

Unit-IV (Nuclear Power Plant)

NUCLEAR REACTOR:

A nuclear reactor is an apparatus in which heat is produced due to nuclear fission chain reaction.

Fig. 1 shows the various parts of reactor, which are as follows:

1. Nuclear Fuel
2. Moderator
3. Control Rods
4. Reflector
5. Reactors Vessel
6. Biological Shielding
7. Coolant.

Fig. 1 shows a schematic diagram of nuclear reactor.

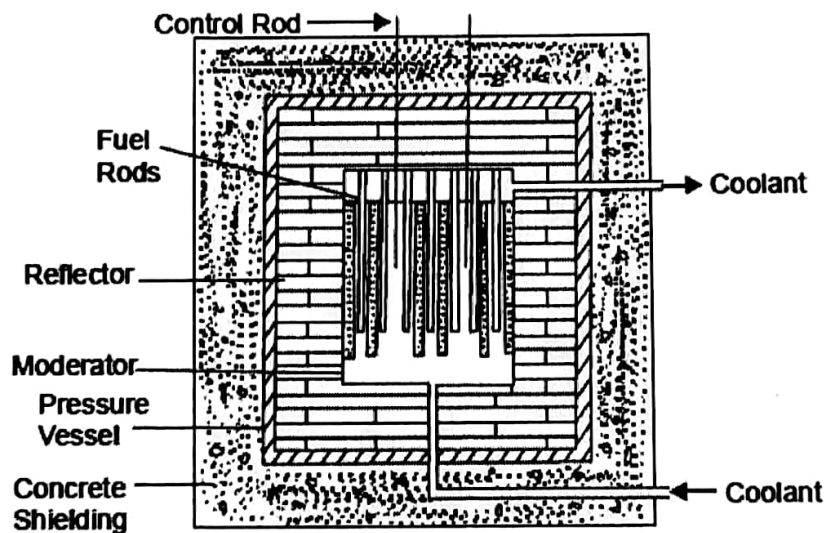


Fig. 1 Nuclear Reactor.

NUCLEAR FUEL

Fuel of a nuclear reactor should be fissionable material which can be defined as an element or isotope whose nuclei can be caused to undergo nuclear fission by nuclear bombardment and to produce a fission chain reaction. It can be one or all of the following

U233, U235 and Pu239.

Natural uranium found in earth crust contains three isotopes namely U234, U235 and U238 and their average percentage is as follows :

U238 — 99.3%

U235 — 0.7%

U234 — Trace

Out of these U235 is most unstable and is capable of sustaining chain reaction and has been given the name as primary fuel. U233 and Pu239 are artificially produced from Th232 and U238 respectively and are called secondary fuel.

Pu239 and U233 so produced can be fissioned by thermal neutrons. Nuclear fuel should not be expensive to fabricate. It should be able to operate at high temperatures and should be resistant to radiation damage.

Uranium deposits are found in various countries such as Congo, Canada, U.S.A., U.S.S.R., Australia.

The fuel should be protected from corrosion and erosion of the coolant and for this it is encased in metal cladding generally stainless steel or aluminum. Adequate arrangements should be made for fuel supply, charging or discharging and storing of the fuel.

For economical operation of a nuclear power plant special attention should be paid to reprocess the spent: up (burnt) fuel elements and the unconsumed fuel. The spent up fuel elements are intensively radioactive and emits some neutron and gamma rays and should be handled carefully. In order to prevent the contamination of the coolant by fission products, a protective coating or cladding must separate the fuel from the coolant stream. Fuel element cladding should possess the following properties:

1. It should be able to withstand high temperature within the reactor.
2. It should have high corrosion resistance.
3. It should have high thermal conductivity.
4. It should not have a tendency to absorb neutrons.
5. It should have sufficient strength to withstand the effect of radiations to which it is subjected.

Uranium oxide (UO₂) is another important fuel element. Uranium oxide has the following advantages over natural uranium:

1. It is more stable than natural uranium.
2. There is no problem or phase change in case of uranium oxide and therefore it can be used for higher temperatures.
3. It does not corrode as easily as natural uranium.
4. It is more compatible with most of the coolants and is not attacked by H₂, N₂.
5. There is greater dimensional stability during use.

Uranium oxide possesses following disadvantages:

1. It has low thermal conductivity.
2. It is more brittle than natural uranium and therefore it can break due to thermal stresses.
3. Its enrichment is essential.

Uranium oxide is a brittle ceramic produced as a powder and then sintered to form fuel pellets. Another fuel used in the nuclear reactor is uranium carbide (UC). It is a black ceramic used in the form of pellets.

Table indicates some of the physical properties of nuclear fuels.

Fuel	Thermal conductivity K-cal/m. hr°C	Specific heat kcal/kg °C	Density kg/m ³	Melting point (°C)
Natural uranium	26.3	0.037	19000	1130
Uranium oxide	1.8	0.078	11000	2750
Uranium carbide	20.6	—	13600	2350

MODERATOR

In the chain reaction the neutrons produced are fast moving neutrons. These fast moving neutrons are far less effective in causing the fission of U235 and try to escape from the reactor. To improve the utilization of these neutrons their speed is reduced. It is done by colliding them with the nuclei of other material which is lighter, does not capture the neutrons but scatters them. Each such collision causes loss of energy, and the speed of the fast moving neutrons is reduced. Such material is called Moderator. The slow neutrons (Thermal Neutrons) so produced are easily captured by the nuclear fuel and the chain reaction proceeds smoothly. Graphite, heavy water and beryllium are generally used as moderator.

