NUCLEAR POWER PLANT

1. Define Isotopes?

Those pairs of atoms which have the same atomic number and hence similar chemical properties but different atomic mass number are called isotopes.

2. Define Isobars?

Those atoms which have the same mass number but different atomic numbers are called isobars. Obviously, these atoms belong to different chemical elements.

3. Define Isomers?

Those pairs of atoms (nuclides) which have the same atomic number and atomic mass number but have different radioactive properties are called isomers and their existence is referred to as nuclear isomerism.

4. Define isotones?

Those atoms whose nuclei have the same number of neutrons are called isotones**.**

5. Define Radioactivity?

The phenomenon of spontaneous emission of powerful radiations exhibited by heavy element is called radioactivity. The radioactivity may be natural or artificial.

6. Write the types of Nuclear radiations?

The five types of nuclear radiations are :

(i) Gamma rays (or photons) : electromagnetic radiation.

(ii) Neutrons : uncharged particles, mass approximately 1.

(iii) Protons : + 1 charged particles, mass approximately 1.

(iv) Alpha particles : helium nuclei, charge + 2, mass 4.

(v) Beta particles : electrons (charge – 1), positrons (charge + 1), mass very small**.**

7. Define Fertile Materials?

It has been found that some materials are not fissionable by themselves but they can be converted to the fissionable materials, these are known as fertile materials.

8. Define Fission?

Fission is the process that occurs when a neutron collides with the nucleus of certain of heavy atoms, causing the original nucleus to split into two or more unequal fragments which carry-off most of the energy of fission as kinetic energy. This process is accompanied by the emission of neutrons and gamma rays.

9. Define chain reaction?

A chain reaction is that process in which the number of neutrons keeps on multiplying rapidly (in geometrical progression) during fission till whole the fissionable material is disintegrated. The multiplication or reproduction factor (K) is given by:

$$K = \frac{\text{No. of neutrons in any particular generation}}{\text{No. of neutrons in the preceding generation}}$$

If K > 1, chain reaction will continue and if K < 1, chain reaction cannot be maintained.

10. Define Nuclear fusion?

Nuclear fusion is the process of combining or fusing two lighter nuclei into a stable and heavier nuclide. In this case large amount of energy is released because mass of the product nucleus is less than the masses of the two nuclei which are fused.

11. Define Nuclear Reactor?

A nuclear reactor is an apparatus in which nuclear fission is produced is the form of a controlled self-sustaining chain reaction.

12. Write the Essential components of a nuclear reactor?

Essential components of a nuclear reactor are:

(i) Reactor core

(ii) Reflector

(iii) Control mechanism

(iv) Moderator

(v) Coolants

(vi) Measuring instruments

(vii) Shielding.

13. What are the main components of a nuclear power plant?

The main components of a nuclear power plant are:

(i) Nuclear reactor

(ii) Heat exchanger (steam generator)

(iii) Steam turbine

(iv) Condenser

(v) Electric generator

(vi) Steam turbine

(vii)Condender

(viii)Electric generator

14. Mention some important reactors?

Some important reactors are :

(i) Pressurized water reactor (PWR)

(ii) Boiling water reactor (BWR)

(iii) Gas-cooled reactor

(iv) Liquid metal-cooled reactor

(v) Breeder reactor.

15. What are the factors are consider to selecting the site for Nuclear power plant?

Following factors should be considered while selecting the site for a nuclear power plant:

1. **Availability of Water:** working fluid
2. **Distance from Populated Area:** danger of radioactivity
3. **Nearness to the load centre:** reduction in transmission cost
4. **Disposal of Waste:** radioactive waste
5. **Accessibility by Rail and Road:** transport of heavy equipment

16. What are the advantages of nuclear power plant?

1. It can be easily adopted where water and coal resources are not available.
2. The Nuclear power plant requires very small quantity of fuel. Hence fuel transport cost is less.
3. Space requirement is very less compared to other power plant of equal capacity.
4. It is not affected by adverse weather condition.

