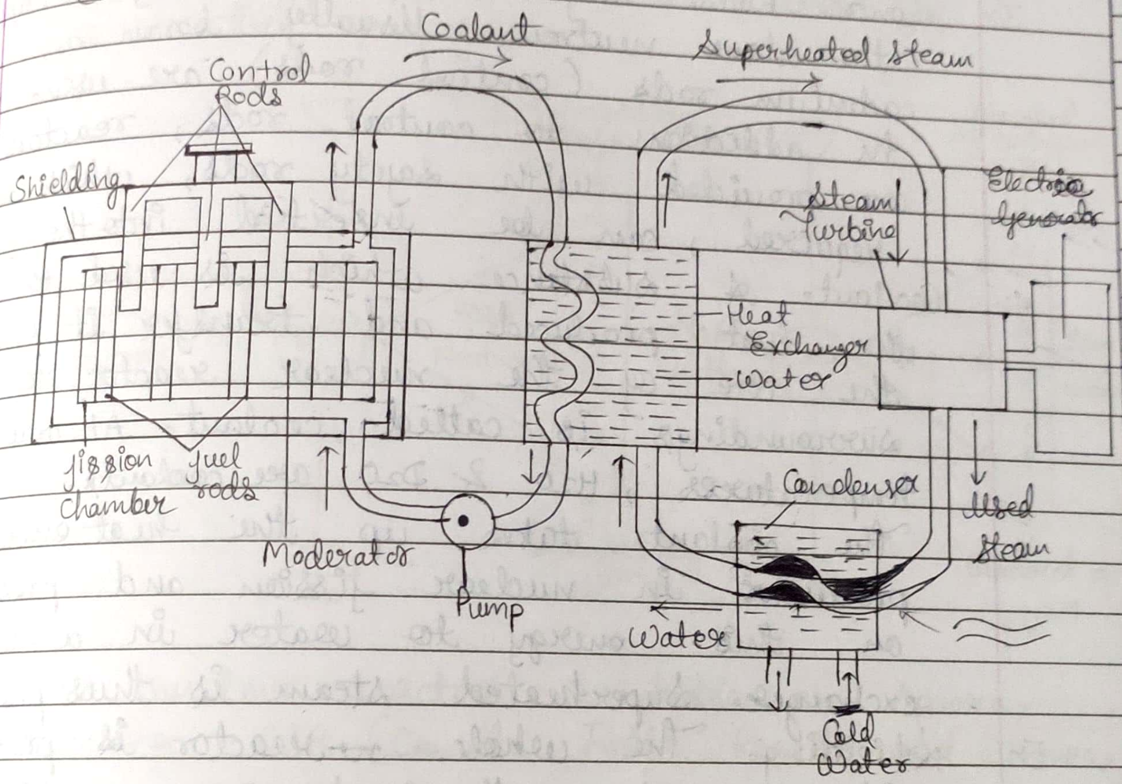
Nuclear Reactor.

It is a powerful device, wherein the nuclear energy produced is utilised for constructive purposes. A nuclear reactor is based upon controlled nuclear chain reaction.

Construction.



Nuclear Fuel. It is a fissionable material used for the fission process to take place. Commonly used fuels are U^{233}, U^{235}, Pu^{239}, etc. Generally, uranium oxide pellets are inserted end to end into long hollow metal tubes constituting the fuel rods. When slow neutrons interact with the fuel, the fission starts and the energy is released.

