Unit: IV Nuclear Reactors

(1) Characteristics Of Fission:-

Definition:-
Fission is the splitting of a large atom into two (or) more smaller one.

Nuclear occurance of the process:-
Fission reaction does not normally occur in nature

By products of the reaction:-
Fission produces many highly radioactive particles.

Condition:-
Critical mass of the substance and high speed neutrons are required.

Energy requirement:-
Takes little energy by splits two atoms in a fission reaction.

Energy released:-
The energy released by fission is a million times greater than chemical reaction.

Nuclear weapon:-
One class of nuclear weapon is a fission bomb, also known as an atom bomb (or) atomic bomb.

Energy Production:- Fission is used in nuclear power plant.

Fuel:- Uranium is the primary fuel used in Power plants

② Characteristics of Fusion:-

Definition:-

Fusion is the fusing of two (or) more lighter atom into a larger one.

Fusion occurs in stars, Such as the sun.

Few radioactive particles are produced by fusion reaction but if a fusion "trigger" is used radioactive particle will result from that.

* Fusion reaction normally occur in nature
* Fusion produces lowly radio active particles.
* Critical mass of the substance and low speed neutrons are required.
* Takes high energy 2 (or) more lighter atoms to a larger one.
* Chemical reaction lower energy released by nuclear fusion.
* Nuclear weapon as nuclear fusion Hydrogen bomb.
* It was not used in a primary fuel and power plants.

Laser fusion

1) Fusion is the reaction in which two atoms of hydrogen combine to form a helium atom. During this process, hydrogen is converted into energy, potentially giving this fusion technique the potential to serve as an inexhaustible energy source.

2) Laser fusion, also known as 'inertial confinement fusion', is a method of initiating nuclear fusion reactions through heating, and compressing, fuel tragets in the form of pellets containing deuterium and tritium.

3) In order to produce nuclear fusion three criteria must be met: high temperature (greater than about 100 million degrees), high density of nuclei (So that collisions are frequent), and the nuclei must remain together for a long enough time to fuse and release energy.

* Two different Schemes have been used to try to confine nuclei to a tiny space and heat them in order to produce fusion.

One involves magnetic confinement using a Tokomalk while the other involves using high powered Lasers to provide the energy in a Scheme known as "inertial Confinement".

During laser fusion, Small pellets of deuterium - tritium (DT) isotopes are introduced into a blast chamber where the pellets are Compressed to high densities using an intense laser.

This technique employs a single laser beam that is divided into a number of beams which are amplified and passed into the chamber.

Bohr-Wheeler theory of Nuclear Fission:-

In 1939 Bohr & Wheeler gave a theorectical proof for the Nuclear Fission, they applied a simple form of analyses using legendre polynomial expansion to express the radius 'r' making an angle 'θ' with the axis of major deformation, according to him

$$r = R\left[1 + \sum_{l=0}^{\infty} \alpha_l P_l \cos\theta\right] \rightarrow (1).$$

Where, R is the radius of the spherical nucleus.

$$R = R_0 A^{1/3}$$

Here α_0 and α_1 are taken as Zero as the Centre of mass of the drop is assumed to remain unchanged.

$$\therefore\ r = R\left[1 + \alpha_2 P_2 \cos\theta + \alpha_3 P_3 \cos\theta + \cdots\right] \rightarrow (2)$$

α_2, α_3 are known as Deformation Parameter. Thus the co-efficient $P_l \cos\theta$ gives the distance through which the Centre of the drop moves and for a pure deformation without any translation.

The Surface energy of the spherical drop, $E_s^{sph} = 4\pi R^2 T \rightarrow (3)$

Where,

T is Surface tension.

The Surface energy of the deformed drop is,

$$E_{SD}^{sph} = 4\pi R^2 T\left[1 + \frac{2}{5}\alpha_2^2 + \cdots\right] \rightarrow (4)$$

∴ Change in Surface energy due to deformation is equ (4) - (3)

$$\Delta E_S = 4\pi R^2 T (2/5)\alpha_2^2$$

from equ (3)

$$\Delta E_S = E_S^{sph}(2/5)\alpha_2^2 \rightarrow (5)$$

Coloumb energy of the Spherical drop is,

$$E_C^{sph} = 3/5\ \frac{(Ze)^2}{4\pi\varepsilon_0 R} \rightarrow (6).$$

In the case of a deformed drop the Coloumb energy interms of deformation parameters are given as,

$$E_{CD}^{sph} = \frac{3}{5}\cdot\frac{(Ze)^2}{4\pi\epsilon_0 R}\left[1 - \frac{1}{5}\alpha_2^2 + \cdots\right] \rightarrow (7)$$