17. Mention any 3 fast breeder reactors?

1. Liquid Metal

2. Helium
3. Carbon dioxide

18. What are the ways the liquid wastes are dispose?

1. Dilution
2. Concentration to small volumes and storages.

Short notes (a) Fission Energy (b) Chain Reaction (c) Fusion Energy

A nuclear power plant is similar to a conventional steam power plant except how that energy is evolved. The heat is produced in the nuclear power plant by fission, whereas in steam and gas turbine plants, the heat is produced by combustion in the furnace. The nuclear reactor acts as a furnace where nuclear energy is evolved by splitting or fissioning of the nucleus of fissionable material like Uranium U-235. It is claimed that 1 kg U-235 can produce as much heat energy that can be produced by burning 4500 tones of high grade coal or 1700 tons of oil.

1. Fission energy

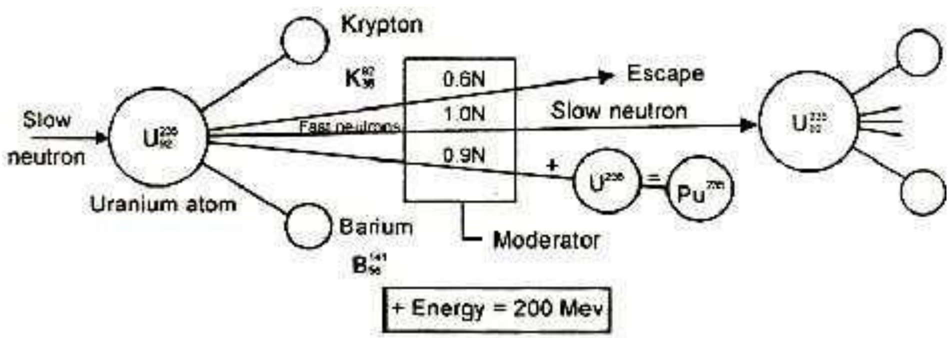


Figure : Nuclear fission

Nuclear energy is divided from splitting (or) fissioning of the nucleus of fissionable

Material like Uranium U-235. Uranium has several isotopes (Isotopes are atoms of the same element having different atomic masses) such as U-234, U-235 and U-238. Of the several isotopes, U-235 is the most unstable isotope, which is easily fissionable and hence used as fuel in an atomic reactor.

When a neutron enters the nucleus of an unstable U-235, the nucleus splits into two equal fragments (Krypton and Barium) and also releases 2.5 fast moving neutrons with a velocity of 1.5×10^7 m/sec and along with this produces a large amount of energy, nearly 200 million electro- volts. This is called nuclear fission.

2. Chain reaction

The neutrons released during fission are very fast and can be made to initiate the fission of other nuclei of U-235, thus causing a chain reaction. When a large number of fission occurs, enormous amount of heat is generated, which is used to produce steam. The chain reaction under controlled conditions can release extremely large amount of energy causing atomic explosion. Energy released in chain reaction, according to Einstein law is $E=mc^2$

Where E = Energy liberated (J)

m= Mass (kg)

c = Velocity of light (3×10^8 m/sec).

Out of 2.5 neutrons released in fission of each nucleus of U-235, one neutron is used to sustain the chain reaction, about 0.9 neutron is captured by U-238, which gets converted into fissionable material Pu-239 and about 0.6 neutron is partially absorbed by control rod materials, coolant and moderator. If thorium is used in the reactor core, it gets converted to fissionable material U-233.

Thorium 232 + Neutron U-233

Pr-239 and U-233 so produced are fissionable materials are called secondary fuels. They can be used as nuclear fuels. U-238 and Th-232 are called fertile materials.

3. Fusion energy

Energy is produced in the sun and stars by continuous fusion reactions in which four nuclei of hydrogen fuse in a series of reactions involving other particles that continually appear and disappear in the course of the reaction, such as He^3, nitrogen, carbon, and other nuclei, but culminating in one nucleus of [1]helium of two positrons.

