Module-5

Nuclear Power

Nuclear power is the use of nuclear reaction that release nuclear energy to generate heat which most frequently is then used in steam turbines to produce electricity in a nuclear power plant. Nuclear power can be obtained from Nuclear fission, Nuclear decay & Nuclear fusion.

Nuclear Fission → It is either a nuclear reaction or radioactive decay process in which the nucleous of an atom splits ito smaller parts. The fission process often produces free neutron & gamma photons & releases a very large amount of energy even by the energetic standards of radioactive decay.

$${}_{92}U^{235} + {}_{0}n^{1} \longrightarrow {}_{54}Xe^{140} + {}_{38}Sr^{94} + 2\,{}_{0}n^{1}$$

Radioactive decay :— It is the process by which an unstable atomic nucleous loses energy by emitting radiation, such as an α, β particles with neutrino or only a neutrino in the case of electron capture, or γ ray or electron in the case of internal conversion.

$${}_{94}Pu^{239} \xrightarrow{\alpha} {}_{92}U^{235} + {}_{2}He^{4}, \quad {}_{82}Pb^{214} \xrightarrow{\beta} {}_{83}Bi^{214} + {}_{-1}e^{0} + \bar{\nu}$$

Nuclear fusion :— It is reaction in which two or more atomic nuclei are combined to form one or more different nuclei & sub-atomic particles (neutrons or protons).

Nuclear Reaction :— It is sematically considered to be the process in which two nuclei or else a nucleous of an atom & a subatomic particle (such as Proton, neutron or high energy electron) from outside the atom, collide to produce one or more nuclides that are different from the nuclides that began the process.

Nuclear fuels: — It 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. generally fuel used Uranium-235 or Plutonium-239. i.e heavy fissile materials.

Fissile material → It can sustain a chain reaction with neutrons of any energy

Reactor classification:—

Neutron flux Spectrum	Moderator	Coolant	Fuel material
1) Thermal	i) light H_2O ii) Heavy H_2O iii) Graphite	i) light water ii) Heavy water iii) gas (CO_2)	i) Enriched Uranium ii) Natural Uranium iii) Natural/enriched U.
2) Fast	NIL	Liquid metal (Na, K)	Plutonium, Thorium

Types of Reactors: Reactors can be homogeneous or heterogeneous.

A heterogeneous reactors has a large number of fuel rods with the coolant circulating around them & carrying away the heat released by nuclear fission. In a homogeneous reactor, the fuel & moderator are mixed. e.g. a fissionable salt of uranium like uranium sulphate (or Nitrate) dissolved in the moderator like H_2O or D_2O. The solution is critical in the core. Due to difficulties in component maintenance, induced radioactivity, erosion & corrosion, homogeneous reactors are not common. Present day nuclear reactors are of the heterogeneous class.

1) Pressurized water reactor (PWR)
2) Boiling " " (BWR)
3) Pressurized heavy water Reactor (PHWR)
4) High temperature gas-cooled Reactor (HTGR)
5) Liquid-metal fast breeder reactor (LMFBR)

Opr^n Power plant in India (MW)

1) Kaiga (Karnatka) → 880
2) Kakrapar (Gujrat) → 440
3) Kudankulam (TN) → 2000
4) Kalpakkam (TN) → 440
5) Narora (UP) → 440
6) Tarapur (MH) → 1400
7) Rawatbhata (Raj) - 1180