Reactors using enriched uranium do not require moderator. But enriched uranium is costly due to processing needed.

A moderator should possess the following properties:

1. It should have high thermal conductivity.
2. It should be available in large quantities in pure form.
3. It should have high melting point in case of solid moderators and low melting point in case of liquid moderators. Solid moderators should also possess good strength and machinability.
4. It should provide good resistance to corrosion.
5. It should be stable under heat and radiation.
6. It should be able to slow down neutrons.

Control Rods. The Control and operation of a nuclear reactor is quite different from a fossil and fuelled (coal or oil fired) furnace. The furnace is fed continuously and the heat energy in the furnace is controlled by regulating the fuel feed, and the combustion air whereas a nuclear reactor contains as much fuel as is sufficient to operate a large power plant for some months. The consumption of this fuel and the power level of the reactor depends upon its neutron flux in the reactor core. The energy produced in the reactor due to fission of nuclear fuel during chain reaction is so much that if it is not controlled properly the entire core and surrounding structure may melt and radioactive fission products may come out of the reactor thus making it uninhabitable. This implies that we should have some means to control the power of reactor. This is done by means of control rods.

Control rods in the cylindrical or sheet form are made of boron or cadmium. These rods can be moved in and out of the holes in the reactor core assembly. Their insertion absorbs more neutrons and damps down the reaction and their withdrawal absorbs less neutrons. Thus power of reaction is controlled by shifting control rods which may be done manually or automatically.

Control rods should possess the following properties:

1. They should have adequate heat transfer properties.
2. They should be stable under heat and radiation.
3. They should be corrosion resistant.
4. They should be sufficiently strong and should be able to shut down the reactor almost instantly under all conditions.
5. They should have sufficient cross-sectional area for the absorption.

REFLECTOR

The neutrons produced during the fission process will be partly absorbed by the fuel rods, moderator, coolant or structural material etc. Neutrons left unabsorbed will try to leave the reactor core never to return to it and will be lost. Such losses should be minimized. It is done by surrounding the reactor core by a material called reflector which will send the neutrons back into

the core. The returned neutrons can then cause more fission and improve the neutrons economy of the reactor. Generally the reflector is made up of graphite and beryllium.

REACTOR VESSEL

It is a strong walled container housing the core of the power reactor. It contains moderator, reflector, and thermal shielding and control rods.

BIOLOGICAL SHIELDING

Shielding the radioactive zones in the reactor from possible radiation hazard is essential to protect the operating men from the harmful effects. During fission of nuclear fuel, alpha particles, beta particles, deadly gamma rays and neutrons are produced. Out of these neutrons and gamma rays are of main significance. A protection must be provided against them. Thick layers of lead or concrete are provided round the reactor for stopping the gamma rays. Thick layers of metals or plastics are sufficient to stop the alpha and beta particles.

COOLANT

Coolant flows through and around the reactor core. It is used to transfer the large amount of heat produced in the reactor due to fission of the nuclear fuel during chain reaction. The coolant either transfers its heat to another medium or if the coolant used is water it takes up the heat and gets converted into steam in the reactor which is directly sent to the turbine.

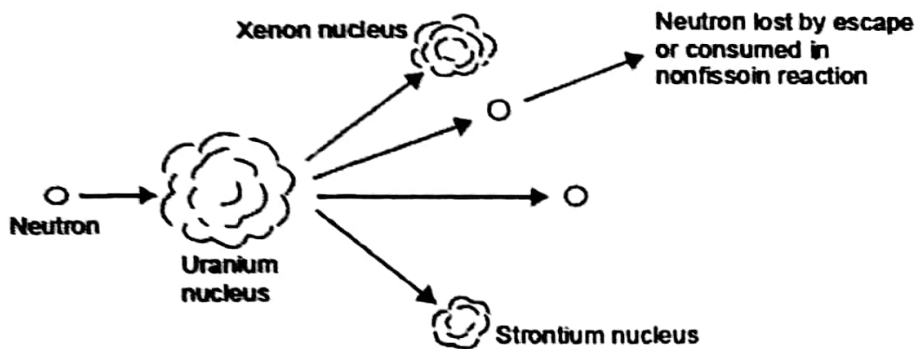
Coolant used should be stable under thermal condition. It should have a low melting point and high boiling point. It should not corrode the material with which it comes in contact. The coolant should have high heat transfer coefficient. The radioactivity induced in coolant by the neutrons bombardment should be nil. The various fluids used as coolant are water (light water or heavy water), gas (Air, CO₂, Hydrogen, Helium) and liquid metals such as sodium or mixture of sodium and potassium and inorganic and organic fluids. Power required to pump the coolant should be minimum. A coolant of greater density and higher specific heat demands less pumping power and water satisfies this condition to a great extent. Water is a good coolant as it is available in large quantities can be easily handled, provides some lubrication also and offers no unusual corrosion problems. But due to its low boiling point (212 F at atmospheric pressure) it is to be kept under high pressure to keep it in the liquid state to achieve a high heat transfer efficiency. Water when used as coolant should be free from impurities otherwise the impurities may become radioactive and handling of water will be difficult.

REACTOR CORE

Reactor core consists of fuel rods, moderator and space through which the coolant flows.