∴ Change in coloumb energy due to deformation is,

$$\Delta E_c = -\frac{3}{5}\frac{(Ze)^2}{4\pi\epsilon_0 R}\cdot(1/5)\alpha_2^2$$

$$\Delta E_c = -E_c^{sph}(1/5)\alpha_2^2 \rightarrow (8).$$

Total Variation in energy,

$$\Delta E = \Delta E_S + \Delta E_C$$

$$= E_S^{sph}(2/5)\alpha_2^2 - E_c^{sph}(1/5)\alpha_2^2$$

$$= 1/5\,\alpha_2^2(2E_S^{sph} - E_c^{sph}) \rightarrow (9).$$

The above eqn shows that the surface energy appears with the +ve sign and Coloumb energy with a -ve sign.

Case (i)

If $2E_S > E_c$.

When the ΔE is +ve, the surface energy prevents distruption and coloumb energy promotes it. So the nucleus will be stable.

Case (ii)

If $2E_S = E_c$. We have the critical case,

$$2E_S = E_c$$

$$2\cdot(4\pi R^2 T) = \frac{3}{5}\cdot\frac{(Ze)^2}{4\pi\epsilon_0 R} \qquad \{\because R = R_0 A^{1/3}\}$$

$$2\cdot(4\pi R_0^2 A^{2/3} T) = \frac{3}{5}\cdot\frac{Z^2e^2}{4\pi\epsilon_0 R_0 A^{1/3}}$$

$$2\cdot(4\pi R_0^2 A^{2/3} T)(R_0 A^{1/3}) = \frac{3}{5}\cdot\frac{Z^2e^2}{4\pi\epsilon_0}$$

$$\frac{2\cdot(4\pi R_0^2 A^{2/3} T)\cdot(R_0 A^{1/3})\cdot 5\cdot 4\pi\epsilon_0}{3\cdot e^2} = Z^2$$

$$\frac{160\pi^2 R_0^3 A T \varepsilon_0}{3e^2} = Z^2$$

$$\frac{160\pi^2 R_0^3 \varepsilon_0 T}{3e^2} = \frac{Z^2}{A}$$

i.e, $$\frac{Z^2}{A} = \frac{160\pi^2 R_0^3 \varepsilon_0 T}{3e^2}$$

$$\cong 50$$

In R.H.S all the terms are Const ∴ Z^2/A will have value $\cong 50$ from that we define a quantity called fissionable Parameter χ.

$$\chi = \frac{E_c}{2E_s}$$

The fission in terms of high can be discussed as if $\chi > 1$ the nucleus is unstable, against decay and $\chi < 1$. It is stable spontaneous Fission.

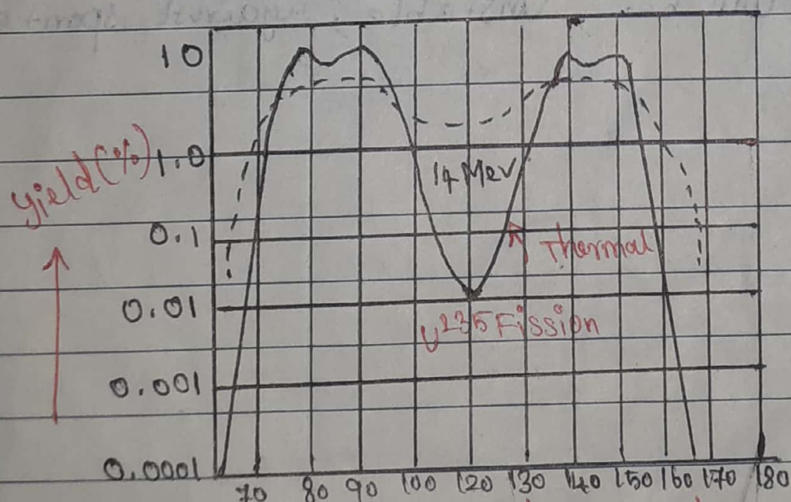
Case (iii)

If $2E_s < E_c$. ΔE is $-ve$, and the nucleus will be unstable; against spontaneous decay

Mass Distribution Of fragments:~

Nuclear Fission may be taken to a special type of nuclear reaction in which the Compound nucleus formed by a incident projectile (neutron) and the target nuclei, such as, $_{92}U^{235}$, U^{238}, Pu^{239} etc Breaks into two fragment nuclei of intermediate mass numbers. In general the nucleus breaks up into two fragments. The fission may be more than two fragments is extremely rare.