To cause fusion, it is necessary to accelerate the positively charged nuclei to high kinetic energies, in order to overcome electrical repulsive forces, by raising their temperature to hundreds of millions of degrees resulting in plasma. The plasma must be prevented from contacting the walls of the container, and must be confined for a period of time (of the order of a second) at a minimum density. Fusion reactions are called thermonuclear because very high temperatures are required to trigger and sustain them. n, p, D, and T are the symbols for the neutron, proton, deuterium , and tritium , respectively.

Many problems have to be solved before an artificially made fusion reactor becomes a reality. The most important of these are the difficulty in generating and maintaining high temperatures and the instabilities in the medium (plasma), the conversion of fusion energy to electricity, and many other problems of an operational nature.

Types of Reactors

The nuclear reactors are classified on the following basis:

1. On the basis of neutron energy

a) Fast reactors

In these reactors, the fission is effected by fast neutrons without any use of moderators.

b) Thermal reactors

In these reactors, the fast neutrons are slowed with the use of moderators. The slow neutrons are absorbed by the fissionable fuel and chain reaction is maintained. The moderator is the most essential component in these reactors.

2. On the basis of fuel used

a) Natural fuel

In this reactor, the natural uranium is used as fuel and generally heavey water or graphite is used as moderator.

b) Enriched uranium

In this reactor, the Uranium used contains 5 to 10% U^{235} and ordinary water can be used as moderator.

3. On the basis of moderator used

a) Water moderated

b) Heavy water moderated

c) Graphite moderated

d) Beryllium moderated

4. On the basis of coolant used

a) Water cooled reactors (ordinary or heavy),

b) Gas cooled reactors

c) Liquid metal cooled reactors

d) Organic liquid cooled reactors

Main components of nuclear power plants:

i) Moderators

In any chain reaction, the neutrons produced are fast moving neutrons. These are less effective in causing fission of U^{235} and they try to escape from the reactor. It is thus implicit that speed of these neutrons must be reduced if their effectiveness is carrying out fission is to be increased. This is done by making these neutrons collide with lighter nuclei of other materials, which does not absorb these neutrons but simply scatter them. Each collision causes loss of energy and thus the speed of neutrons is reduced. Such a material is called a ‘Moderator’. The neutrons thus slowed down are easily captured by the fuel element at the chain reaction proceeds slowly.

i) Reflectors

Some of the neutrons produced during fission will be partly absorbed by the fuel elements, moderator, coolant and other materials. The remaining neutrons will try to escape from the reactor and will be lost. Such losses are minimized by surrounding (lining) the reactor core with a material called a reflector which will reflect the neutrons back to the core. They improve the neutron economy. Economy: Graphite, Beryllium.

ii) Shielding

During Nuclear fission α, β and ɣ particles and neutrons are also produced. They are harmful to human life. Therefore it is necessary to shield the reactor with thick layers of lead, or concrete to protect both the operating personnel as well as environment from radiation hazards.

iii) Cladding

In order to prevent the contamination of the coolant by fission products, the fuel element is covered with a protective coating. This is known as cladding.

Control rods are used to control the reaction to prevent it from becoming violent. They control the reaction by absorbing neutrons. These rods are made of boron or cadmium. Whenever the reaction needs to be stopped, the rods are fully inserted and placed against their seats and when the reaction is to be started the rods are pulled out.

iv) Coolant

The main purpose of the coolant in the reactor is to transfer the heat produced inside the reactor. The same heat carried by the coolant is used in the heat exchanger for further utilization in the power generation.

Some of the desirable properties of good coolant are listed below:

1. It must not absorb the neutrons.
2. It must have high chemical and radiation stability
3. It must be non-corrosive.
4. It must have high boiling point (if liquid) and low melting point (if solid)
5. It must be non-oxidising and non-toxic.
6. It must also have high density, low viscosity, high conductivity and high specific heat. These properties are essential for better heat transfer and low pumping power

The above-mentioned properties are essential to keep the reactor core in safe condition as well as for the better functioning of the content.