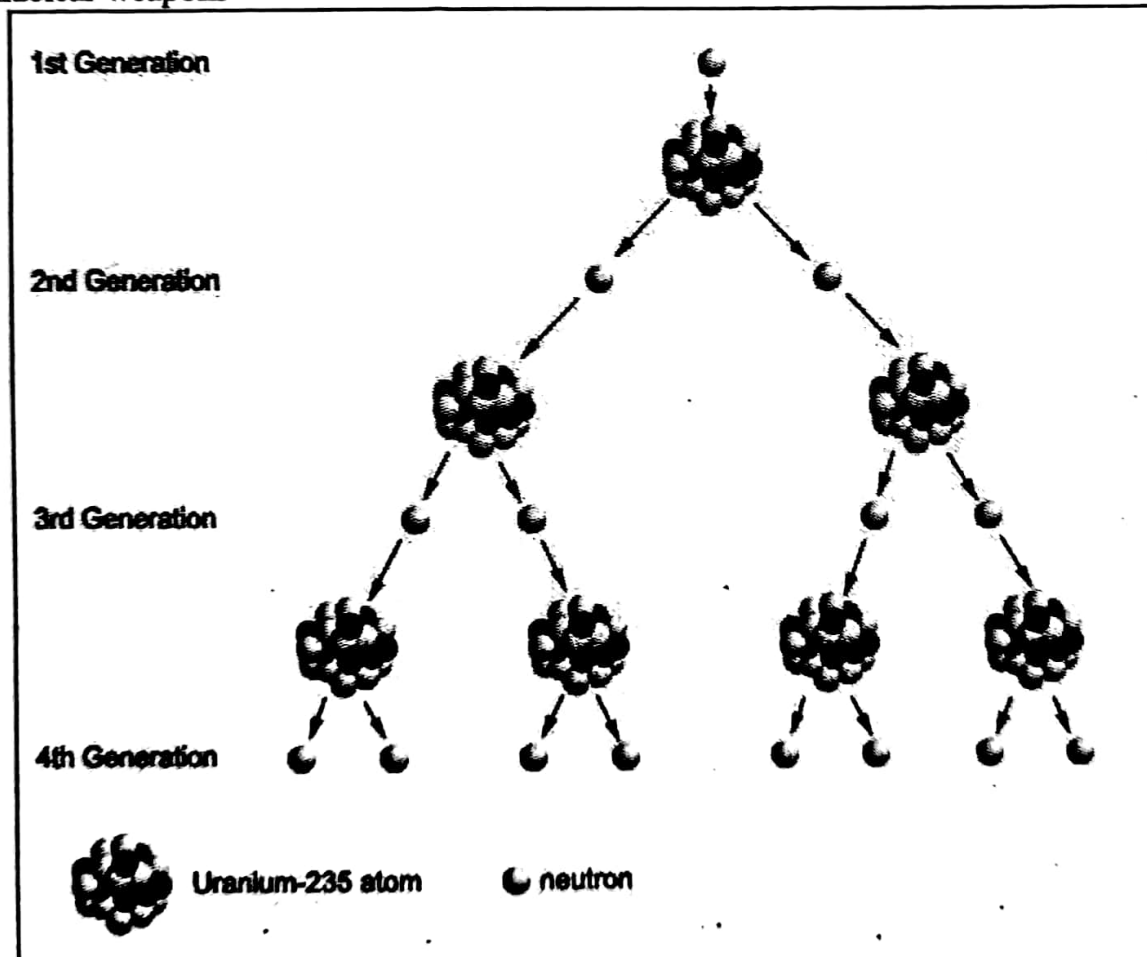
Fission

Which involves nuclei of similar electric charge and therefore requires high kinetic energies, fission can be caused by the neutron, which, being electrically neutral, can strike and fission the positively charged nucleus at high, moderate, or low speeds without being repulsed. Fission can be caused by other particles, but neutrons are the only practical ones that result in a sustained reaction because two or three neutrons are usually released for each one absorbed in fission. These keep the reaction going. There are only a few fissionable isotopes U²³⁵, Pu²³⁹ and U²³³. These are fissionable by neutrons of all energies. The immediate (prompt) products of a fission reaction, such as Xe⁰ and Sr⁹⁴ above, are called fission fragments. They, and their decay products, are called fission products.



Nuclear Chain Reaction

- A chain reaction refers to a process in which neutrons released in fission produce an additional fission in at least one further nucleus.
- This nucleus in turn produces neutrons, and the process repeats.
- If the process is controlled it is used for nuclear power or if uncontrolled it is used for nuclear weapons



- $U_{235} + n \rightarrow \text{fission} + 2 \text{ or } 3 n + 200 \text{ MeV}$
(1 MeV, 1 megaelectronvolt = 1,000,000 eV)
- If each neutron releases two more neutrons, then the number of fissions doubles each generation.
- In that case, in 10 generations there are 1,024 fissions and in 80 generations about 6×10^{23} (a mole) fissions.

Naturally occurring fertile materials:

Naturally occurring fertile materials that can be converted into a fissile material by irradiation in a reactor include:

- thorium-232 which converts into uranium-233
- uranium-234 which converts into uranium-235
- uranium-238 which converts into plutonium-239

Artificial isotopes formed in the reactor which can be converted into fissile material by one neutron capture include:

- plutonium-238 which converts into plutonium-239
- plutonium-240 which converts into plutonium-241

Some other actinides need more than one neutron capture before arriving at an isotope which is both fissile and long-lived enough to probably be able to capture another neutron and fission instead of decaying.

