ME8792-POWER PLANT ENGINEERING
UNIT III- NUCLEAR POWER PLANTS

3.1-BASICS OF NUCLEAR ENGINEERING, LAYOUT AND SUBSYSTEMS OF NUCLEAR POWER PLANTS

BASICS OF NUCLEAR ENGINEERING

Cheap and abundant power is essential to the modern world in coming years. The rapid increase in industry and living standard of the people advance the pressure on conventional sources of power i.e. coal, oil and hydro. The resources of these fuels are becoming depleted in many countries, and thus there is a tendency to seek alternative sources of energy. Hydroelectric stations produce cheap power, but need a thermal backing to increase the firm capacity.

In a nuclear power station instead of a furnace, there is a nuclear reactor, in which heat is generated by splitting atoms of radioactive material under suitable conditions. This splitting or nuclear fission of materials like uranium (U), Plutonium (Up), has opened up a new source of power of great importance.

The heat produced due to fission of uranium and plutonium is used to heat water to generate steam which is used for running turbo generators.

A nuclear power plant differs from a conventional power plant only in the steamgenerating part. The schematic arrangement of a simple nuclear power plant using liquid coolant with and without heat exchanger is shown in Figure other type of nuclear power station will be considered latter.

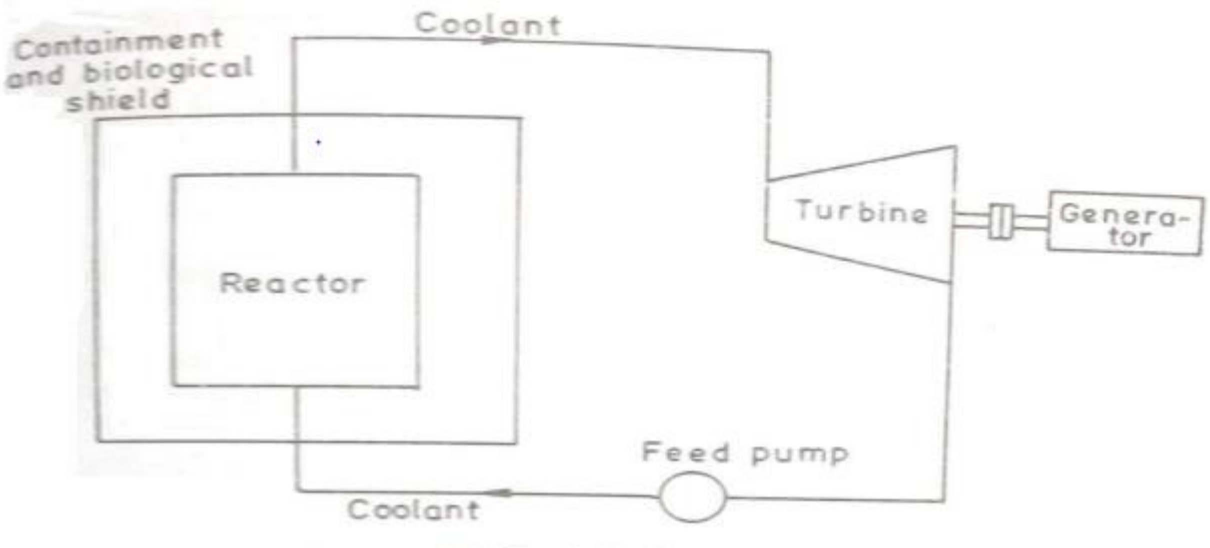
The main parts of a nuclear power station are the nuclear reactor and a heat exchanger, together with the familiar steam turbine, condenser and a generator. Heat is provided by fashioning or splitting of uranium atoms, in a reactor.

A cooling medium takes up this heat and deliver it to the heat exchanger, where steam for the turbine is raised. The reactor and heat exchanger are equivalent to the furnace and boiler in a conventional steam plant. When the uranium atoms split, there is radiation as well, so that the reactor and its cooling circuit must be heavily shielded against radiation hazards. The rest of the plant is similar to the ordinary steam plant.