The water, heavy water, gas (He, CO2), a metal in liquid form (Na) and an organic liquid are used as coolants. The coolant not only carries large amounts of heat from the core but also keeps the fuel assemblies at a safe temperature to avoid their melting and destruction.

v)Nuclear reactor

A nuclear reactor may be regarded as a substitute for the boiler fire box of a steam power plant. Heat is produced in the reactor due to nuclear fission of the fuel U^{235} The heat liberated in the reactor is taken up by the coolant circulating through the core. Hot coolant leaves the reactor at top and flows into the steam generator (boiler).

Radiation hazards and Shieldings

The reactor is a source of intense radioactivity. These radiations are very harmful to human life. It requires strong control to ensure that this radioactivity is not released into the atmosphere to avoid atmospheric pollution. A thick concrete shielding and a pressure vessel are provided to prevent the escape of these radiations to atmosphere

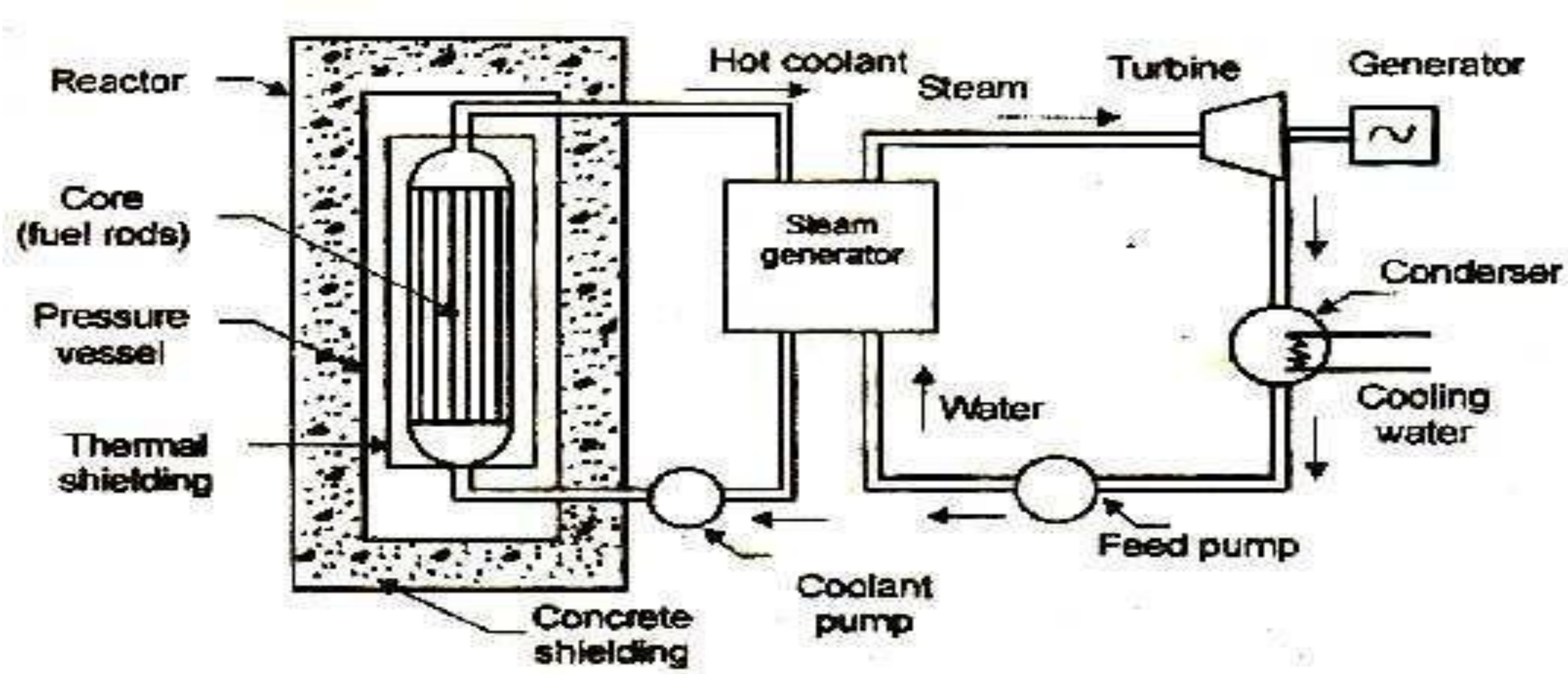


Figure : Nuclear Power Plant layout

vi) Steam generator

The steam generator is fed with feed water which is converted into steam by the heat of the hot coolant. The purpose of the coolant is to transfer the heat generated in the reactor core and use it for steam generation. Ordinary water or heavy water is a common coolant.