The two fission fragments can be almost any one of the nuclides laying in the centre third of the periodic table. The frequency with which the various nuclides appear among the fission fragments varies within very wide limits. The mass distribution of fission fragments can be shown in the form of fission yield curve. In which percentage yield of the different products is plotted against mass number.



fig(i)

The curve shows, the neutron fission of U^{235} in thermal neutron fission with energy 14Mev.

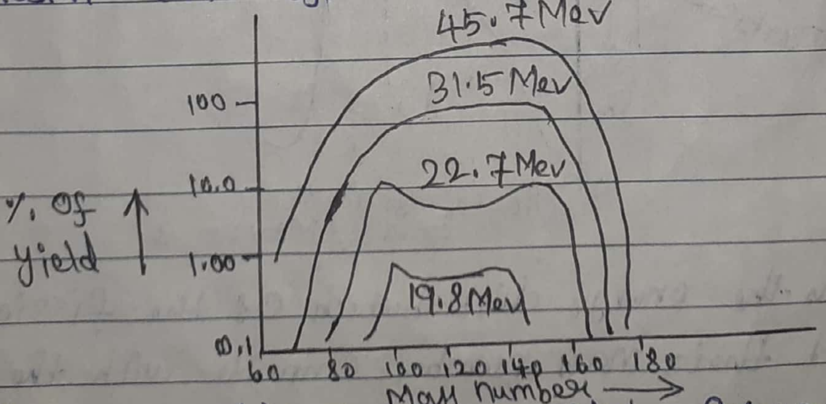
The yield two peaks One at A-95 and Other at A=139. This shows that these are the most probable mass number for the fission fragments.

The yield curve shows in the above diagram that the mass distribution of fission process is highly asymmetric. This shows the mass distribution of fission fragments in thermal neutron fission.

To get a Symmetric fission to require higher excitation energies, in case of U^{235}. Symmetric fission is about 100 times more probable for 14 Mev, neutrons then for thermal neutrons has the energy Of the bombarding neutrons increases Symmetric fission.

Becomes increasing for higher energy neutrons. The two peaks merge to give only a single peak indicating there by the Symmetric fission is the most likely event for high energy neutron fission. this has been confirmed with in the fission Uranium with 150 Mev protons and in the fission Of Bismuth with 190 Mev deutrons.

This is shown in fig. yield a increase in the energy of Bombarding neutrons the fission also symmetric



The mass distribution Of fission fragments can be obtained from the distribution of their K.E.

Which can be determined by measuring the ionisation produced in a ionisation chamber. The Fissile material is placed at one of the electrodes and the ions which are produced when the fission fragment enters the region between the electrodes are collected.

The Nucleus undergoing fission may be taken to be intially at rest and the 2 fragments having masses M_1 and M_2 with velocities V_1 & V_2 respectively then the momentum conservation law gives,