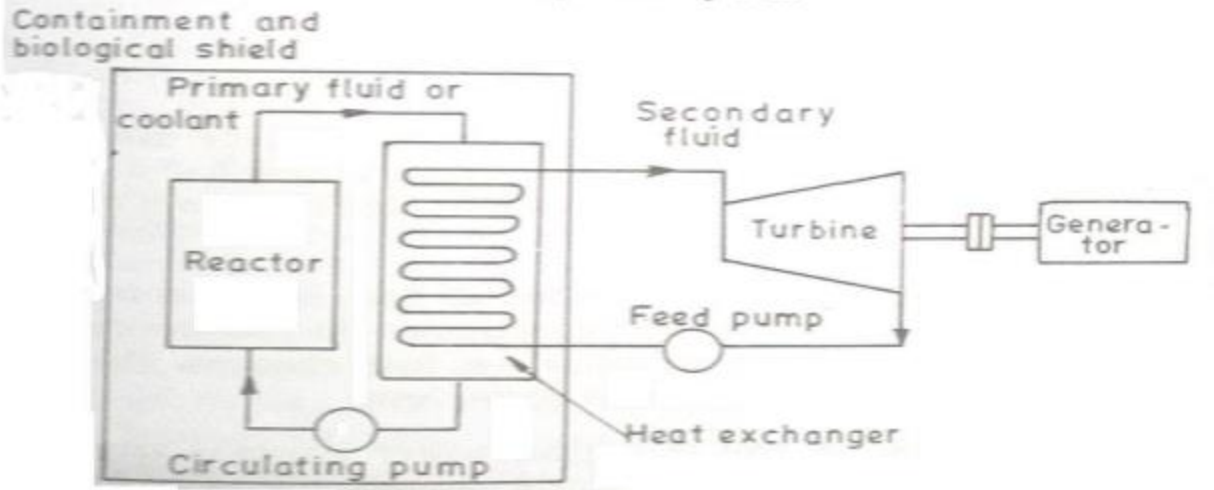
The steam generated in the heat exchanger is admitted to the turbine, and after work has been done by the expansion of steam through the turbine, the steam is condensed into the condensate in the condenser.

The condensate pump sends the condensate back to the heat exchanger, thus forming a closed feed system. The other auxiliaries are similar to those in a familiar steam station.

For economical use in a power system a nuclear power station generally has to be large, and where large units are justifiable, nuclear power stations are considered as alternatives to conventional station



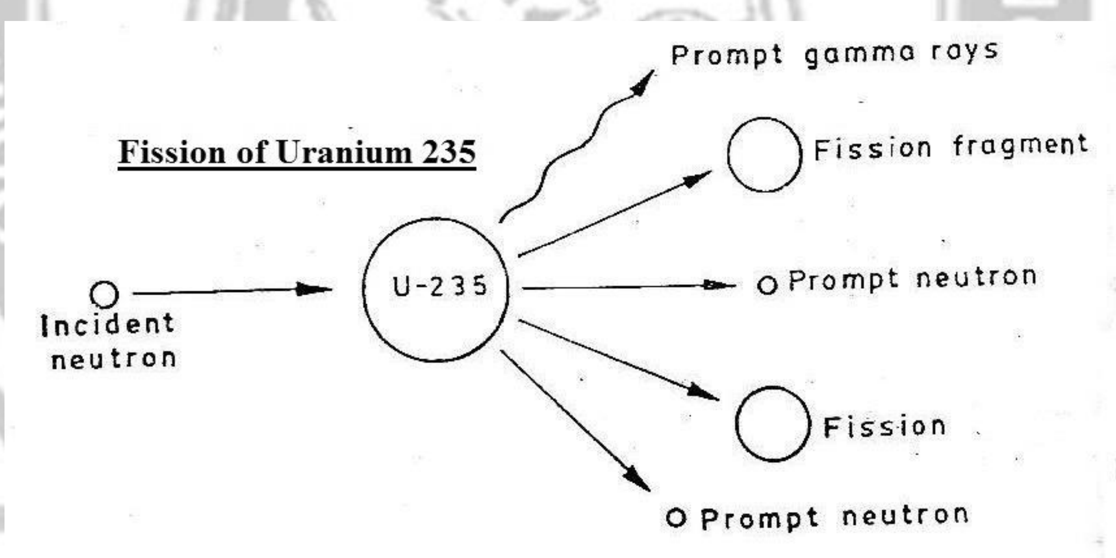
(a) Single fluid system



(b) Dual-fluid nuclear power plant

NUCLEAR FISSION

Fission is the process that occurs when a neutron collides with the nucleus of certain of the heavy atoms, causing the original nucleus to split into two or more unequal fragments which carry of most of the energy of fusion as kinetic energy. This process is accompanied by the emission of neutron and gamma rays. Fig. below is a representation of the fission of Uranium 235. The energy released as a result of fission is the basis for nuclear power generation. The release of about 2.5 neutrons / fission makes it possible to produce sustained fissioning.