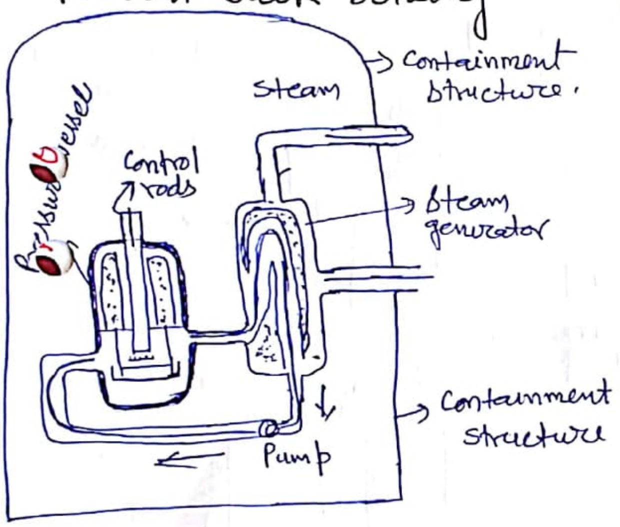
Total = 6780

Under construction → 04

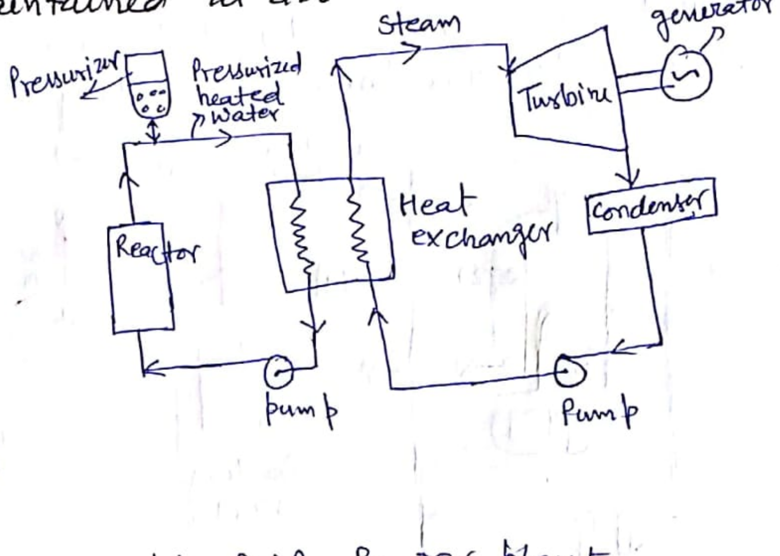
Planned → 11

Scanned by CamScanner

Pressurized water Reactor (PWR) — The excellent properties of water as a moderator & coolant make it a natural choice for power reactors. The most important limitation on a PWR is the critical temperature of water 370°C. This is the maximum possible temperature of the coolant in the reactor, & in practice it is considerably less, possibly about 300°C, to allow a margin of safety. In a PWR, the coolant pressure must be greater than the saturation pressure at 300°C (85.93 bar) to supress boiling. The pressure is maintained at about 155 bar so as to prevent bulk boiling.



a) PWR



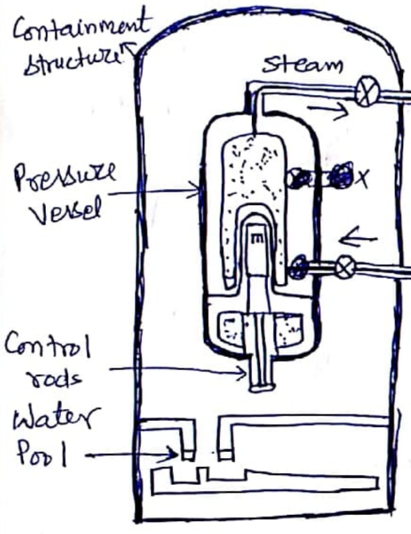
b) PWR Power plant

A PWR power plant is composed of two loops in series, the coolant Loop, called the primary Loop & water-steam or working fluid loop as shown in figure. The coolant picks up heat in the reactor & transfers to the working fluid in the steam generator. The steam is then used in a Rankine type cycle to produce electricity.

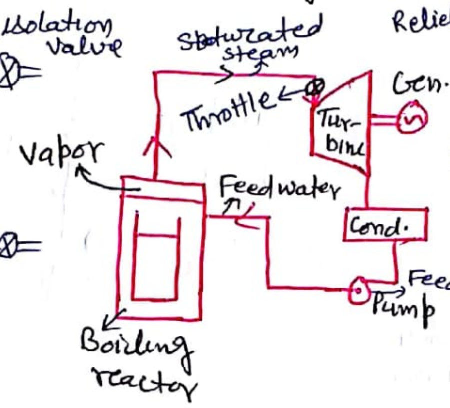
The fuel in PWR is slightly enriched uranium in the form of thin rods or plates. The Cladding is either of stainless steel or Zircaloy. Because of very high coolant pressure, the steel pressure vessel containing the core must be about 20 to 25 cm thick. The typical PWR contains about 200 fuel assemblies, each assembly being an array of rods. In a typical fuel assembly, there are 264 fuel rods & 24 guide tubes for control rods. Grid spacers maintain a separation between the fuel rods to prevent excessive vibration & allow some axial thermal expansion. The coolant leaving the reactor enters the steam generator which can be either shell & tube type with U-tube bundles or once through type, the former being more common. In the U-tube steam generator, the hot coolant enters an inlet channel head at the bottom, flows through the U-tubes & reverses direction to an outlet at the bottom. It can produce only staturated steam.

In the once-through design, the primary coolant enters at top, flows downward through tubes & exits at the bottom to the main pumps. Feedwater is on the shell side. A dry or low degree of superheat steam is possible.

