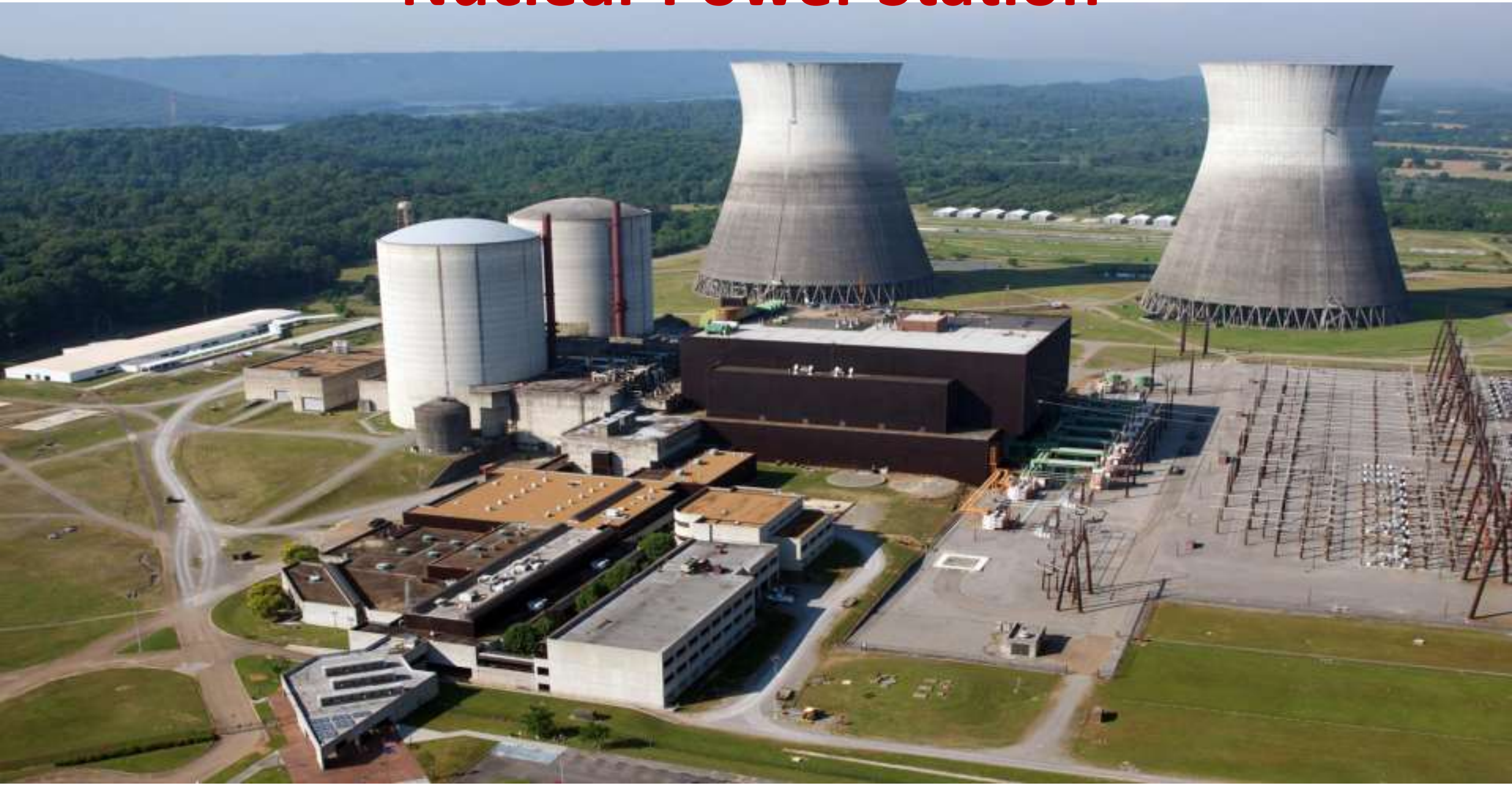
Nuclear Power Station



Unit…3

Nuclear Power Stations: Introduction - Nuclear Fission and Chain reaction - Principle of operation of Nuclear power plant

Nuclear Reactor components and their functions : Moderators - Control rods - Reflectors and Coolants- Radiation hazards: Shielding and Safety precautions - Types of Nuclear reactors and their brief description - Pressurized Water Reactor (PWR), Boiling Water Reactor (BWR) and Fast Breeder Reactor - Merits and demerits of Nuclear Power Plant.

IMPORTANCE OF NUCLEAR ENERGY:

Every day the demand for power is becoming increasing. In order to meet these increasing power demand it is not enough with the utilization of available fossil fuels. Because the availability of fossil fuels are limited and causing depleting by its usage.

In India, the availability of fossil fuels are very limited and hence we must depend more on nuclear fuels for generation of electrical power. It saves the considerable amount of fossil fuels and also reduces the transportation problems.

From the above, it is very important to use nuclear energy for generation of power in India and also it is economical to generate power from Nuclear energy

INTRODUCTION:

A nuclear power plant or nuclear power station is a thermal power station in which the heat source is a nuclear reactor. As is typical in all conventional thermal power stations the heat is used to generate steam which drives a steam turbine connected to an electric generator which produces electricity

The fission in a nuclear reactor heats the reactor coolant. The coolant may be water or gas or even liquid metal depending on the type of reactor. The reactor coolant then goes to a steam generator and heats water to produce steam. The pressurized steam is then usually fed to a multi-stage steam turbine.

After doing useful work in the turbine the steam is allowed to **condenser.**

The condenser condenses the steam and is pumped to the heat exchanger

The steam drives the turbine coupled to an Alternator which converts mechanical energy of the turbine into electrical energy

The nuclear reactor is the heart of the station. In its central part, the reactor core's heat is generated by controlled nuclear fission.