- plutonium-242 to americium-243 to curium-244 to curium-245
- uranium-236 to neptunium-237 to plutonium-238 to plutonium-239
- americium-241 to curium-242 to curium-243 (or, more likely, curium-242 decays to plutonium-238, which also requires one additional neutron to reach a fissile nuclide)

Since these require a total of 3 or 4 thermal neutrons to eventually fission, and a thermal neutron fission generates only about 2 to 3 neutrons, these nuclides represent a net loss of neutrons. In a fast reactor, they may require fewer neutrons to achieve fission, as well as producing more neutrons when they do fission.

CLASSIFICATION OF REACTORS

The nuclear reactors can be classified as follows:

1. **Neutron Energy.** Depending upon the energy of the neutrons at the time they are captured by the fuel to induce fissions, the reactors can be named as follows:

- (a) *Fast Reactors.* In such reactors fission is brought about by fast (non moderated) neutrons.
(b) *Thermal Reactors or Slow Reactors.* In these reactors the fast moving neutrons are slowed down by passing them through the moderator. These slow moving neutrons are then captured by the fuel material to bring about the fission of fundamental research.

On the basis of fuel used

1. Natural uranium fuel reactors

2. Enriched uranium fuel reactor

On the basis of coolant used

1. Water /heavy water cooled reactors

3. Gas cooled reactors

2. Liquid metal /organic liquid cooled reactors

On the basis of moderator:

1. Water moderated

3. Heavy water moderated

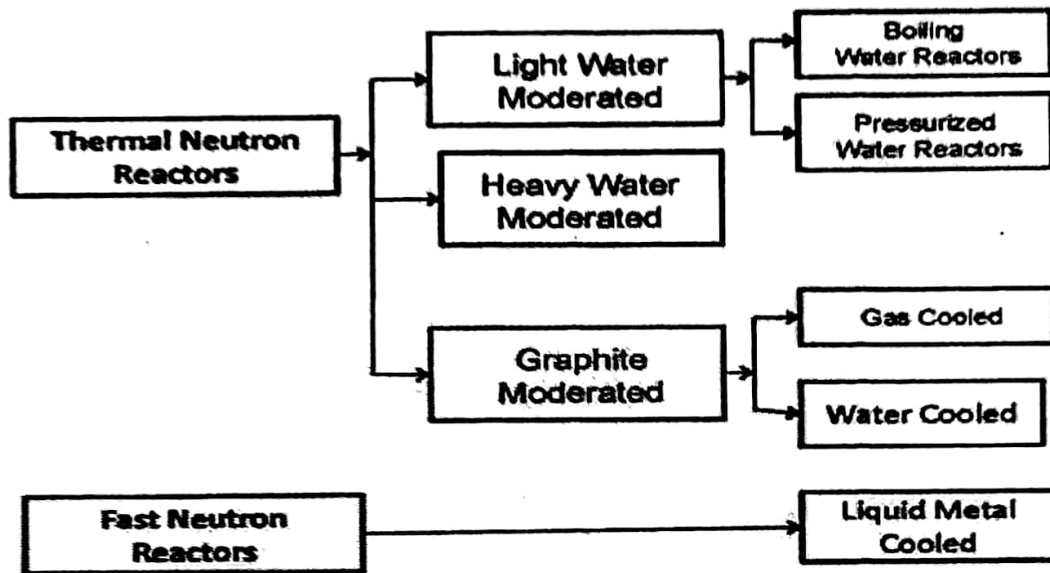
2. Graphite moderated

4. Beryllium moderated

On the basis of reactor core used

1. Homogeneous reactor

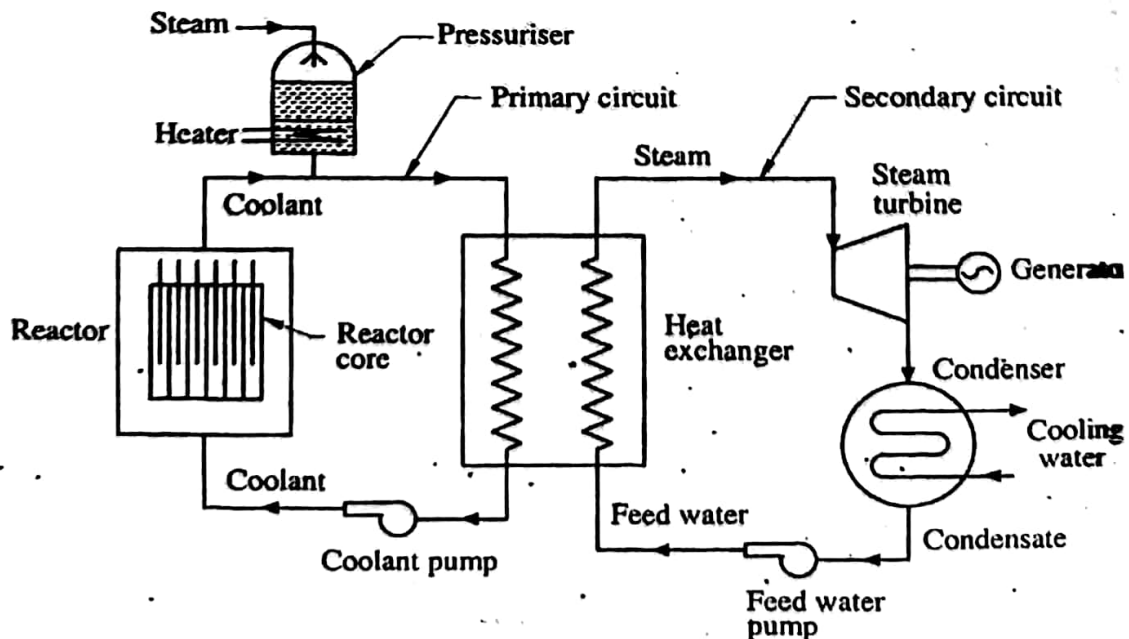
2. Heterogeneous reactor



Pressurized Water Reactor (PWR):