vii) Turbine

The steam produced in the steam generator is passed to the turbine and work is done by the expansion of steam in the turbine.

viii) Coolant pump and Feed pump

The steam from the turbine flows to the condenser where cooling water is circulated. Coolant pump and feed pump are provided to maintain the flow of coolant and feed water respectively.

Advantages of nuclear power plant

1. It can be easily adopted where water and coal resources are not available.
2. The nuclear power plant requires very small quantity of fuel. Hence fuel transportation cost is less.
3. Space requirement is less compared to other power plants of equal capacity.
4. It is not affected by adverse weather conditions.
5. Fuel storage facilities are not needed as in the case of the thermal power plant.
6. Nuclear power plants will converse the fossils fuels (coal, petroleum) for other energy needs.
7. Number of workmen required at nuclear plant is far less than thermal plant.
8. It does not require large quantity of water.

Disadvantages

1. Radioactive wastes, if not disposed of carefully, have adverse effect on the health of workmen and the population surrounding the plant.
2. It is not suitable for varying load condition.
3. It requires well-trained personnel.
4. It requires high initial cost compared to hydro or thermal power plants.

Construction and working principle of Boiling Water Reactor (BWR)

Figure shows a simplified BWR. Light water, which acts as the coolant and moderator, passes through the core where boiling takes place in the upper part of the core. The wet steam then passes through a bank of moisture separators and steam dryers in the upper part of the pressure vessel. The water that is not vaporized to steam is recirculated through the core with the entering feed water using two recirculation pumps coupled to jet pumps (usually 10 to 12 per recirculation pump). The steam leaving the top of the pressure vessel is at saturated conditions of 7.2 MPa and 278□C.

The steam then expands through a turbine coupled to an electrical generator. After condensing to liquid in the condenser, the liquid is returned to the reactors as feedwater. Prior to entering the reactor, the feedwater is preheated in several stages of feedwater heaters. The balance of plant systems (Example: Turbine generator, feedwater heaters) are similar for both PWR and BWRs.