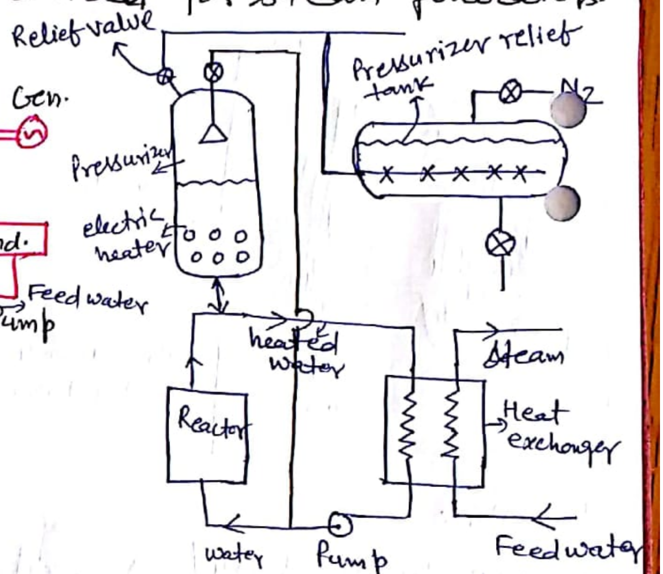
Boiling Water Reactor (BWR): — A BWR differs from the PWR in that the steam flowing to the turbine is produced directly in the reactor core. Steam is separated & dried by mechanical devices located in the upper part of the pressure vessel assembly. The dried steam is sent directaly to the high pressure turbine thus eliminating the need for steam generators.



a) BWR



b) Direct-cycle BWR Plant

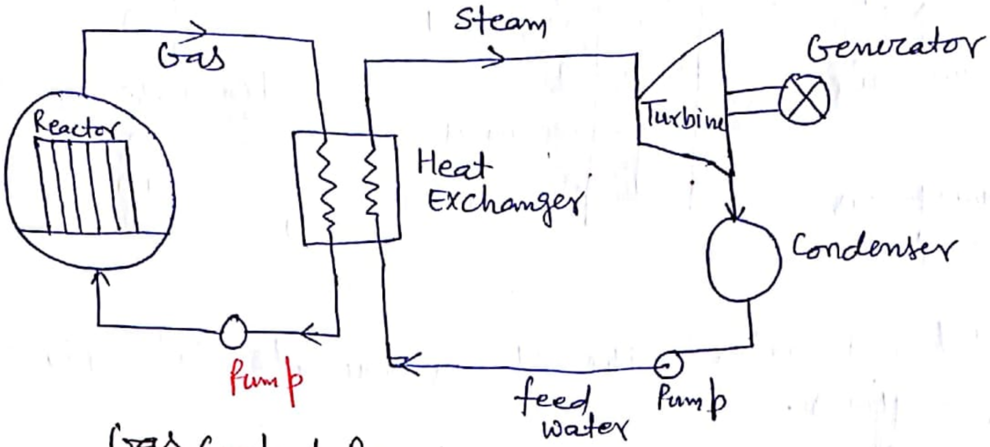


c) A PWR primary loop with a vapor type pressurized system

The coolant thus serves the triple function of coolant, moderator & working fluid. Since the coolant boils in the reactor itself, its pressure is much less than that in a PWR & it is maintained at about 70 bar with steam temperature around 285°C. However, an increase in the boiling rate displaces water (moderator) in the core & reduces the ability of the moderator to thermalize neutrons & hence, reduces the reactor power level. At power levels above 60% at the nominal, the fraction of steam in the core can be kept nearly constant by varying the coolant circulation rate.