In a typical design concept of a commercial PWR, the following process occurs:

1. The core inside the reactor vessel creates heat.
2. Pressurized water in the primary coolant loop carries the heat to the steam generator.
3. Inside the steam generator, heat from the primary coolant loop vaporizes the water in a secondary loop, producing steam.
4. The steam line directs the steam to the main turbine, causing it to turn the turbine generator, which produces electricity.



In a PWR the primary coolant (water) is pumped under high pressure to the reactor core where it is heated by the energy generated by the fission of atoms. The heated water then flows to a steam generator where it transfers its thermal energy to a secondary system where steam is generated and flows to turbines which, in turn, spins an electric generator.

Nuclear fuel in the reactor vessel is engaged in a fission chain reaction, which produces heat, heating the water in the primary coolant loop by thermal conduction through the fuel cladding. The hot primary coolant is pumped into a heat exchanger called the steam generator, where it flows through hundreds or thousands of tubes (usually 3/4 inch in diameter).

Heat is transferred through the walls of these tubes to the lower pressure secondary coolant located on the sheet side of the exchanger where it evaporates to pressurized steam. The transfer of heat is accomplished without mixing the two fluids, which is desirable since the primary coolant might become radioactive. Some common steam generator arrangements are u-tubes or single pass heat exchangers. In a nuclear power station, the pressurized steam is fed through a steam turbine which drives an electrical generator connected to the electric grid for distribution.

After passing through the turbine the secondary coolant (water-steam mixture) is cooled down and condensed in a condenser. The condenser converts the steam to a liquid so that it can be pumped back into the steam generator, and maintains a vacuum at the turbine outlet so that the pressure drop across the turbine, and hence the energy extracted from the steam, is maximized.

Before being fed into the steam generator, the condensed steam (referred to as feed water) is sometimes preheated in order to minimize thermal shock.

Advantages

- PWR reactors are very stable due to their tendency to produce less power as temperatures increase; this makes the reactor easier to operate from a stability standpoint.
- It uses ordinary water as a coolant, moderator and reflector since water is available near the plant location this is great savings in cost.
- Reactor is compact and high power density.
- As steam is not affected by radiation so the inspection and maintenance of the turbine condenser and feed pump is possible.
- Small numbers of control rods are required.
- PWR turbine cycle loop is separate from the primary loop, so the water in the secondary loop is not contaminated by radioactive materials.

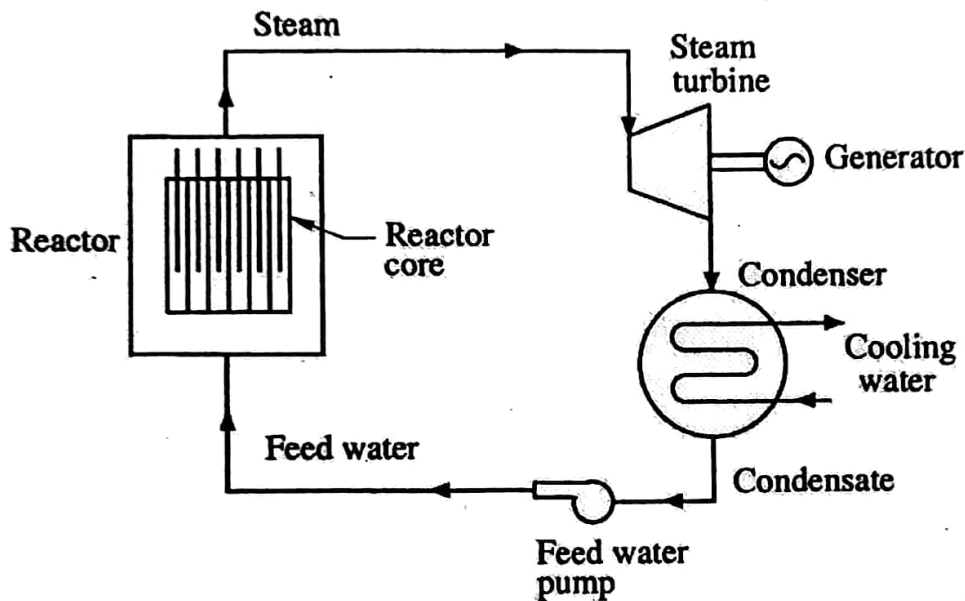
Disadvantages

- Its capital cost is high due to heavy and strong pressure vessel is required in the primary circuit.
- Thermodynamic efficiency is less 20% due to low pressure in secondary circuit.
- Its required enriched uranium fuel cost of enriched uranium is high.
- It is necessary to shut down the reactor for fuel charging.
- Because water acts as a neutron moderator, it is not possible to build a fast neutron reactor with a PWR design.