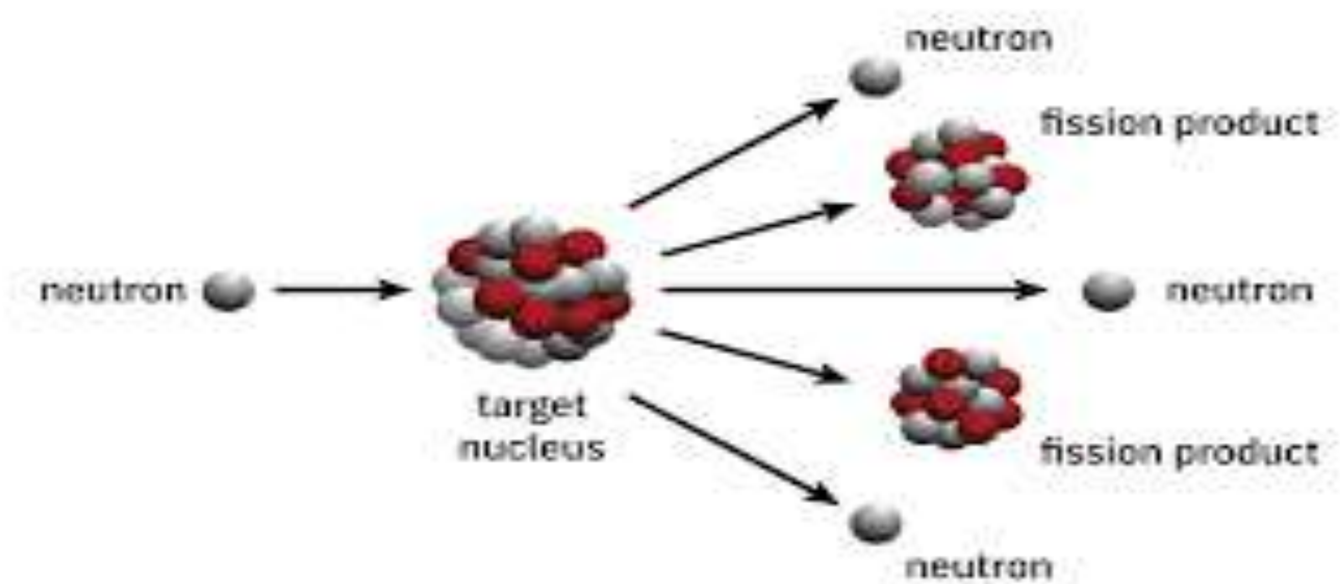
Heat from nuclear fission is used to raise steam, which runs through turbines, which in turn powers the electrical generators.

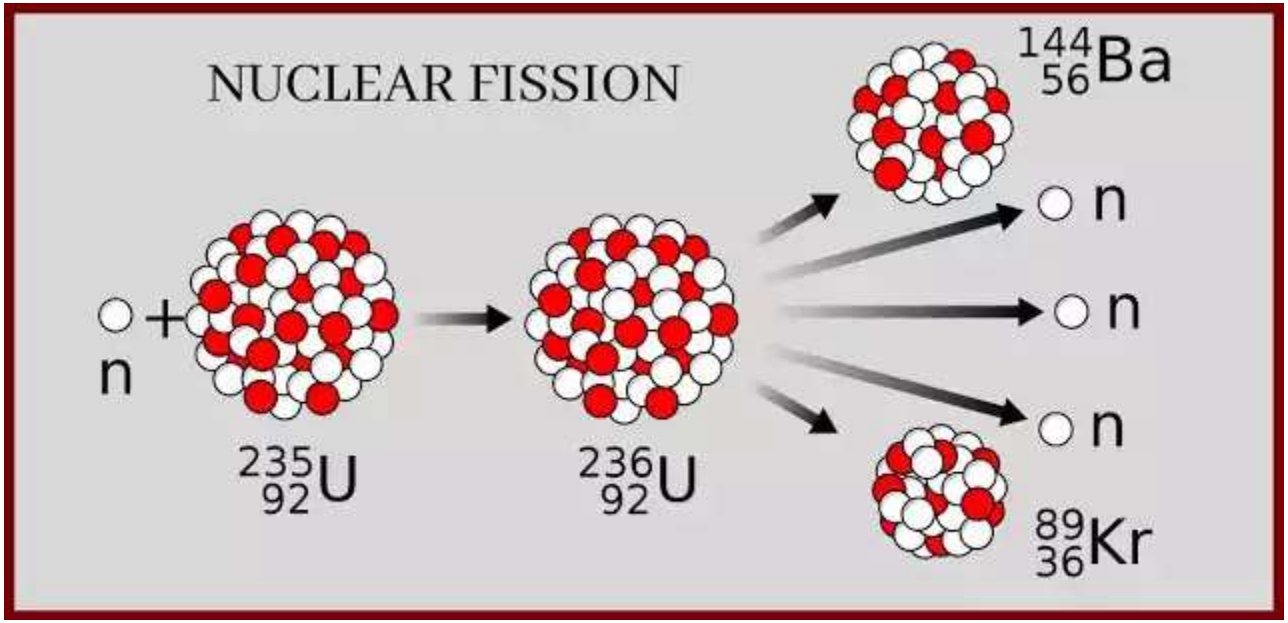
Nuclear reactors usually rely on uranium to fuel the chain reaction. Uranium is a very heavy metal that is abundant on Earth and is found in sea water as well as most rocks.

Nuclear Fission:

The splitting of a heavy nucleus into two or more smaller nuclei is called "Nuclear Fission". when large atoms split into one or more smaller atoms, giving off other particles and energy in the process, we call it **nuclear fission.**

The fission of a heavy atom can be caused by bombarding it with a neutron. The main advantage of neutrons compared to other particles (such as protons, x-rays etc) is that they are neutral (have no charge) and therefore they can make their journey through the orbits of electrons and then through the nuclear at low energy.