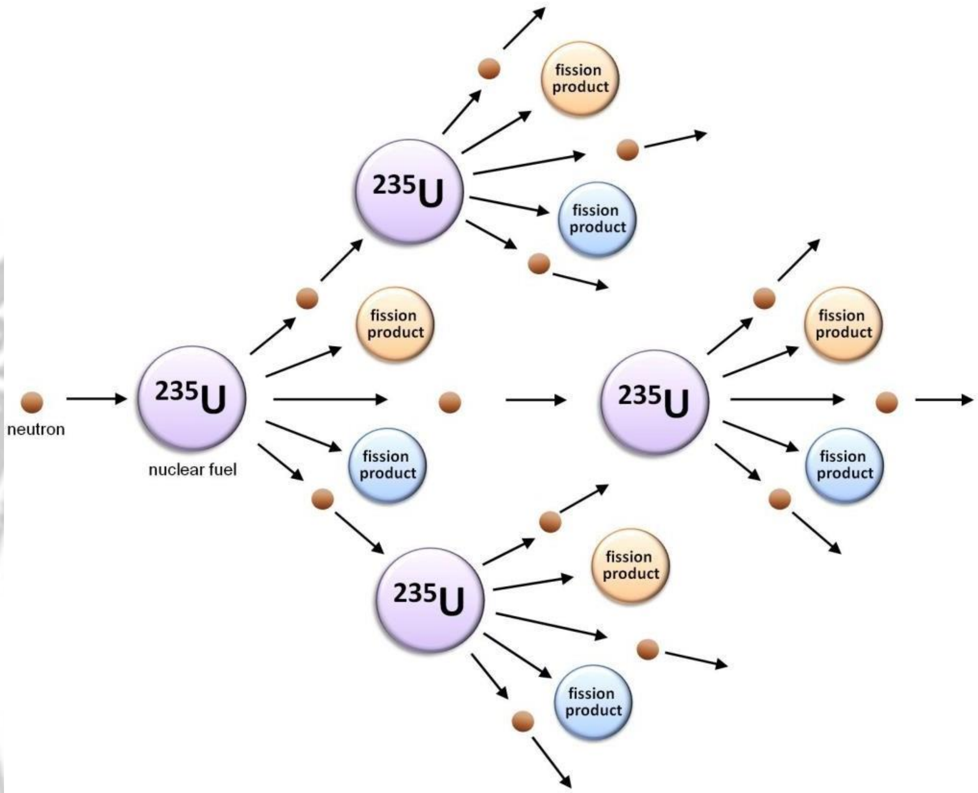


1. NUCLEAR FUSION

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

2. 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 of the fissionable material is disintegrated. The chain reaction will become self-sustaining or self propagating only if, for every neutron absorbed, at least one fission neutron becomes available for causing fission of another nucleus.



3. ISOTOPES

Isotopes are atoms of the same element having the same numbers of protons (atomic number), but different numbers of neutrons. They have same chemical properties due to the same electron configuration, but different physical properties.

There are many forms or "isotopes" of uranium:

$^{235}_{92}U$ $^{238}_{92}U$

A	235
Z	92
Number of protons	92
Number of neutrons	143

A	238
Z	92
Number of protons	92
Number of neutrons	146

Isotopes of any particular element contain the same number of protons, but different numbers of neutrons.

4. NUCLEAR FUEL

Nuclear fuel is a substance that is used in nuclear power stations to produce heat to power turbines. Heat is created when nuclear fuel undergoes nuclear fission. Most nuclear fuels contain heavy fissile elements that are capable of nuclear fission, such asUranium-235 or Plutonium-239. When the unstable nuclei of these atoms are hit by a slow-moving neutron, they split, creating two daughter nuclei and two or three more neutrons. These neutrons then go on to split more nuclei. This creates a self-sustaining chain reaction that is controlled in a nuclear reactor.

5. URANIUM ENRICHMENT

Enriched uranium is a type of uranium in which the percent composition of uranium-235 has been increased through the process of isotope separation. Natural uranium is 99.284% ^{238}U isotope, with ^{235}U only constituting about 0.711% of its mass. ^{235}U is the only nuclide existing in nature (in any appreciable amount) that is fissile with thermal neutrons.

Uranium found in nature consists largely of two isotopes, U-235 and U-238. The production of energy in nuclear reactors is from the 'fission' or splitting of the U-235 atoms, aprocess which releases energy in the form of heat. U-235 is the main fissile isotope of uranium.

Natural uranium contains 0.7% of the U-235 isotope. The remaining 99.3% is mostly the U-238 isotope which does not contribute directly to the fission process (though it does so indirectly by the formation of fissile isotopes of plutonium). Isotope separation is a physical process to concentrate (‘enrich’) one isotope relative to others. Most reactors are light water reactors (of two types – PWR and BWR) and require uranium to be enriched from 0.7% to 3- 5% U-235 in their fuel. This is normal low-enriched uranium (LEU). There is some interestin taking enrichment levels to about 7%, and even close to 20% for certain special power reactor fuels, as high-assay LEU (HALEU).