Boiling Water Reactor (BWR):

In a typical design concept of a commercial BWR, the following process occurs:

1. The core inside the reactor vessel creates heat.
2. A steam-water mixture is produced when very pure water (reactor coolant) moves upward through the core, absorbing heat.
3. The steam-water mixture leaves the top of the core and enters the two stages of moisture separation where water droplets are removed before the steam is allowed to enter the steam line.
4. The steam line directs the steam to the main turbine, causing it to turn the turbine generator, which produces electricity.



The BWR uses dematerialized water as a coolant and neutron moderator. Heat is produced by nuclear fission in the reactor core, and this causes the cooling water to boil, producing steam. The steam is directly used to drive a turbine, after which it is cooled in a condenser and converted back to liquid water. This water is then returned to the reactor core, completing the loop.

Advantages

- The pressure inside the reactor is less than PWR as water is allowed to boil inside the reactor. Therefore the reactor vessel can be much lighter than PWR and reduce the cost of pressure vessel considerably.
- It eliminates the use of heat exchanger pressure equalizer circulating pump and piping therefore the cost of further reduced.
- The thermal efficiency of this reactor is 30% is considerably higher than PWR plant.
- The metal temperature remains low for given output conditions.

Disadvantages

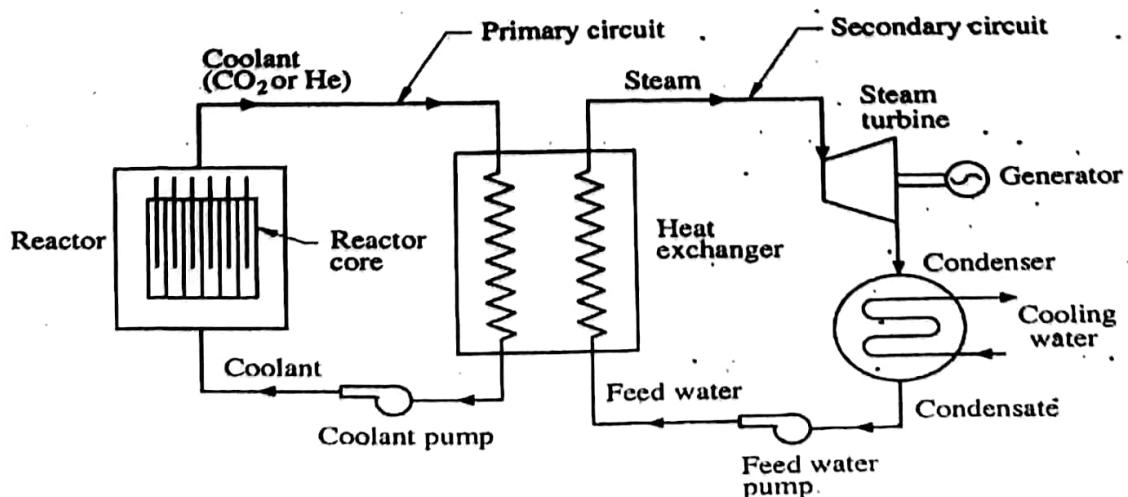
- The steam leaving the reactor is slightly radioactive. Therefore light shielding of turbine and piping is necessary.
- It cannot meet the sudden changes in load the plant.
- The size of vessel is comparatively large as compare to PWR.
- It required enriched uranium as a fuel.

The salient differences between PWR and BWR are:

- The operating pressure of BWR is lower than that of a PWR
- Separate steam generators are not required for BWR as the steam is generated in the core itself
- There is only one coolant loop in BWR as against two in PWR
- (iv) There is no requirement for pressurizer in BWR as against the requirement of a pressurizer in PWR
- (v) Control rods are inserted from the bottom in BWR as against their insertion from top in a PWR. The moderating capability of water is higher at lower temperatures. At increased coolant temperatures near the top of the core, appreciable boiling results in the formation of steam, leading to reduced moderation. Hence to control the reactor power, control rods must be inserted from the bottom where the flux of thermal neutrons is high.
- (vi) BWR plant is a simpler one due to lack of steam generator, pressurizer and the associated pipelines. The lower operating pressure in BWR leads to lower structural problems compared to that of a PWR. BWR plant has good response to operational transient where in higher temperature results in boiling of water resulting in steam and hence a reduction in moderation and heat generation.

Gas-Cooled Reactor (GCR):

A schematic diagram of a gas-cooled reactor is shown in Figure. This is a type of nuclear reactor that uses a gas as the coolant. Mostly CO_2 is used. Graphite blocks are used as moderator, within which channels are made for housing fuel rods. Control rods are inserted into the graphite blocks. Channels are established between the graphite blocks for the flow of coolant. Natural uranium is used as the fuel while cladding is made of a magnesium alloy called magnox. This reactor derives its name from the alloy used for cladding, 'magnox'. The coolant gas is supplied by a gas circulator and enters the core from bottom. Gas flows through the coolant channels between the graphite blocks. As the gas moves up through the core, it gets heated up and leaves the top of the core at high temperature



This high temperature gas exchanges heat with water in a heat exchanger, resulting in the production of steam, which runs the turbine. The spent steam is condensed and returned back to the heat exchanger, while the gas returns to the reactor. The heat exchanger is located outside the pressure vessel and the containment.