Gas-Cooled Reactors :-

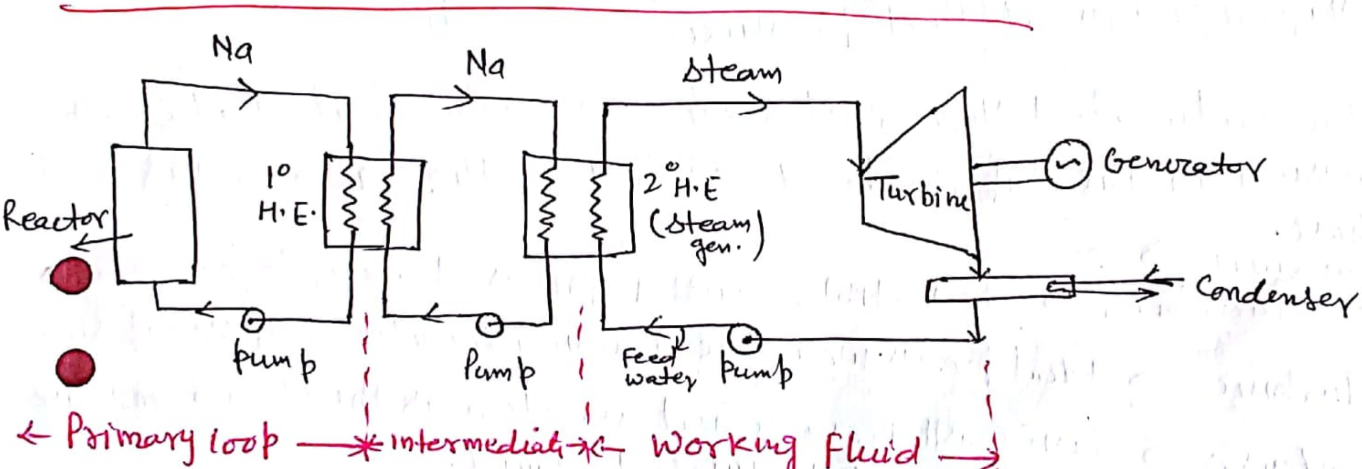
The first gas-cooled reactors with CO_2 gas (at P = 16 bar) as coolant & graphite as moderator were developed in Britain during 1956-69. The fuel was a Uranium, clad with an alloy of magnesium called Magnox.



Gas Cooled Reactor Plant

$\sin\theta = x \Rightarrow \theta = \sin^{-1}x$ or $\arcsin x$

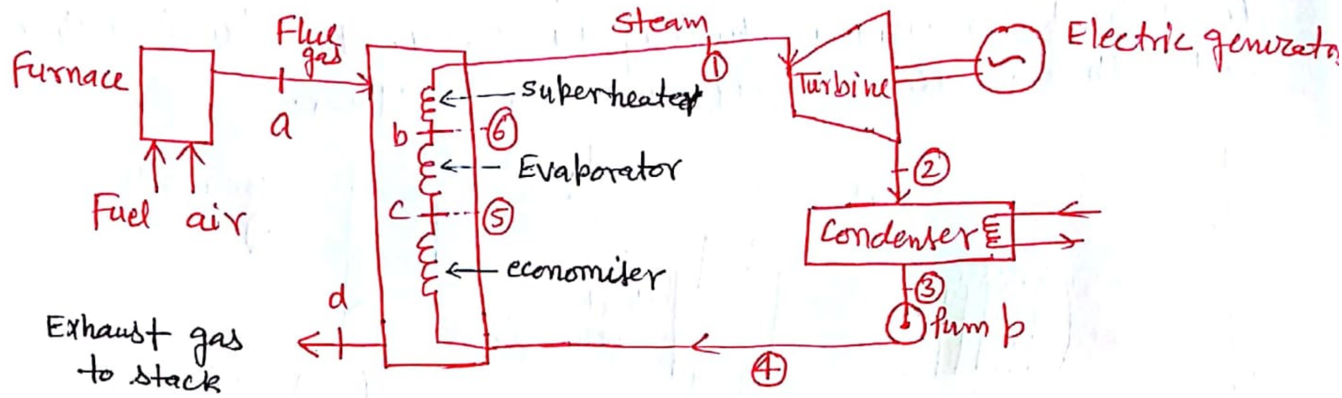
Liquid metal Fast Breeder reactor (LMFBR) :-



Fast breeder reactors are designed to create or breed new fissile material, while producing useful electric power. Most produce fissile plutonium from fertile uranium-238. The fuel rods in the core region thus contain a mixture of of fissile Pu-239 & U-238. The active core region is surrounded by a blanket of fertile U-238. This blanket region captures neutrons that would otherwise be lost through leakage, thus producing additional fissile material.

Sodium is the most common coolant for fast reactors. Na or NaK

Economiser, Evaporator & superheater: — "Plant representation of Rankine cycle"



Heat transfer to water in the steam generator takes place in the three different regimes.

I) Water is first heated sensibly in the economiser in the liquid phase at certain pressure from state 4 to 5 till it becomes sat. liquid.

II) Evaporator or Boiler, there is phase change or boiling with the state changing from 5 to 6 by absorbing the latent heat of vaporization at that pressure.

III) The saturated vapour at state 6 is further heated at constt pressure in the superheater to state 1 in the vapor or gaseous phase.

Rankine cycle →

for steam Boiler → Reversible constt P process of water to form steam.

for Turbine → Ideal process would be a rev. adiabatic expansion of steam.

for condenser → Rev. constt Pressure heat rejection as the steam condenses till it becomes saturated liquid.

for pump → Ideal process would be the reversible adiabatic compression of this liquid ending at the initial pressure.