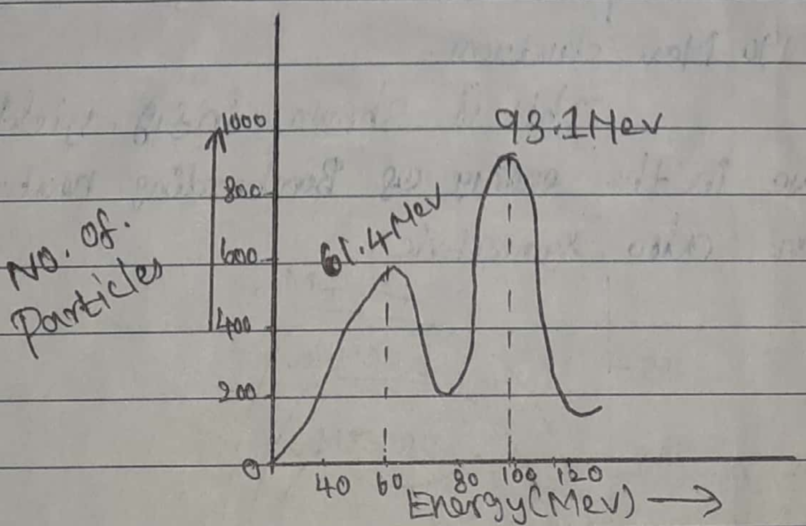
$$M_1V_1 = M_2V_2 \rightarrow (1)$$

an energy

$$\frac{E_2}{E_1} = \frac{\frac{1}{2}M_2V_2^2}{\frac{1}{2}M_1V_1^2} = \frac{M_1}{M_2} \rightarrow (2)$$

These two equs are for U^{235} fission having $M_1 \simeq 95$ Mev and $M_2 \simeq 139$ Mev

$$\frac{E_2}{E_1} = \frac{95}{139} = 0.6$$



Thus the energy distribution of the fission fragments and their mass number coincide with the estimated values.

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Plasma Confinement:~

The confinement of plasma is based on the fact that the plasma particles hardly cross the lines of force of magnetic field. The major hurdle in the way has been put by the tendency of plasma particles to escape from the field which should theoretically confine them.

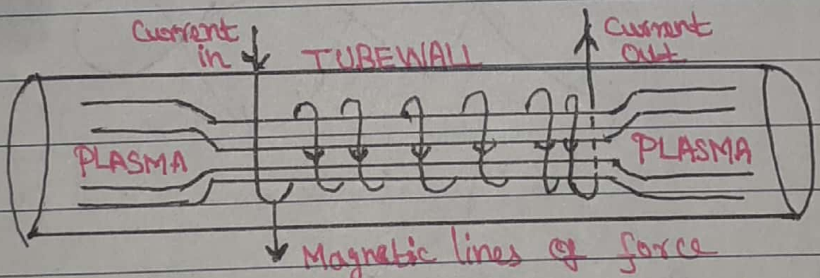
The condition due to motion of the particles in the plasma,

$$\frac{B^2}{8\pi} = 2nKT$$

Methods for the confinement of Plasma:~

(i) The Pinch:~

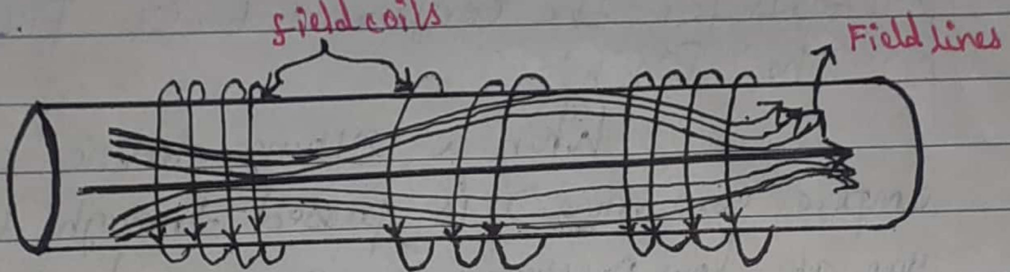
When a strong electric current ($\simeq 10^6$ ampere (or) more) is passed through the deuterium gas at low pressure, the current heats up the gas and ionises it, creating there by the plasma state. The flow of current produces a magnetic field, the lines of forces of which encircles the Plasma.



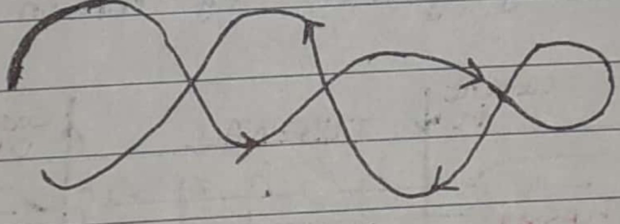
Magnetic pressure compresses the plasma into a narrow region into the centre of the containing vessel which may be torus or a straight tube. The pinch effect keeps the plasma away from the walls of the container. The plasma in this confinement process is heated by the current and the magnetic pressure which the current produces. The major drawback in the pinched plasma is that it is highly unstable.

(ii) The pyrotron:~

It uses straight tube with magnetic coils wound around it in such a way as to provide a field that is considerably stronger at the ends that in the middle. The stronger magnetic field regions at the ends constitute magnetic mirror region where charged particles under certain conditions are reflected into the central region. In this way magnetic mirrors inhibit, but donot prevent entirely, the escape plasma from the ends of the tube.



a) Magnetic Mirror



b) Reflection of charged particle in magnetic Mirror.