CHAIN REACTION::

Nuclear chain reactions are series of nuclear fissions , each initiated by a neutron produced in fission process.
It may be defined as a fission reaction in which the neutrons from a previous step continue to propagate and repeat the reaction.

in nuclear fission heavy nucleus split into two or more nuclei when it is bombarded by slow moving neutrons. This causes emission of neutrons (fission neutrons) with the release of huge amount of energy. These fission neutrons cause further fission. If this process is repeated, then in a short time huge amount of energy will be released which may cause explosion. This is known explosive chain reaction.

Actually in a reactor, controlled chain reaction is taking place which can be done by systematically removing fission neutrons from the reactor.

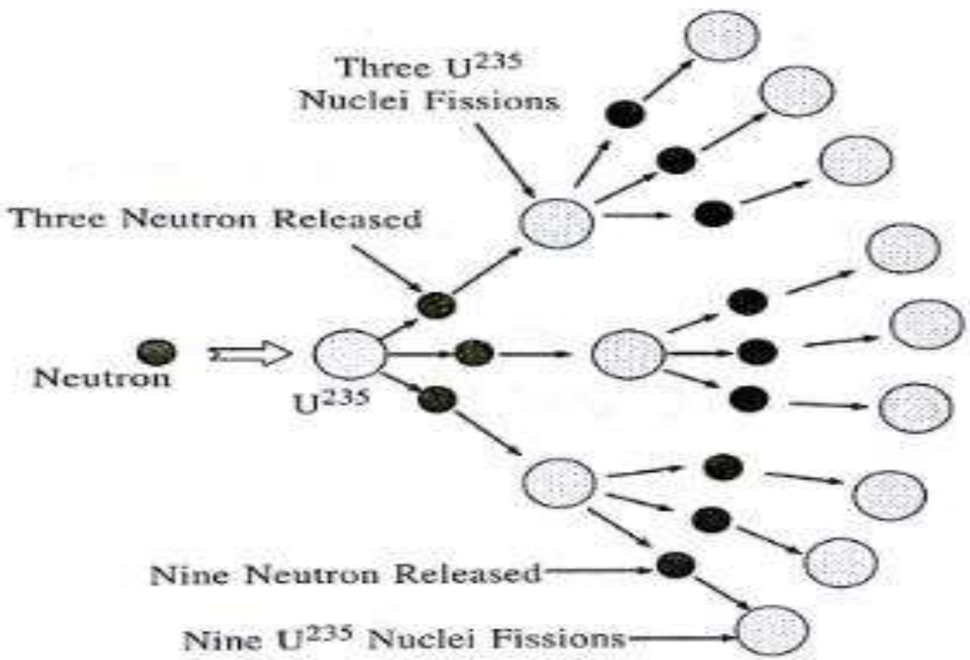


Figure . Chain Reaction

For example when U-235 nucleus hit by a neutron the reaction is as follows.

U235 + n1 → Ba144 + kr89 + 3 neutrons

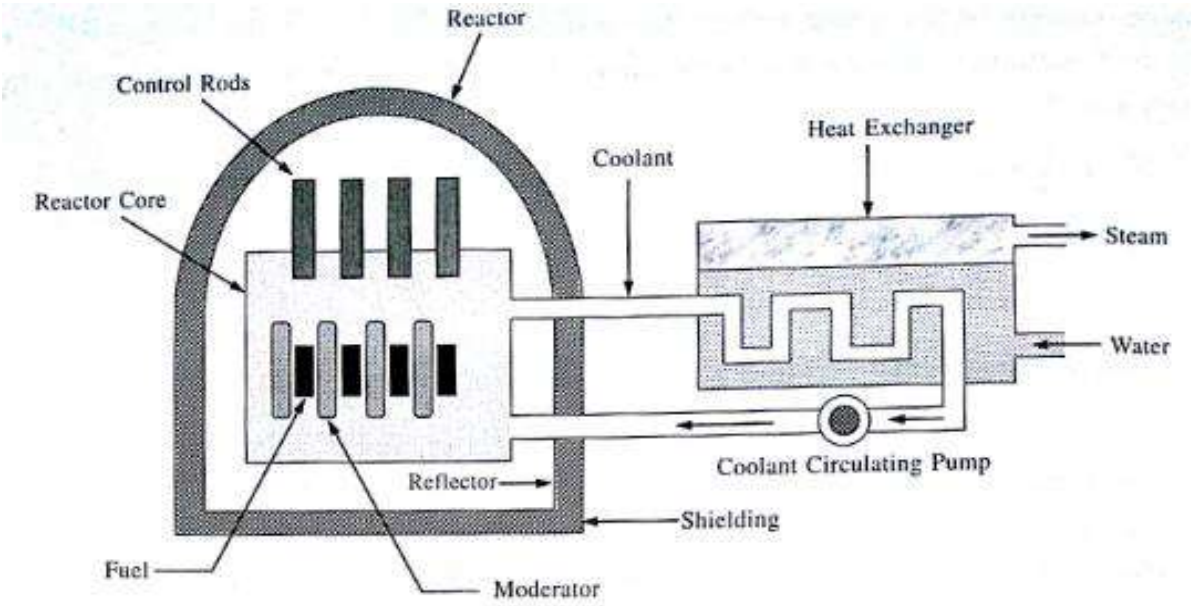
Each of the three neutrons produced in this reaction strikes another U-235 nucleus, which further causes production of nine subsequent reactions. These nine reactions in turn further give rise to twenty seven reactions and so on. The process of reaction by multiplication in threes at each fission is shown in above Fig.

NUCLEAR REACTOR-MAIN PARTS AND THEIR FUNCTIONS

Nuclear reactor is the heart of the nuclear power station, where tremendous amount of heat energy is released as a result of nuclear fission of radio-active materials. This heat is utilized to heat the coolant which in turn generates steam. Nuclear reactor consists of the following basic components which are shown in Fig.