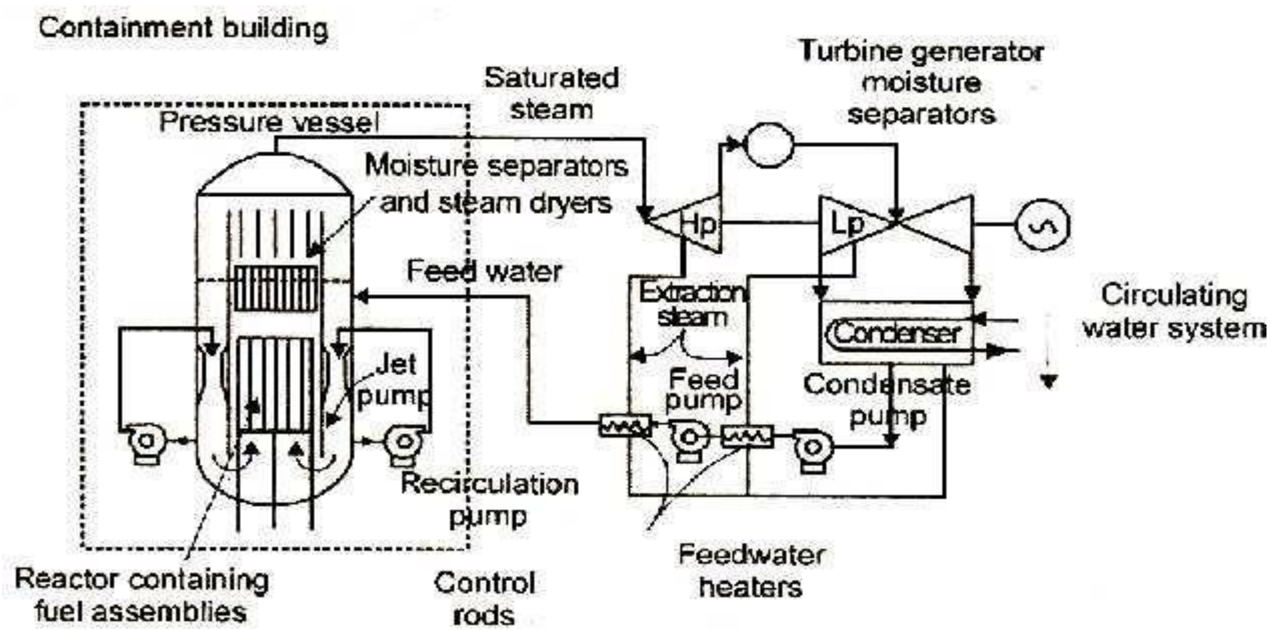


Figure: Schematic for a boiling water reactor.(BWR)

The BWR reactor core, like that in a PWR, consists of a large number of fuel rods housed in fuel assemblies in a nearly cylindrical arrangement. Each fuel assembly contains an 8×8 or 9×9 square array of 64 or 81 fuel rods (typically two of the fuel rods contain water rather than fuel) surrounded by a square Zircaloy channel box to ensure no coolant cross flow in the core. The fuel rods are similar to the PWR rods, although larger in diameter. Each fuel rod is a zirconium alloy- clad tube containing pellets of slightly enriched uranium dioxide (2% to 5% U-235) stacked end-to- end. The reactor is controlled by control rods housed in a cross-shaped arrangement called a control element. The control elements enter from the bottom of the reactor and move in spaces between the fuel assemblies.

The BWR reactor core is housed in a pressure vessel that is larger than that of a PWR. A typical BWR pressure vessel, which also houses the reactor core, moisture separators, and steam dryers, has a diameter of 6.4 m, with a height of 22 m. Since a BWR operator at a nominal pressure of 6.9 MPa, its pressure vessel is thinner than that of a PWR.

Fast Breeder Reactor

Figure shows a fast breeder reactor system. In this reactor the core containing U^{235} in surrounded by a blanket (a layer of fertile material placed outside the core) of fertile material U^{238}. In this reactor no moderator is used. The fast moving neutrons liberated due to fission of U^{235} are absorbed by U^{238} which gets converted into fissionable material Pu^{239} which is capable of sustaining chain reaction. Thus this reactor is important because it breeds fissionable material from fertile material U^{238} available in large quantities. Like sodium graphite nuclear reactor this reactor also uses two liquid metal coolant circuits. Liquid sodium is used as primary coolant when circulated through the tubes of intermediate heat exchange transfers its heat to secondary coolant sodium potassium alloy. The secondary coolant while flowing through the tubes of steam generator transfers its heat to feed water.

Fast breeder reactors are better than conventional reactors both from the point of view of safety and thermal efficiency. For India which already is fast advancing towards self reliance in the field of nuclear power technology, the fast breeder reactor becomes inescapable in view of the massive reserves of thorium and the finite limits of its uranium resources. The research and development efforts in the fast breeder reactor technology will have to be stepped up considerably if nuclear power generation is to make any impact on the country’s total energy needs in the not too distant future.