So, there is a Plasma Confinement.

Fast Breeder Reactor:-

The development of power reactors in which the bulk of fissions are produced by high energy neutrons is of importance in the civilian power reactor development programmes. In a fast neutron spectrum, besides fission of Uranium-235, there is a gainful Conversion of the 99.3% of U^{238} to Pu^{239}. Which in turn is a fissionable material. When the fissile material produced is more that that Consumed, the reactors are referred to as breeder reactor. The first Experimental Breeder was Completed in August 1951 and produced over 100 Watts of eletric power on 20th December. It produced the first electricity from nuclear energy. In addition to the use of plutonium oxide and Carbide, Other alloy of plutonium, Cerium and Cobalt were also used as a fuel in designing of such reactors.

Dr. Vikram Sarabhai recognized the effective Utilization of the indigenous Uranium resources through FBR route to achieve a power Capacity of 300,000 MWe in India. In this second phase of nuclear programme, a nuclear Reactor Research Centre later named as Indira Gandhi Centre for Atomic Research (IGCAR) in 1985 was established in 1969 at Kalpakkam 8 km South of Chennai.

Fission Cross section:~

Fission can be induced in some nuclearized by certain incident particle of an appropriate energy.

For eg:~

U^{235} undergoes fission when bombarded by thermal neutrons. Where as U^{238} doesnot U^{235} fast neutrons undergo fission when bombarded by fast neutrons i.e., >1 Mev. Slow neutron fission occurs quite often in nuclei containing an odd number of neutrons such as U^{235} this can be interrupted as due to a large excitation produced in the compound nucleus. Because of the energy released in the pairing of neutrons when the incident neutron is absorbed.

The slow neutron fission cross-section for U^{235} varies energy in a complecated way. In the region of about 0.28ev. The fission cross-section of varies as the reciprocal of the neutron velocity v, from 0.28 - 1000ev. There are many closely spaced resonance. This resonance corresponding to the capture of a neutron with K.E such that the binding energy of the neutron. (≃ 6Mev) plus the K.E of motion equal some quantum level in general the fission cross section for U^{235} decreases with increasing energy until around 2 Mev. Where is levels of near 1.5 barns. The resonance peaks absorbed in fission are often analysed by using the Breit-Wigner single isolated level formula,

$$\sigma_f^{(l)} = (2l+1)\frac{\pi}{k^2} \cdot \frac{\Gamma_n \cdot \Gamma_f}{4(E-E_{res})^2 + (\Gamma/2)^2}$$

Where,

$l \rightarrow$ angular momentum.

E and $E^{l}_{res} \rightarrow$ The incident energy of neutron and neutron energy resonance.

$\Gamma \rightarrow$ total width of the level.

$\Gamma_n \rightarrow$ Sum of the neutrons width

$\Gamma_f \rightarrow$ Radiation and fission width.

$K \rightarrow$ the wave number of neutrons.