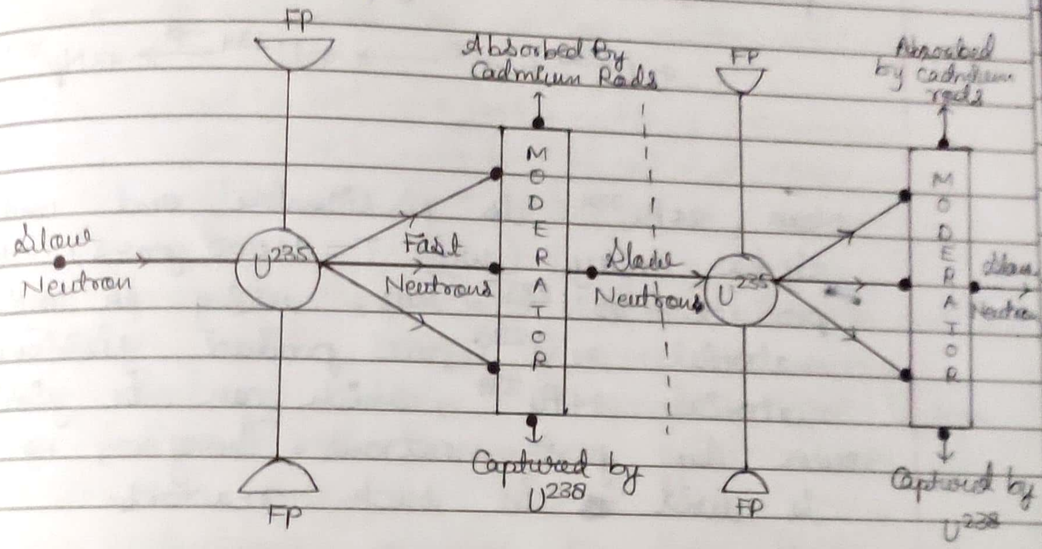
2> Moderator. Its function is to slow down the fast moving secondary neutrons produced during the fission. The material of moderator should be light, it should not absorb neutrons. Usually D_2O, graphite, D_2, and paraffins, etc. act as moderators (rich in p+).

3> Control Rods. They have the ability to capture the slow neutrons. Usually boron or cadmium rods (control rods) are used. In addition to control rods, reactors are provided with safety rods, which when required, can be inserted into the reactor.

4> Coolant. A substance which is used to remove the heat produced and transfer it from the core of the nuclear reactor to the surroundings is called coolant. At ordinary temperatures, H_2O & D_2O are coolants. The coolant takes up the heat energy productor in nuclear fission and passed on this energy to water in a heat exchanger. Superheated steam is thus produced.

5> Shielding. The whole ~~r~~ reactor is protected with concrete walls, 2 to 2.5 m thick, so that radiations emitted during nuclear reactions may not produce harmful effects on the persons working on the reactor.

Working. Slow neutrons cause the fission of U^{235} nuclei. FP stands for fission products. To start the nuclear reaction, the cadmium rods are slowly removed and to stop it, they are inserted. This brings out a controlled nuclear chain reaction and hence the energy produced can be used for constructive purposes.



The nuclear reactors in India are Apsara, Zerlina, CIR (Canada India Reactor) and Dhruva.

Uses :-

(i) Nuclear reactors are used to produce radioactive isotopes which in turn are used in medicine, industry and agriculture.

(ii) They are used in electric power generation.

(iii) They can be used for the propulsion of ships, submarines and aircrafts.

(iv) They are used to produce neutron beam of high intensity which is used in the treatment of cancer and nuclear research.

Fast Breeder ~~Reactions~~ Reactors.

They use thorium or natural uranium as fuel elements. When fast neutrons strike uranium fuel in a reactor, $_{92}U^{238}$ (which is present along with $_{92}U^{235}$ in natural uranium) absorbs a neutron and becomes $_{92}U^{239}$. This is radioactive and undergoes β-decay twice to produce $_{94}Pu^{239}$, as :-

$$_{92}U^{238} + {}_0n^1 \longrightarrow {}_{92}U^{239} \xrightarrow{-\beta} {}_{93}Np^{239} \xrightarrow{-\beta} {}_{94}Pu^{239} \xrightarrow{-\alpha} {}_{92}U^{235}$$

Now, $_{94}Pu^{239}$ is fissionable and undergoes alpha decay (with T = 24000 years) to produce $_{92}U^{235}$. Thus, using an unfissionable material $_{92}U^{238}$, we produce fissionable material $_{94}Pu^{239}$, which can be fissioned even by fast neutrons. Therefore, no moderator is used in such reactors.