Advantages of gas cooled reactor:

1. Processing of fuel is simpler.
2. No corrosion problem.
3. Graphite remains stable under irradiation at high temperature.
4. Use of CO₂ as coolant completely eliminates the possibility of explosion in the reactor which is always present in water cooled plants.
5. Uranium carbide and graphite are able to resist high temperatures.

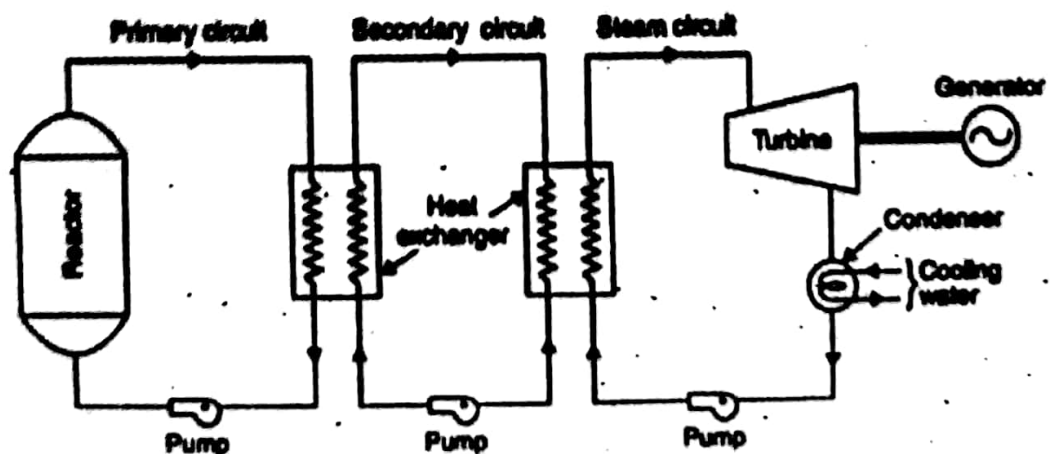
Disadvantages of gas cooled reactor:

1. Fuel loading is costly.
2. Due to high critical mass large amount of fuel loading is initially required.
3. If helium is used instead of CO₂ then leakage may occur.
4. Controlling these reactors is a complicated task

Sodium Graphite Reactor (SGA):

The reactor shown in figure uses two liquid metal coolants. Liquid sodium (Na) serves as the primary coolant and an alloy of sodium potassium (NaK) as the secondary coolant.

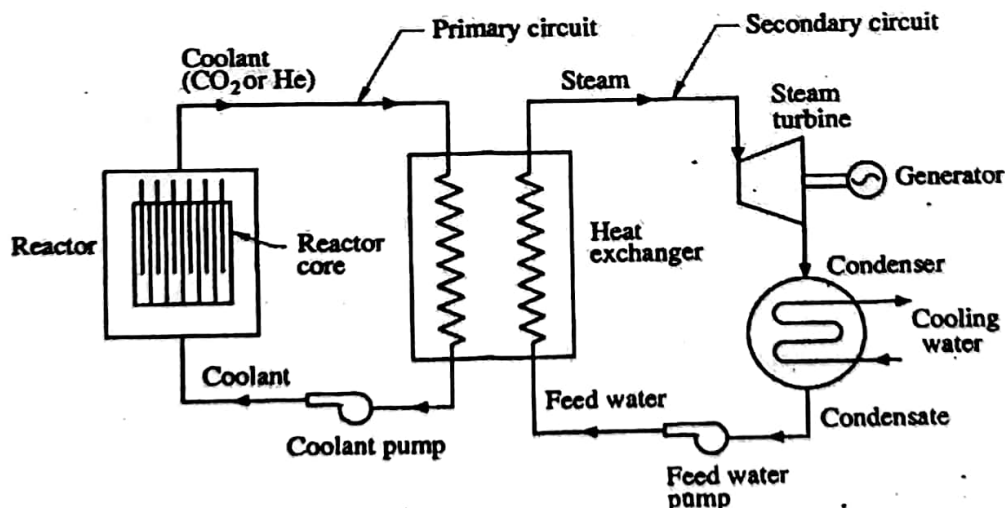
Sodium melts at 208°C and boils at 885°C. This enables to achieve high outlet coolant temperature in the reactor at moderate pressure nearly atmospheric which can be utilized in producing steam of high temperature, thereby increasing the efficiency of the plant. Steam at temperature as high as 540°C has been obtained by this system. This shows that by using liquid sodium as coolant more electrical power can be generated for a given quantity of the fuel burn up.



Secondly low pressure in the primary and secondary coolant circuits, permits the use of less expensive pressure vessel and pipes etc. Further sodium can transfer its heat very easily. The only disadvantage in this system is that sodium becomes radioactive while passing through the core and reacts chemically with water. So it is not used directly to transfer its heat to the feed water, but a secondary coolant is used. Primary coolant while passing through the tubes of intermediate heat exchanges (I.H.X) transfers its heat to the secondary coolant. The secondary coolant then flows through the tubes of steam generator and passes on its heat to the feed water. Graphite is used as heat transfer media have certain advantages of using liquids used for heat transfer purposes. The various advantages of using liquid metals as heat transfer media are that they have relatively low melting points and combine high densities with low vapour pressure at high temperatures as well as with large thermal conductivities.