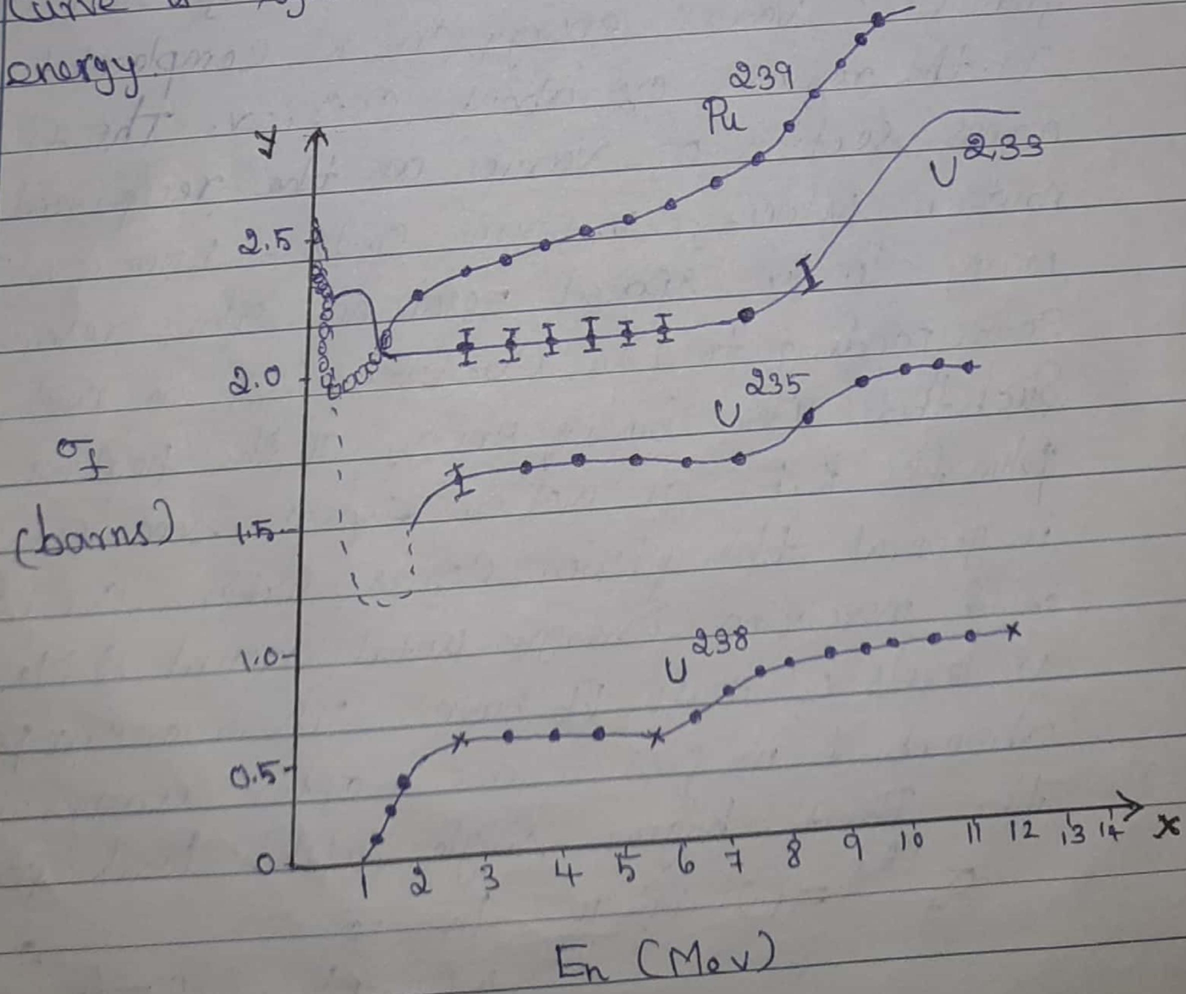
$K^2 \rightarrow \frac{1}{\lambda \lambda_0}$

where,

$\lambda \rightarrow$ wave length of neutrons

$\lambda_0 \rightarrow$ wavelength at resonance.

From this parameters we can find the fission cross section (can be computed accurately). The formula indicates the shape of the resonance curve is symmetric with maximum at the resonance energy.



The experimental shape is quite often asymmetric and deviates from the production of the Briet - wigner formula.

This deviation may be used to due to unresolved levels are to interfaced from the neighbouring resonance formula.

Energy in Fission:~

The difference between the atomic number and mass number.

Mass defect = 0.2235 amu

1 amu = 931 Mev.

Energy released = 208.08 Mev.

Thus in the process of fission of Uranium atom about 208 Mev, of energy is released. Since large number of Uranium atoms are involved the fission process, tremendous, quantity of energy is released.

Hence atomic energy is used for the generation of electricity.

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Generation of Electric Power reactor:-
(or)
(Power Reactor):-

The primary purpose of a power reactor is the utilization of the fission energy produced in the reactor core and to convert it into useful power. Heat generated in fission process is used, either directly (or) indirectly, to produce steam at high temperature and pressure (or) to heat a compressed gas. The steam (or) heated gas is used as a working substance in a turbine. The turbine canbe connected to an electric generator (or) can be used as a source of mechanical power.

Now we shall discuss some of the reactor types which appear to show the greatest promise for power production.

(i) Pressurized Water Reactor:-

It is a hetrogeneous reactor 1957, with power production of 60 MW. It United State Natural Uranium. Fuel elements rods (or) Plates. Planted in USA in 1957. Power of 60megawatt. Large amount of power production.