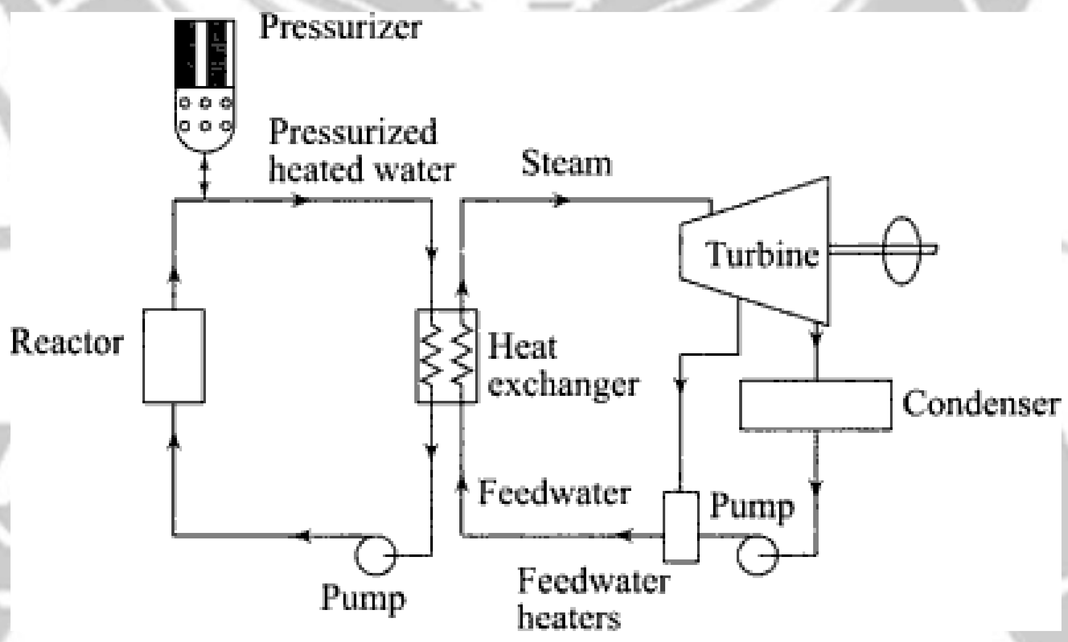
Uranium-235 and U-238 are chemically identical, but differ in their physical properties, notably their mass. The nucleus of the U-235 atom contains 92 protons and 143 neutrons, giving an atomic mass of 235 units. The U-238 nucleus also has 92 protons but has 146 neutrons – three more than U-235 – and therefore has a mass of 238 units.

The difference in mass between U-235 and U-238 allows the isotopes to be separated and makes it possible to increase or "enrich" the percentage of U-235. All present and historicenrichment processes, directly or indirectly, make use of this small mass difference.

LAYOUT OF NUCLEAR POWER PLANT

A nuclear reactor is basically a furnace where the fashioning of atoms can be controlled and the heat put to useful work. In a nuclear fission reactor, the conditions are such that fission energy is released at a controlled rate. The fission energy is converted into heat in the reactor, and this heat is utilized to raise steam directly or indirectly. The steam then drives a turbine generator to produce electricity in the conventional manner

Figure shows the main components of a reactor. The location of fuel, moderator, control rods and coolant in a typical power reactor are shown. These components are enclosed in a pressure vessel. The coolant heated in passing by the fuel elements, flows through a heat exchanger where it turns water in a secondary circuit, into steam. The steam is then used to drive a turbine generator.



COMPONENTS OF NUCLEAR POWER PLANT

1. Nuclear reactor
2. Heat exchanger or steam generator
3. Steam turbine
4. Condenser
5. Electric generator or Alternator