Fast Breeder Reactor (FBR)

The process of converting more fertile material into fissile material in a reactor is called breeding. In fast breeder reactor the core containing U235 is surrounded by a blanket of fertile material U238. In this reactor no moderator is used the fast moving neutrons liberated due to fission of U235 are absorbed by U238 which gets converted in to Pu239 a fissile material. This reactor also uses two liquid metal coolants in which sodium is used as primary coolant and sodium potassium as secondary coolant (sodium boils at 850°C under atmospheric pressure and freeze at 95°C). The reactor also used two liquid metal coolants in which sodium is used as primary coolants and sodium potassium as secondary coolants. Liquid sodium is circulated through the reactor to carry the heat produced. The heat produced by the sodium is transferred to secondary coolant sodium potassium in the primary heat exchanger which in turn transfers the heat in secondary heat exchanger called steam generator.



Advantages

- It gives high power density than any other reactor therefore small core is sufficient.
- Moderator is not required.
- Secondary fusible materials by breeding are obtained.
- Absorption of neutrons is slow.

Disadvantages

- It requires highly enriched uranium fuel.
- Safety must be provided against melt down.
- Neutron flux is high at the center of the core.
- Thick shielding is necessary.

Coolants are used for Fast Breeder Reactors

The commonly used coolants for fast breeder reactors are as follows:

- i) Liquid metal (Na or NaK).
- ii) Helium (He)
- iii) Carbon dioxide.

Sodium has the following advantages:

- i) It has very low absorption cross-sectional area.
- ii) It possesses good heat transfer properties at high temperature and low pressure.
- iii) It does not react on any of the structural materials used in primary circuits.

Homogeneous reactor:

A nuclear reactor in which the active core consists of a homogeneous mixture of nuclear fuel and a moderator. The distinguishing feature of the homogeneous reactor is the absence of fuel elements; the nuclear fuel and the raw material for breeding (uranium, thorium, or plutonium) may be placed into the active core as a salt solution with ordinary or heavy water, or as a dispersion in a solid moderator (for example, graphite). Possible modifications of the homogeneous reactor contain the fuel in gaseous forms such as gaseous compounds of uranium or a suspension of uranium dust in a gas. Heat released in the core may be conducted away by a heat transfer agent (water, gas, or other materials), which is circulated through pipelines that pass through the core, or else the homogeneous mixture of fuel and moderator is conducted out of the core directly.

Because of considerable difficulties of engineering and design, homogeneous reactors are not widely used and are applied only for experimental purposes. There are only isolated examples of projects using homogeneous reactors as heat sources in the industrial production of electrical power.

Nuclear Waste and its Disposal

The radioactive emission during the operation of the plant is negligible but the emission intensity is very high which comes out from the waste. Therefore, safe nuclear waste disposal is a major problem before the nuclear industry. It is estimated that the radioactive products of 400 MW power plants would be equivalent to 100 tons of radium daily and the radioactive effect of this plant's products if exposed to atmosphere would kill all the living organisms within the area about 160 square kilometers. The waste produced in a nuclear power plant may be in the form of liquid, gas and solid and each is treated in different ways.

Solid waste

It will arise used filters, sludge from the cooling ponds, pieces from discarded fuel element cans, splitters control rods etc. The combustible solid waste is burnt and flue gases formed are filtered and then exposed to the high level of atmosphere. Active solid wastes are stored in water for

about 100 or more days to allow radioactivity to decay then these are disposed to deep salt mines or an ocean floor or in deep wells drilled in stable geological strata.

Liquid waste

Radioactive effluents will arise from the laundry, personal decontamination etc. together with activity accumulating from the corrosion of the irradiated fuel elements in the storage ponds. The disposal of liquid waste has done in two ways.

1. Dilution

The liquid waste are diluted with large quantity of water and then released in to the ground. The major drawback of this method there is a chance of contamination of underground water if dilution factor is not adequate.

2. Concentration to small volumes and storage

If the dilution of water is not possible then liquid will store in leakage proof and high strength material storage can or tank and then stored in deep drilled salt mines.

Gaseous Waste

Gaseous wastes are generally diluted with air passed through filters and then released to the atmosphere through large chimneys. Krypton is removed by cryogenic treatment of dissolved off gas stream and packed in gas cylinder under pressure. Generally gaseous waste filtered in filter and then allows escaping to the atmosphere or stored in pressure tanks and then stored in deep drilled salt mines.

• Geological Disposal

The process of geological disposal centers on burrowing nuclear waste into the ground to the point where it is out of human reach. The waste needs to be properly protected to stop any material from leaking out. Seepage from the waste could contaminate the water table if the burial location is above or below the water level. Furthermore, the waste needs to be properly fastened to the burial site and also structurally supported in the event of a major seismic event, which could result in immediate contamination.

• Reprocessing

Reprocessing has also emerged as a viable long term method for dealing with waste. As the name implies, the process involves taking waste and separating the useful components from those that aren't as useful. Specifically, it involves taking the fissionable material out from the irradiated nuclear fuel.

• Transmutation

Transmutation also poses a solution for long term disposal. It specifically involves converting a chemical element into another less harmful one. Common conversions include going from Chlorine to Argon or from Potassium to Argon. The driving force behind transmutation is chemical reactions that are caused from an outside stimulus, such as a proton hitting the reaction materials. Natural transmutation can also occur over a long period of time. Natural transmutation also serves as the principle force behind geological storage on the assumption that giving the waste enough isolated time will allow it to become a non-fissionable material that poses little or no risk