(ii) Boiling water Reactor:-

First in chicago in 1956 - 5 Megawatt. India is Tarapur (two), with the energy of 420 Megawatt.

(iii) Heavy Water Reactor:-

In Canada NPR with heavy water, Nuclear power demonstration reactor in 1962. It has been designed 20megawatts. India Rana Pradhab Sagar in 1972-73, heavy water with 430 Mws. Power Station at Kalpakkam at 470 Mws.

Draw back → Cost

(iv) Organic Moderated reactor:-

Hydrogen Contents.

(v) Sodium Graphite:-

High temp Can be achieved with out high pressure. First designed in 1957. Graphite is the reactor used in moderator. Na is coolant. Natural Uranium are used.

(vi) Gas Coolent:-

Berlium Oxide as a moderator in gas Cooled power reactor in 1944 by F. Danniell.

Purpose ⇒ fabrication of cost is significicant. Disadvantage in this type.

(vii) Liquid Fuel:-

It is a homogeneous reactor having fissionable material. Such as Uranyl sulphate (or) nitrate dissolved in water (or) heavy water. Circulating with solution through a spherical Styless Stell in which chain reaction takesplace. In this reactor was built at Oak Ridge National Laboratory.

(viii) Fast Reactor:-

The development of Power reactor in which the balb of fission produced by high energy. Neutrons not only produced useful power but also regeneration more fissile material then is consumed. This type of reactor was completed in 1951 & produced over 100 watts of electricity power.

Scanned by CamScanner

Fission Reactors:-

Reactors may be classified in a wide variety of ways. They are,

(i) Homogeneous Nuclear Reactor.

(ii) Heterogeneous Nuclear Reactor.

So,

Homogeneous Nuclear reactor:

In this fuel and the moderator are intimately and uniformly mixed as a solid mixture (or) a liquid solution of a Uranium Salt in the moderator.

Heterogeneous Nuclear reactor:-

In this fissionable material and the moderator are arranged in a geometric pattern (or) lattice. The fissionable material may be in the forms of rods, plates (or) Hollow cylinders.

Reactors are further classified according to the energy of the neutrons that cause fission. These reactors known as thermal, intermediate (or) fast according to the thermal neutrons (0.025eV), intermediate neutrons (1 to 10 keV), and fast neutrons (above than 10keV) respectively. Reactors are also classified according to their purpose. They types to be examined here are: (a) research reactors, (b) production reactors and (c) power reactors.

(a) Research Reactors:-

In these reactors the total energy liberated is comparatively small, since they operate at a low level of reactivity. In these cases cooling is required only to prevent over heating. We shall describe here three main types of research reactors.

(i) Graphite - Moderated Research Reactor:-

* It is a heterogeneous reactor.
* In 1942 it was built with natural Uranium (CP-1)
* Power 200 watts generated

(ii) Water Boiler Type Reactor:-

* It is homogeneous mixture.
* Ordinary H_2O is used as a Coolant.
* The first reactor was built as Los Alamos in early 1944. It was named as, LOPO (low power) because of its low power (1W) operation. It was improved in December for high power operation and was named HYPO (high power). It was further improved for super power, named SUPO (Super power), and is in operation since 1951.

(iii) Swimming pool Coolants:-

* It is a heterogeneous reactor.
* It is the popular name of light water moderated heterogeneous reactor.
* The Uranium fuel it was arranged as lattice arrangement.
* In a large pool of water the chief advantages of this type simplicity, low cost, Safety, flexibility and accessibility.
* It was Completed in 1950 and named as BSR.
* An India Apsara belongs to this type. It was Completed in 1956. It was designed and built by the Indian engineers and Scientists

Under the guidance of the late Dr. H.J. Bhaba.

(b) Production Reactors:-

* The purpose of a production reactor is to convert fertile into fissile material. It was used as a fuel in other reactors. In Hanford works production reactors, the natural Uranium is used as a fuel, graphite as a moderator and water as a coolant. The efficiency of conversion of U^{238} into Pu^{239} is thus appreciably less than unity. The ratio is always smaller than 0.8 in this type of reactor.

(c) Power Reactors:-

* The primary purpose of a power reactor is the utilization of the fission energy produced in the reactor core and to convert it into useful power. The turbine can be connected to an electric generator (or) can be used as a source of mechanical power.