An unavoidable ~~wast~~ feature of reactor operation is the accumulation of radioactive waste, including both, fission products and heavy transuranic elements such as plutonium & americium. Thus, the waste of a nuclear power station is extremely hazardous to all forms of life on earth. Elaborate safety measures are needed not only for reactor operation, but also for handling and disposal of radioactive waste.

Nuclear Fusion.

Nuclear fusion is the phenomenon of fusing two or more lighter nuclei to form a single heavy nucleus.

Mass defect results in the release of tremendous amount of energy, in accordance with Einstein's mass energy relation,

$$E = (\Delta m)c^2.$$

Some of examples of nuclear fusion are:

$$_1H^1 + {}_1H^1 \longrightarrow {}_1H^2 + {}_1e^0 + \nu + 0.42\,MeV$$

$$_1H^2 + {}_1H^2 \longrightarrow {}_2H^3 + {}_0n^1 + 3.27\,MeV$$

$$_1H^2 + {}_1H^2 \longrightarrow {}_1H^3 + {}_1H^1 + 4.03\,MeV$$

(i) two protons combine to form a deutron and a positron with release of 0.42 MeV energy.

(ii) two deutrons combine to form a light isotope of helium and a neutron with release of 3.27 MeV energy.

(iii) two deutrons combine to form triton and a proton with release of 4.03 MeV energy.

Two positively charged particles combine to form a heavier nucleus. Coulomb ~~nucleus~~ repulsion between these charges prohibits them to close enough to be within the range of their ~~##~~ attractive nuclear forces and fuse. The height of the Coulomb barrier depends on the charges and the radii of the two interacting nuclei.

The essential condition for carrying out nuclear fusion is to raise the temperature of the material so that the particles have enough energy due to their thermal motions alone and they can penetrate the Coulomb barrier. This process is called Thermonuclear fusion.

Thus, for thermonuclear fusion to occur, extreme conditions of temperature and pressure are required. further, higher density is also desirable so that collisions between light nuclei occur quite frequently. These conditions are met only in the interior of stars, and cannot be arranged in a laboratory. The energy generation in stars takes place via thermonuclear fusion.

Distinction Between Nuclear Fission And Nuclear Fusion.

(i) Both, nuclear fission and nuclear fusion are sources of tremendous energy.

(ii) In both the processes, a certain mass (Δm) disappears, which ~~of~~ appears in the form of energy as per Einstein equation: $E = (\Delta m)c^2$.

(iii) In fission, a heavy nucleus splits into two or more lighter nuclei. In fusion, two or more lighter nuclei fuse together to form a heavier nucleus.

(iv) for carrying out fission, a suitable bullet or projectile like neutron is needed. for carrying out fusion, the lighter nuclei have to be brought very close to each other against electrostatic repulsion. For this, suitable energy is to be made available, often by raising the temperature to the order of 10^7 K. This justifies nuclear fusion being called thermonuclear fusion. In actual practice, such high temperatures are generated by nuclear fission. That is why usually, nuclear fission precedes nuclear fusion.

(v) In a nuclear fusion r^n, energy liberated per unit mass of their nuclei is many times larger than the energy liberated per unit mass in nuclear fission reaction. Therefore, for a given weight, hydrogen bomb (based on nuclear fusion) is far more dangerous than an atom bomb (based on nuclear fission).

(vi) The products of nuclear fission ~~rea~~ reaction are radioactive. They produce environmental pollution and hence require very careful disposal. However, the products of nuclear fusion are not radioactive. They are harmless and can be disposed off easily.

(vii) While producing nuclear energy from fission, we have learnt have to control nuclear chain reaction. But we have yet to learn controlling the thermo nuclear fusion reactions. This would be the basis of fusion reactor, which is seen as the future source of unlimited energy without pollution.