1. Fuel: The fuels generally used in the reactor are 92U235, 94Pu239 and 92U233, 92U238,90Th232 etc. Fuel should be so shaped and located in the reactor such that uniform heat should be produced.

2. Reactor Core: It is built of graphite bricks, having channels machined through them. The core is cylindrical in shape and is placed on a large pressure vessel totally enclosed in a thick walled shielding structure of concrete about 2-3 meters thick. The size of the core is, just sufficient to maintain a chain reaction.

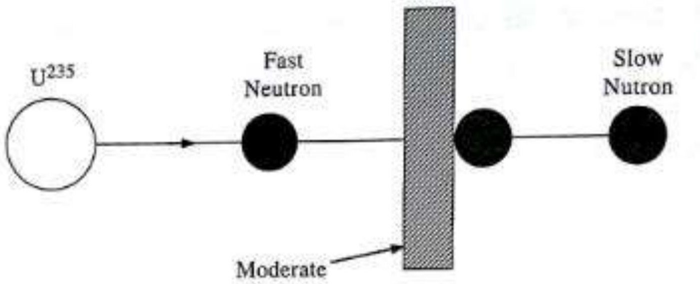


3.Moderator:

A material in the reactor core which moderate or reduce the energy and speed of fast moving neutrons without capturing them, and thereby controlling the chain reaction is known as "Moderator".

We know that during fission process, the neutrons at a very high velocity of about 1.5×10^7 m/s with very large kinetic energy are produced. But for more effective and efficient use in nuclear reactor, it is desirable to slow down the speeds of neutrons to 2.2×10^3 m/s Such neutrons are called slow or thermal neutrons.

When the natural uranium bombarded by these slow moving neutrons, the chain reaction can be maintained. This slow down of neutron speed, can be accomplished with the help of "Moderator".



Heavy water and Graphite are generally used as moderator. The other rarely used moderator materials are hydrogen, Deuterium, Helium, Lithium, Beryllium, Boron, Carbon and Nitrogen.

4. Shielding: The purpose of shielding is to prevent the escape or leak of neutrons (fast and slow) α , β particles and Gama rays from reactor as these radiations are harmful to human being. Lead iron or concrete shields are used for this purpose.

5. Control Rods: The control of chain reaction inside the reactor is obtained by inserting control rods into the reactor core. The control rods are made with cadmium (or boron), because cadmium is a strong neutron absorber. When control rods are pushed into the core they absorb some of the neutrons and hence few neutrons are available for chain reaction.

These rods are in practice suspended from the top of the reactor in the channel of core, and are lowered or raised by special mechanism according to the load requirements.

6. Reflector: In order to avoid the leakage or escape of neutrons from the reactor it is essential to surround the reactor with material acting as a Reflector. As the name indicates, the function of reflector is to reflect as many leakage neutrons as possible back into the reactor. The reflector gets heated due to collision of neutrons with its atoms, hence cooling is essential. The materials used for reflector is same as that of the materials used for moderator
i.e. Graphite, Heavy water.

7. Coolant: A coolant is a medium through which heat produced in the reactor is transferred to the heat exchanger for further utilization in power generation. Liquid sodium is generally used as coolant. When water is used as a coolant it takes up heat and gets converted into steam in the reactor itself, which is directly used to drive the turbine. The commonly used coolants are gas (C02, air, hydrogen, helium) and some organic liquids.

8. Reactor Vessel: The Reactor vessel encloses the reactor core, reflector and shield. It is a strong walled container generally cylindrical in shape and provides the exit for passage of coolant. It should withstand high pressures. The holes are provided at the top of the vessel to insert the control rods.

9.Heat Exchanger: In heat exchanger, the heat carried by sodium metal, is transferred to water and water is converted to high pressure steam here. After releasing heat in water the sodium metal coolant comes back to the reactor by means of coolant circulating pump