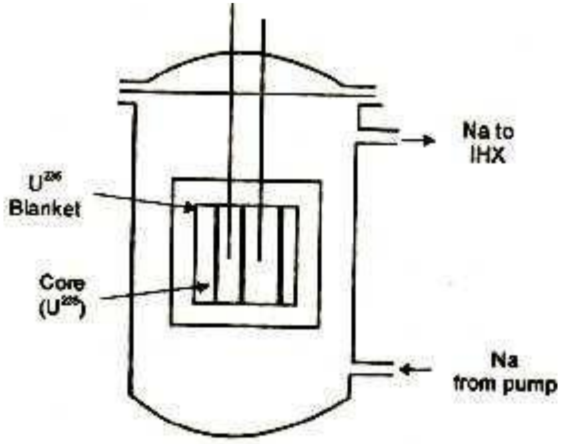


Figure: Fast breeder reactor.

coolants are used for Fast Breeder Reactors

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

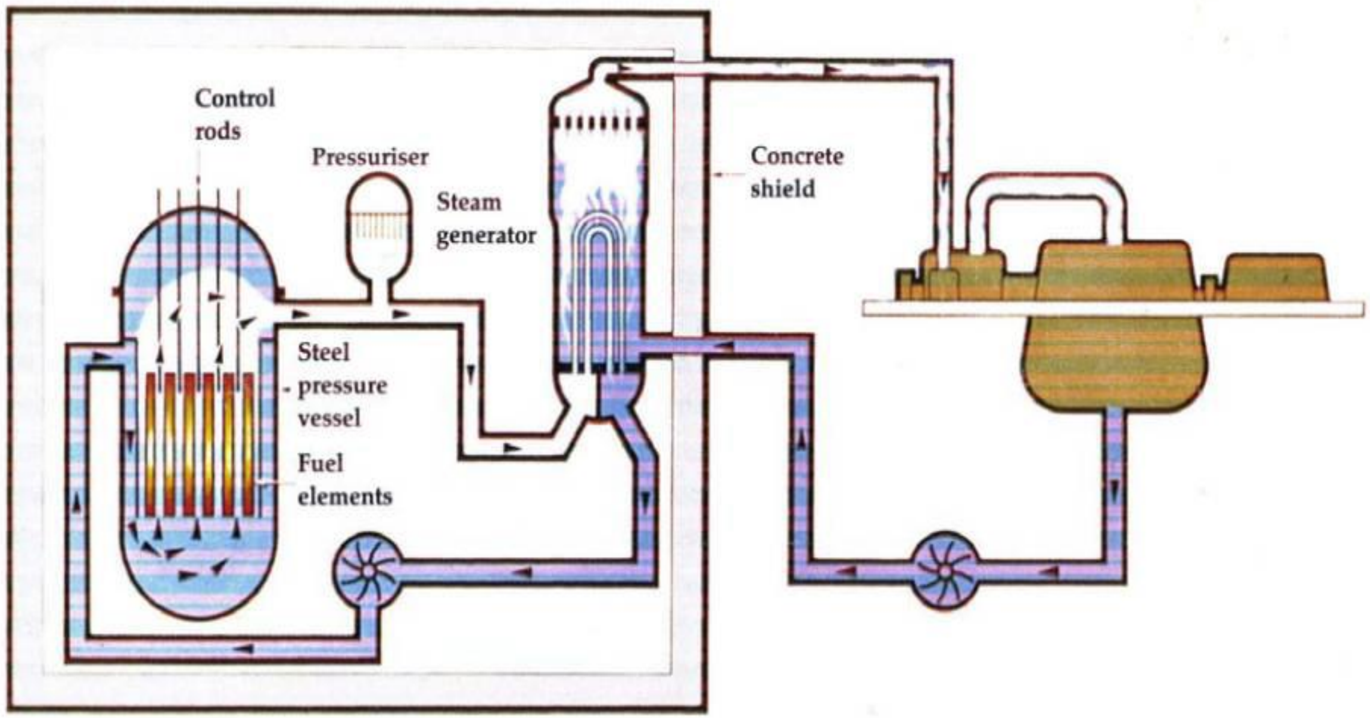
i) Liquid metal .

ii) Helium (He)

iii) carbon dioxide.