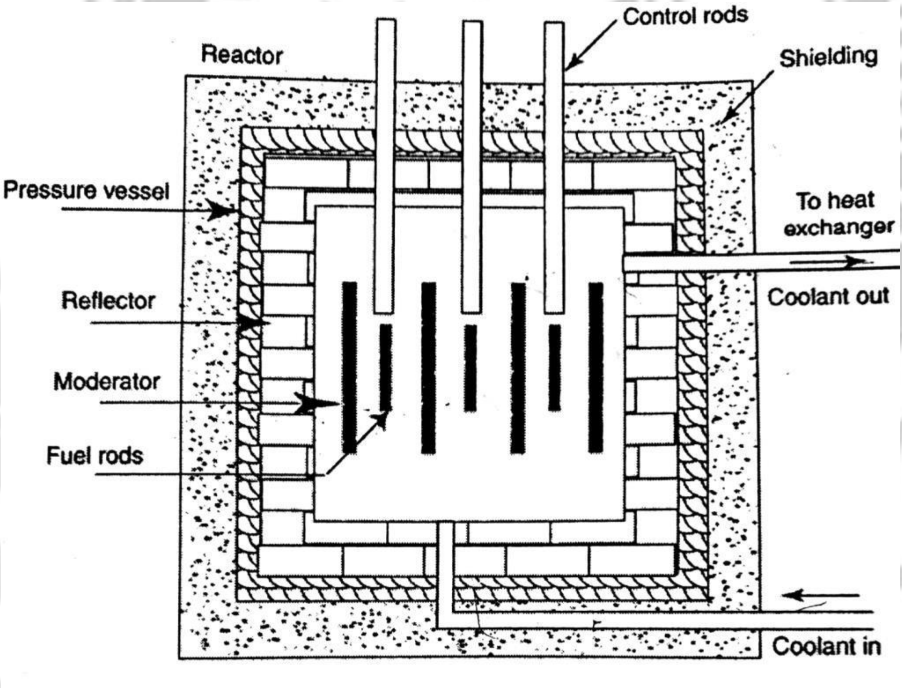
COMPONENTS OF NUCLEAR REACTOR

There are several components common to most types of reactors:

Fuel. Uranium is the basic fuel. Usually pellets of uranium oxide (UO_2) are arranged in tubes to form fuel rods. The rods are arranged into fuel assemblies in the reactor core. In a 1000 MWe class PWR there might be 51,000 fuel rods with over 18 million pellets.

Moderator. Material in the core which slows down the neutrons released from fission so that they cause more fission. It is usually water, but may be heavy water or graphite.

Control rods. These are made with neutron-absorbing material such as cadmium, hafnium orboron, and are inserted or withdrawn from the core to control the rate of reaction, or to halt it.* In some PWR reactors, special control rods are used to enable the core to sustain a low level of power efficiently. (Secondary control systems involve other neutron absorbers, usually boron in the coolant – its concentration can be adjusted over time as the fuel burns up.) PWR control rods are inserted from the top, BWR cruciform blades from the bottom of the core.



Nuclear reactor

Coolant. A fluid circulating through the core so as to transfer the heat from it. In light water reactors the water moderator functions also as primary coolant. Except in BWRs, there is secondary coolant circuit where the water becomes steam. (See also later section on primary coolant characteristics.) A PWR has two to four primary coolant loops with pumps, driven either by steam or electricity – China's Hualong

One design has three, each driven by a 6.6 MW electric motor, with each pump set weighing 110 tonnes.

Pressure vessel or pressure tubes. Usually a robust steel vessel containing the reactor core and moderator/coolant, but it may be a series of tubes holding the fuel and conveying the coolant through the surrounding moderator.

Steam generator. Part of the cooling system of pressurised water reactors (PWR & PHWR) where the high-pressure primary coolant bringing heat from the reactor is used to make steam for the turbine, in a secondary circuit. Essentially a heat exchanger like a motor car radiator.* Reactors have up to six 'loops', each with a steam generator. Since 1980 over 110 PWR reactors have had their steam generators replaced after 20-30 years service, 57 of these in USA.

[* These are large heat exchangers for transferring heat from one fluid to another – here from high-pressure primary circuit in PWR to secondary circuit where water turns to steam. Each structure weighs up to 800 tonnes and contains from 300 to 16,000 tubes about 2 cm diameterfor the primary coolant, which is radioactive due to nitrogen-16 (N-16, formed by neutron bombardment of oxygen, with half-life of 7 seconds). The secondary water must flow through the support structures for the tubes. The whole thing needs to be designed so that the tubes don't vibrate and fret, operated so that deposits do not build up to impede the flow, and maintained chemically to avoid corrosion. Tubes which fail and leak are plugged, and surplus capacity is designed to allow for this. Leaks can be detected by monitoring N-16 levels in the steam as it leaves the steam generator.]

Containment. The structure around the reactor and associated steam generators which is designed to protect it from outside intrusion and to protect those outside from the effects of radiation in case of any serious malfunction inside. It is typically a metre-thick concrete and steel structure.

Newer Russian and some other reactors install core melt localisation devices or 'core catchers'under the pressure vessel to catch any melted core material in the event of a major accident.