WORKING OF NUCLEAR POWER PLANT WITH BLOCK DIAGRAM

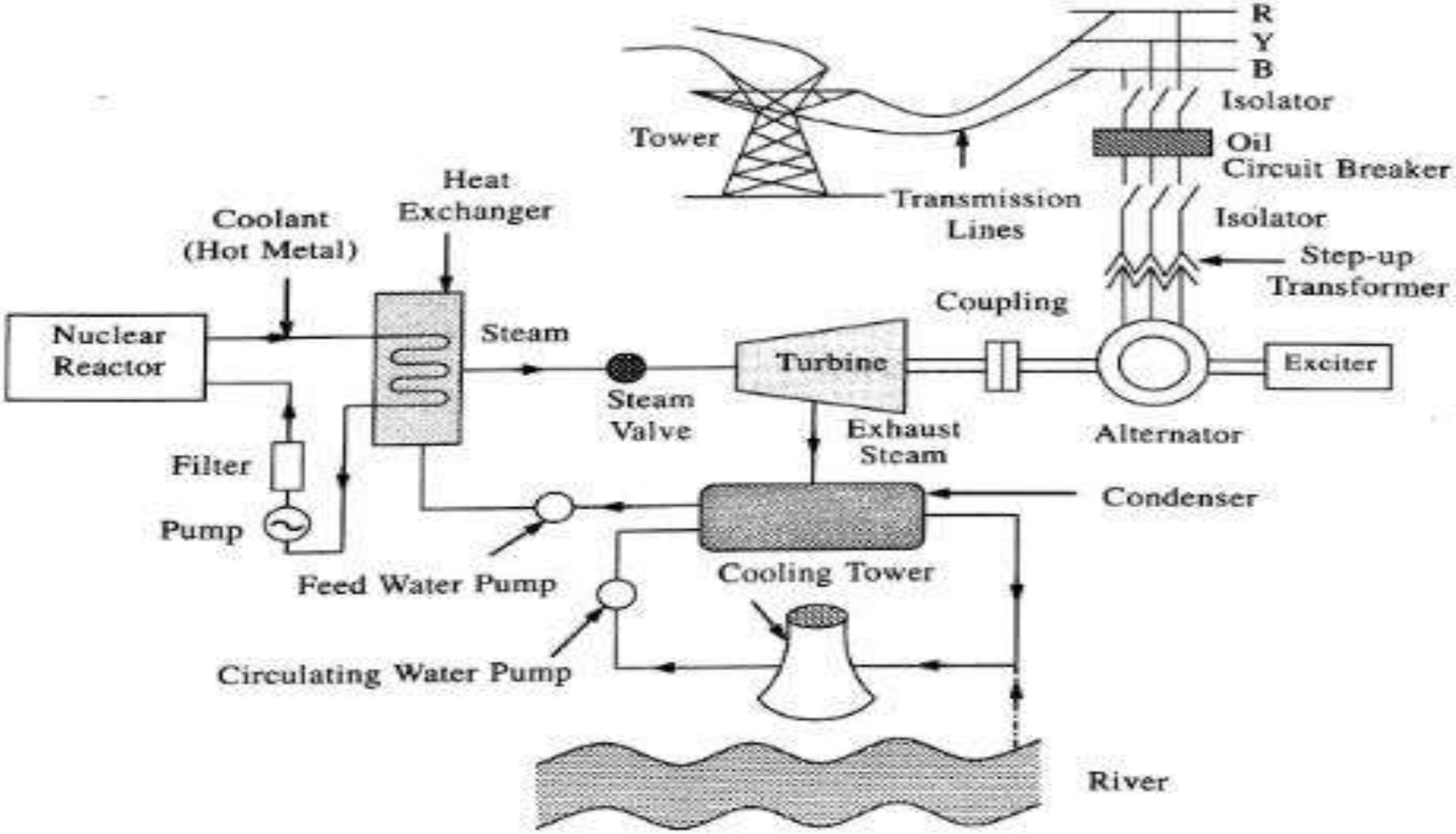


Figure. Block Diagram of Nuclear Power Plant

The block diagram of Nuclear power plant is shown in Fig . The concept of Nuclear power generation is much similar to that of conventional steam power generation. The only difference is that, boiler of the steam power plant is replaced by Nuclear reactor and Heat exchanger.

The essential components of a Nuclear power Plant are:

1. Nuclear reactor
2. Heat exchanger
3. Steam turbine
4. Alternator
5. Condenser
6. Cooling tower.

- First, uranium fuel is loaded up into the reactor .
- In the heart of the reactor (the core), atoms split apart and release heat energy, producing neutrons and splitting other atoms in a carefully controlled nuclear reaction
- Control rods made of materials such as cadmium and boron can be raised or lowered into the reactor to soak up neutrons and slow down the chain reaction
- The Nuclear reactor is the heart of the nuclear power plant. A tremendous amount of heat energy is produced in the reactor in breaking of atoms of Uranium or other fission materials by fission process.
- This heat is extracted by pumping coolant generally a Sodium metal or gas. The coolant carries heat to the heat exchanger.
- The heat exchanger converts water into steam by utilizing the heat of the coolant. After giving up heat, the coolant is again pumped to the reactor.

- The steam produced in the heat exchanger is fed to the steam turbine through steam valve. After doing useful work in the turbine the steam is allowed to condenser.

- The condenser condenses the steam and is pumped to the heat exchanger by feed water pump.

- The steam drives the turbine coupled to an Alternator which converts mechanical energy of the turbine into electrical energy.

- The output of alternator is stepped-up and is fed to the bus-bars through isolators and circuit breakers

MERITS AND DEMERITS OF NUCLEAR POWER STATION

MERITS:

- The amount of fuel required is small; therefore the fuel cost is low.
- Since the fuel required is low, therefore there is no problem of transportation, storage etc.
- The running charges are small as it required less fuel.
- Greater nuclear power production leads to conservation of coal, oil etc.
- These plants need less area as compared to any other plants of the same size.
- Due to negligible transportation cost of the fuel, these plants can be located near load centers, therefore, primary distribution cost is reduced.
- These plants are most economical for producing bulk electric power.
- The output control (zero to an upper limit) is extremely flexible.
- It ensures reliable operation.

Demerits:

- The capital cost is very high as compared to other type of the same size.
- The fuel used is very expensive and is difficult to recover.
- The greater technical known persons are required for erection and commissioning of the plant.
- The fission by-products are radio-active and may cause dangerous amount of radio-active pollution.
- These plants are not well suitable for varying loads, since the reactor does not withstand fluctuations of load efficiently.
- Maintenance of these plants need specially trained personals; thereby salary bill of these staff is high.
- The disposal of the radio-active by-products is a big problem. They have either to be disposed off in a deep trench or in a sea away from sea-shore.
- The cooling water required for this plant is heavy compared to thermal power plants. Hence it required larger and costlier cooling towers.

SHIELDING

Adequate shielding has to be provided to guard personnel and delicate instruments. The various materials used for shielding are:

(a) **Lead**. It is a common shielding material, has high density (11.3gram/cm3) and is invariably used due to its low Cost.

(b) **Concrete**. Its density is 2.4 gram/cm3and is less efficient than lead.

(c) **Steel**. Its density is 7.8 gram/cm3 .It is not an efficient shielding material but has good structural properties. It is sometimes used as attenuating shield.

(d) **Cadmium**. Its density is 8.65 gram/cm3. It can absorb slow neutrons by a nuclear reaction.