Pressurized Water Reactor (PWR)

- The most widely used reactor type in the world is the Pressurized Water Reactor (PWR) which uses enriched (about 3.2% U235) uranium dioxide as a fuel in zirconium alloy cans.
- The fuel, which is arranged in arrays of fuel "pins" and interspersed with the movable control rods, is held in a steel vessel through which water at high pressure (to suppress boiling) is pumped to act as both a coolant and a moderator.
- The high-pressure water is then passed through a steam generator, which raises steam in the usual way.



Pressurized Water Reactor (PWR)

Comparison of PWR and BWR

Pressurized Water Reactor (PWR)	Boiling Water Reactor (BWR)
Pressurized Water Reactor (PWR) power plants consist of two loops—(i) primary loop or coolant loop that takes away heat from reactor, and (ii) secondary loop or working fluid loop that drives the turbine. A heat exchanger (HE) is employed to transfer heat from primary loop to the secondary loop.	Boiling Water Reactor (BWR) power plants consist of a single loop where the coolant that takes away heat from the reactor is directly fed to the turbine. Thus no heat exchanger is desired.
In the primary loop, normal water (H_2O) acts as coolant-cum-moderator. In the secondary loop, the normal water acts as working fluid. However, water from one loop is not allowed to mix with the water of other loop.	Since it has only one loop, so normal water (H_2O) serves all three purposes – cooling, moderation, and working fluid.
Normal water in the primary loop, that acts as moderator-cum-coolant, is not allowed to boil. That means the water remains in liquid phase throughout the cycle of primary loop. However, the water in the secondary loop is allowed to boil.	Here the normal water (H_2O) is allowed to change its phase. Thus the water (liquid phase) is first converted into steam (gaseous phase) within the reactor, and then the steam is again condensed to water before pumping back to reactor.
Here steam is generated in a heat exchanger outside the nuclear reactor.	Here steam is generated within the reactor itself.
Here the water in the primary loop is maintained at high pressure (15 – 17 MPa) to avoid boiling at reactor exit.	Here water pressure remains comparatively low (7 – 8 MPa) as it is allowed to boil.
A pressurizer is required to use mandatorily to maintain water pressure in such a way that it does not evaporate even at very high temperature.	No such pressurizer is employed as evaporation of the water is desired.
The temperature of the water at the reactor exit is kept around 310°C (corresponding to the working pressure to avoid boiling).	Steam temperature at reactor exit remains comparatively low (around 285°C).
PWR has comparatively low thermal efficiency owing to two different loops.	BWR offers higher thermal efficiency.
In PWR, the control rods are inserted from the top of the nuclear reactor.	In BWR, the control rods are inserted from the bottom of the nuclear reactor.
Since the fluid is maintained at high pressure, so the PWR core volume is less.	For the same power generation, core volume of the BWR is comparatively larger.
Since the working fluid loop is separated from the primary loop, so PWR is less risky in spreading of radioactive materials owing to leakage.	Since same fluid passes through the reactor and turbine in BWR plants, so any leakage in the turbine can spread radioactive elements into the atmosphere.

Safety Measures carried out in Nuclear Power Plants:

Nuclear power plants should be located far away from the populated area to avoid the radioactive hazard. A nuclear reactor produces α and β particles, neutrons and ɣ- quanta which can disturb the normal functioning of living organisms. Nuclear power plants involve radiation leaks, health hazard to workers and community, and negative effect on surrounding forests.

At nuclear power plants there are three main sources of radioactive contamination of air.

1. Fission of nuclei of nuclear fuels.
2. The second source is due to the effect of neutron fluxes on the heat carrier in the primary cooling system and on the ambient air.
3. Third source of air contamination is damage of shells of fuel elements.

This calls for special safety measures for a nuclear power plant. Some of the safety measures are as follows.

1. Nuclear power plant should be located away from human habitation.
2. Quality of construction should be of required standards.
3. Waste water from nuclear power plant should be purified.
4. An atomic power plant should have an extensive ventilation system. The main purpose of this ventilation system is to maintain the concentration of all radioactive impurities in the air below the permissible concentrations.
5. An exclusion zone of 1.6 km radius around the plant should be provided where no public habitation is permitted.
6. The safety system of the plant should be such as to enable safe shut down of the reactor whenever required.