MEASURES TO CONTROL RADIO ACTIVITY (SAFETY PRECAUTIONS)

1. The entire plant is designed with a high degree of **inherent safety**.
2. The entire plant is properly **shielded** against radiation hazards.
3. The reactor should enclosed in a thick **concrete casing**.
4. The persons working in the plant should have **radiation meters** with them to know the radiation level now and then.
5. The entire plant operation is automatic and absolutely proof against accidents, which might Results in a release of radiations.
6. The radioactive wastes should be **disposed in deep trench or in the ocean bed**.
7. It is prohibited to build residential buildings, children houses etc. nearby power plant.
8. Proper precautions against **toxic and radiological hazards** are necessary.

TYPES OF REACTORS:

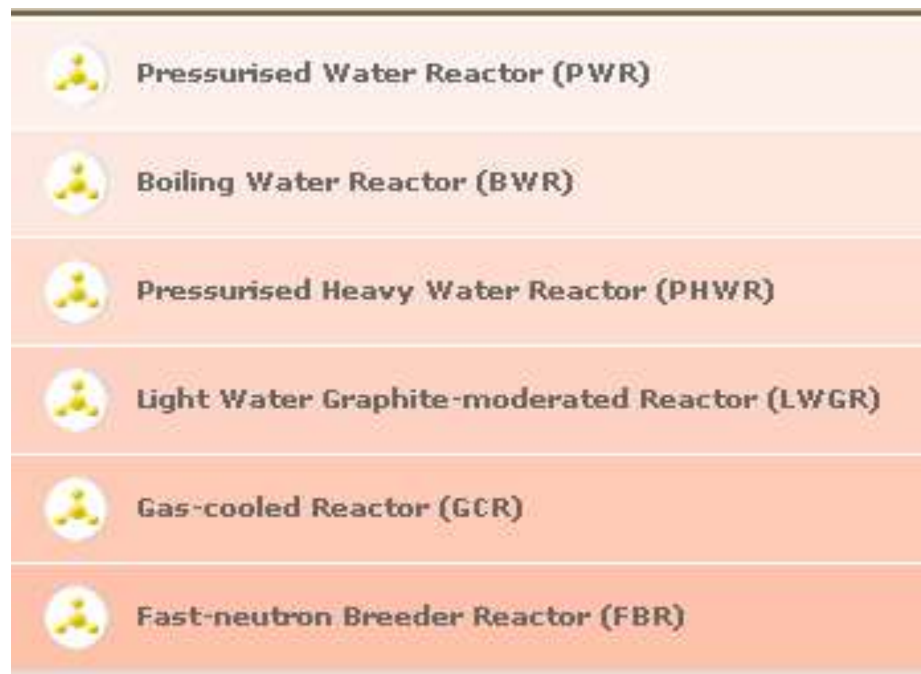
Based on the neutron energy, the reactors are classified as:

(i) **Thermal neutron reactors**

(ii) Fast neutron reactors

Thermal Reactors are those in which the **neutrons are slowed down** with a material called **moderator**, to a velocity of about 2000m/s. before they collide with the nucleus of the fissioning fuel.

Fast Reactors are those in which moderator is not used and the neutrons, as they are released from fission, are used for producing fission, without slowing them intentionally.



Of the six main types listed here, the first five types are thermal reactors and only the last is a fast-neutron reactor.

PRESSURISED WATER REACTOR (PWR)

This is the most common type of commercial reactor.
It uses **water as coolant and moderator** ,an agent that helps control the speed of fission.

In PWR water is maintained at high pressure by pressurizer.The pressure of water is 150 times atmospheric pressure. so that the water heats, but does not boil .

In the **primary system** the **coolant** (water) is heated by thermal energy from fission while passing through the core.
Steam is produced in a secondary coolant loop and is used to drive a turbine that drives an electric generator.

Water from the reactor and the water in the steam generator that is turned into steam never mix.
The steam is condensed in the **condense**r and condensate returns to heat exchanger forming a closed circuit.

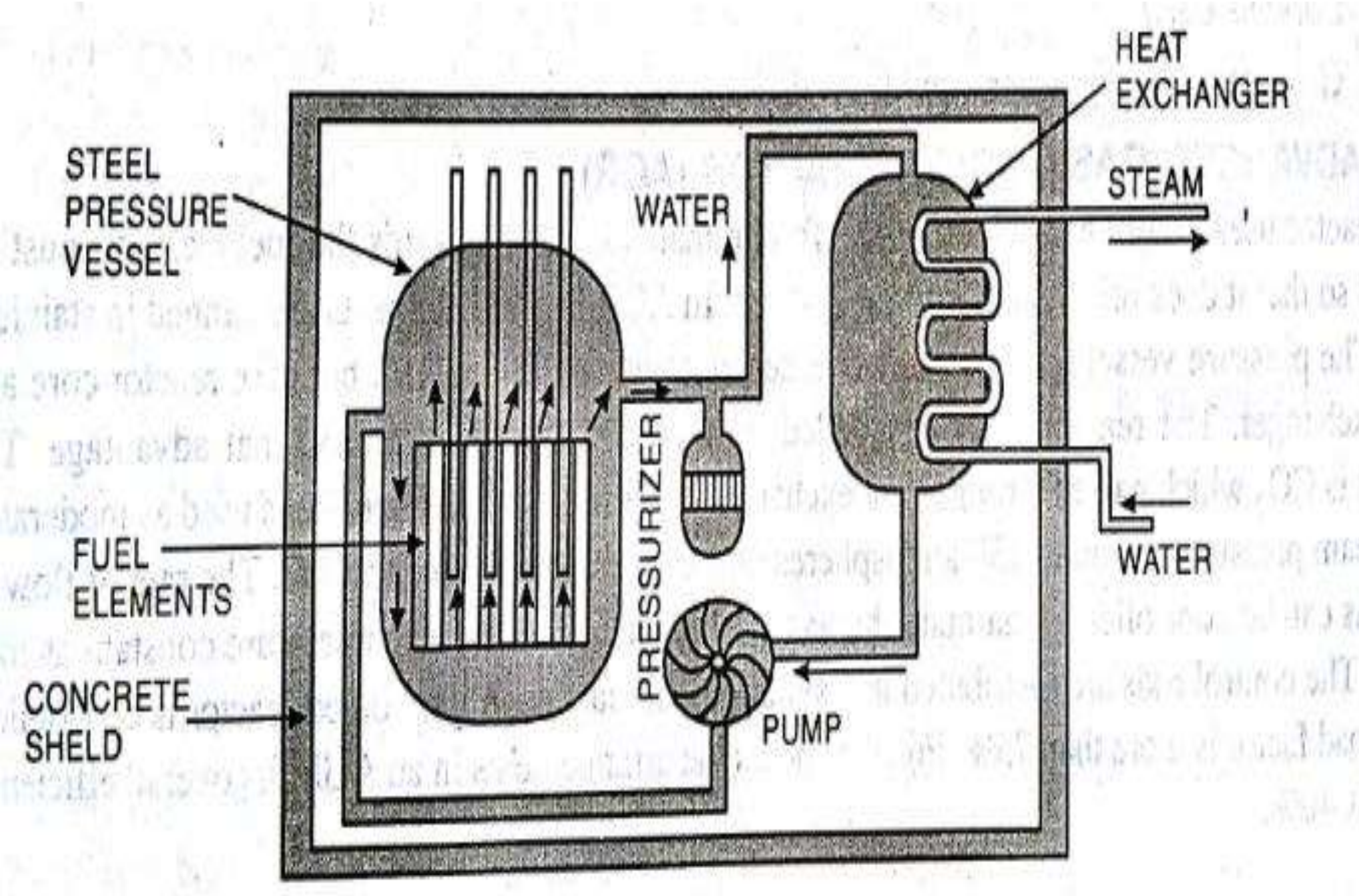


Figure 8. Pressurised Water Reactor (PWR)

Advantages:

The advantage is that steam supplied, to the turbine is completely free from contamination.

Much fewer control rods are required in a PWR

DisAdvantages:

One of the main drawbacks of this reactor is the design of high strength pressure vessel. vessel should be constructed of very strong material such as stainless steel which adds to construction costs of PWR

BOILING WATER REACTOR (BWR):

It is the second most common type of electricity-generating nuclear reactor after the pressurized water reactor (PWR)

In this type of reactor, fission produces heat that **boils water in the reactor core.** Steam from the boiling water rotates the turbine that drives a generator to produce electricity.

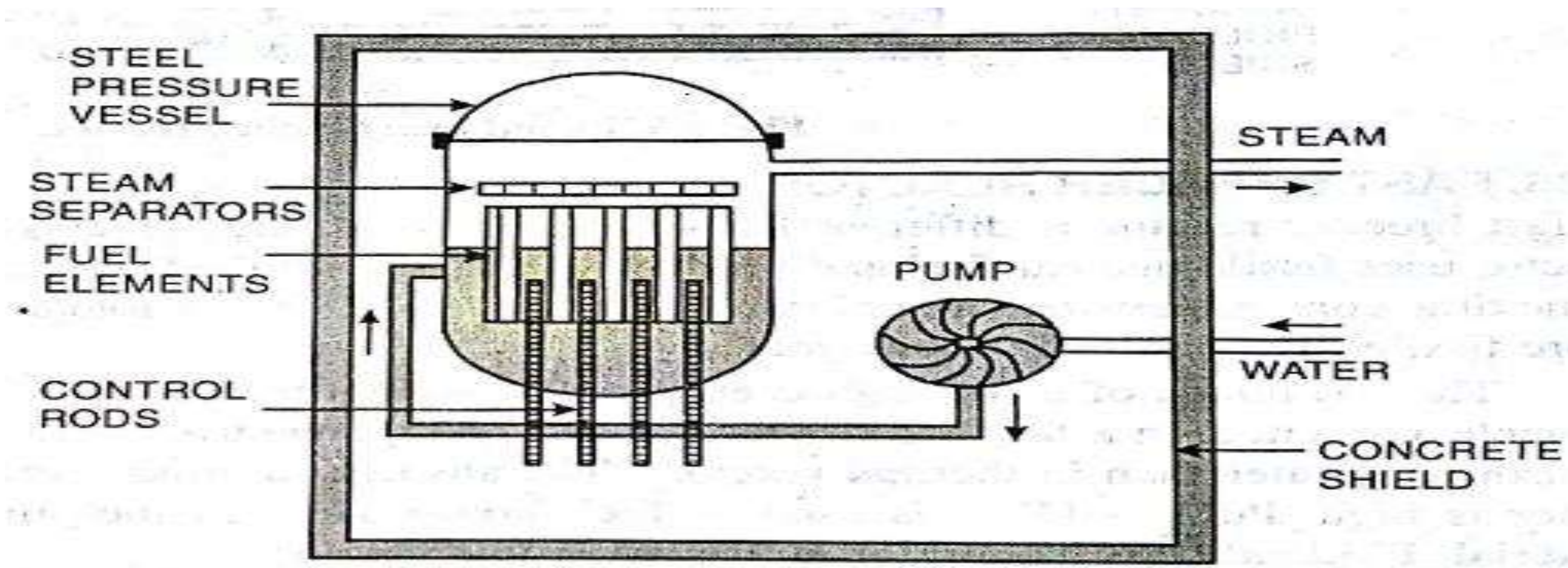
The steam is generated in the **Reactor itself**

It has a steel pressure vessel surrounded by a concrete shield.Fuel used is **enriched uranium oxide**

This is the simplest type of water reactor.

Feed water enters the Reactor vessel at the bottom and takes the heat produced due to **fission of fuel** and gets converted in to steam. This steam leaves the Reactor at the top and after passing through **Turbine and condenser** returns to the Reactor.

Uranium fuel elements are arranged in a particular lattice form inside the **Pressure vessel** containing water.



Boiling Water Reactor (BWR)

Advantages:

1)simple in construction

2) No need of heat exchanger circuit which results in reduction in cost and gain in thermal efficiency.

3) over all efficiency is good

Disadvantages:

1) Danger of radio – active contamination of steam, therefore, more elaborate safety measures are to be provided. These add to cost.
2) More **biological protection is required.**
3) It cannot meet a sudden increase in load

The reactor installed at Tarapur atomic power station is BWR type.

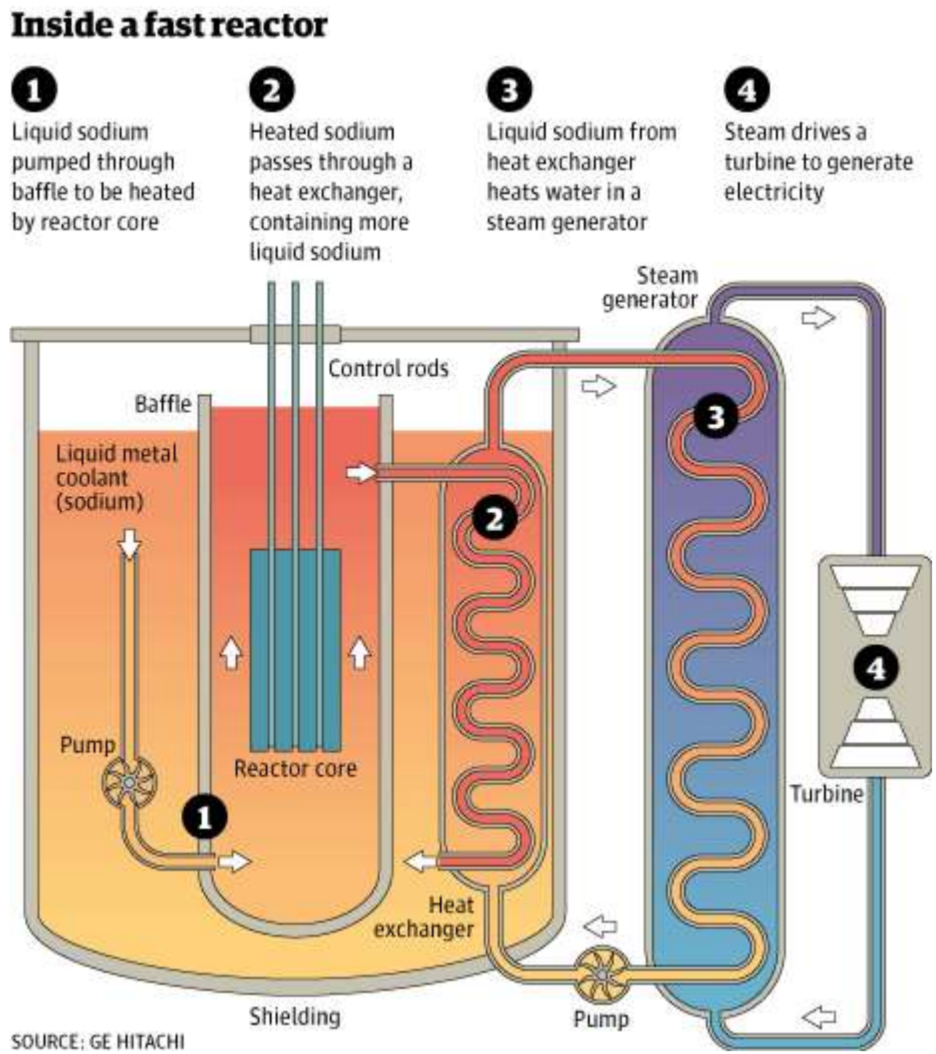
FAST-BREEDER REACTOR

A conventional nuclear reactor can use only the readily fissionable but more scarce isotope uranium-235 for fuel, a breeder reactor employs either uranium-238 or thorium, which are available more in nature. Uranium-238,accounts for more than 99 percent of all naturally occurring uranium. In breeders, approximately 70 percent of this isotope can be utilized for power production. Conventional reactors, in contrast, can extract less than one percent of its energy.

The fast reactor has no moderator and relies on fast neutrons alone to cause fission, which for uranium is less efficient than using slow neutrons. Hence a fast reactor usually uses plutonium as its basic fuel, since it fissions sufficiently with fast neutrons

The active core is surrounded by material (largely U238). This material is referred to as fertile, because it converts to fissile material during operation of the reactor.

A Fast Breeder Reactor (FBR) is a nuclear reactor that uses fast neutron to generate more nuclear fuels than they consume while generating power



Fast Breeder Reactor

There is a coolant surrounding the reactor which is used to protect the core from overheating. It absorbs the heat generated during the fission of plutonium atoms and circulates it to a heat exchanger. This heat converts water in the exchanges into steam, which is used to drive a turbine and generate electricity

Advantages:

1. Heat developed is less.
2. Ease of control.
3. Greater inherent safety.

Disadvantages:

1. Much larger size and weight.
2. Breeder reactors use highly enriched fuels, which pose the danger of critical accidents.
3. Plutonium persists for a long time in the environment, with a life of 24,000 years, and is highly toxic, causing lung cancer even if a small amount is inhaled.
4. The construction and operation is very costly.

MATERIALS USED FOR COOLANT, REFLECTOR AND CONTROL RODS

The materials used for performing the following function in Nuclear power station are:

Coolant:

1. Heavy water
2. Light water
3. Gases (Air, C02, Hydrogen, Helium).
4. Liquid metal coolants (sodium, lithium, bismuth, lead)
5. Organic liquids (Benzene, biphenyl and terphenyl)

Reflector:

1. Graphite
2. Beryllium
3. Heavy Water
4. Ordinary Water

Control Rods:

1. Cadmium
2. Boron
3. Silver
4. Indium
5. Hafnium