7.8 CHAIN REACTION AND CONTROLLED CHAIN REACTION

Chain reaction is a propagating process in which the number of neutrons goes on multiplying rapidly till whole of the fissionable material is disintegrated.

Let us consider the chain reaction in which a single neutron causing fission in uranium (U^{235}). In this fission reaction $_{92}U^{235}$ nucleus is broken into two parts Barium and Krypton. The process is accompanied by emission of three fast neutrons and nearly 200 MeV of energy is released. These three neutrons produced in this process can produce fission in three more $_{92}U^{235}$ nuclei, we shall get nine neutrons which in turn can produce fission in nine $_{92}U^{235}$ nuclei and so on.

Thus a chain reaction would start and a tremendous amount of energy will be released. The chain reaction is shown in fig. (7.3).

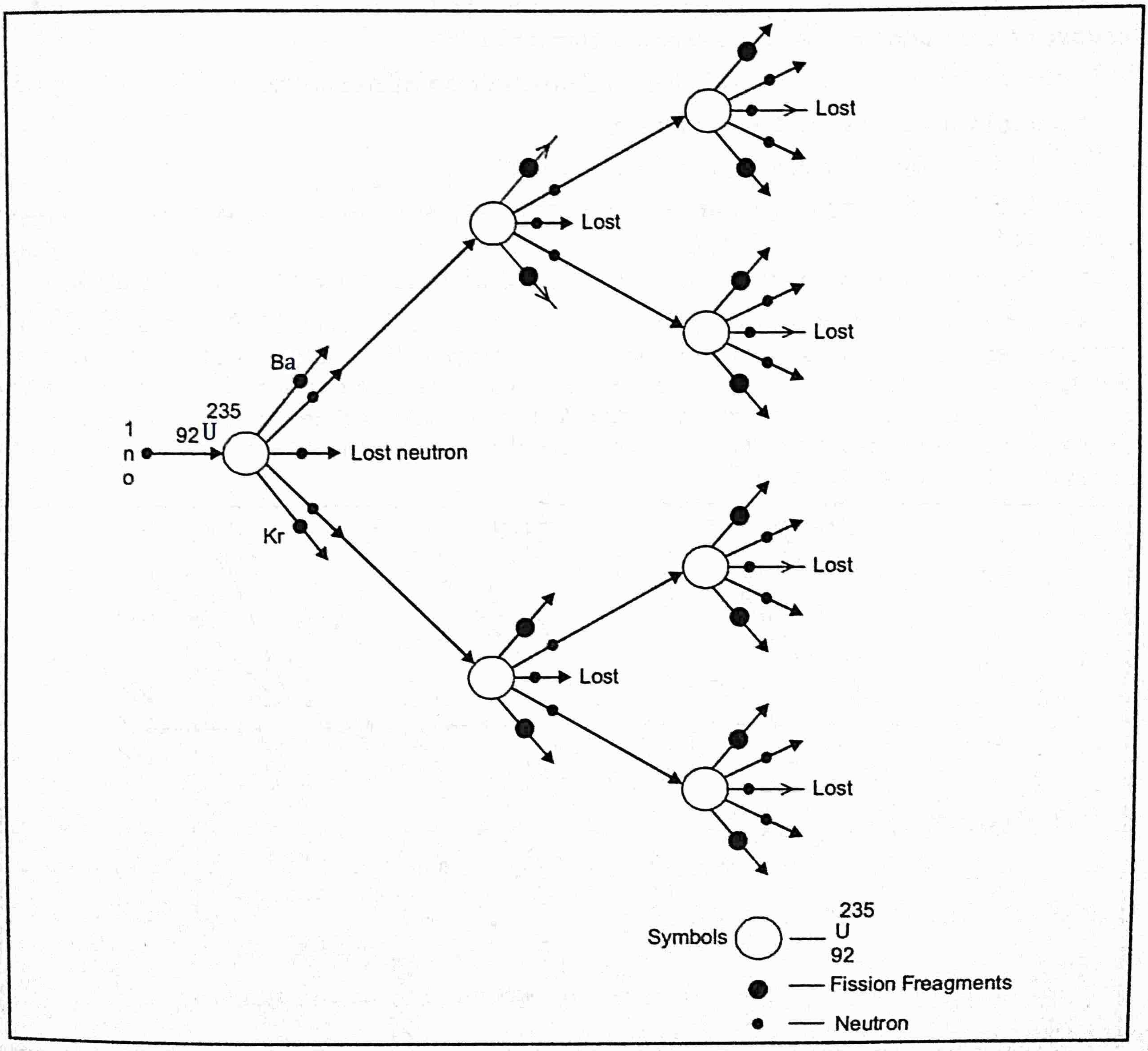

Fig. 7.3

There can be following difficulties for the chain reaction to continue.

(i) Some of the neutrons produced by fission may escape the uranium assembly, hence they may escape the collisions with any nucleus. To avoid this difficulty the uranium sample is taken in the form of large sphere. Moreover the mass of uranium is taken more than critical mass, because if mass is less than critical mass chain reaction cannot take place.

(ii) The second difficulty that every neutron entering uranium does not produce fission. Some neutrons are captured by U^{238} which is in abundance in natural uranium. This difficulty can be reduced by separating U^{235} from U^{238} and by slowing on neutrons using moderator like graphite or heavy water.

This type of uncontrolled chain reaction takes place in atom bomb. In atom bomb, we use 95% enriched uranium.

The ratio of the rate of production of neutrons to the rate of loss of neutrons due to leakage or absorption etc. is called reproduction factor (K).

K = **Rate of production of neutrons** ...(7.12)

Special Cases : Rate of loss of neutrons

(a) If K = 1, the chain reaction will just proceed.

(b) If K > 1, the chain reaction will accelerate, the size of material is said to be super-critical.

(c) If K < 1, the chain reaction stops, the size of material is said to be subcritical.

Controlled Chain Reaction : The chain reaction can be controlled if an average, one neutron per fission causes another fission, then energy will be released at a constant rate. Whether a mass of active material will sustain a chain reaction or not is determined by what is called reproduction factor or multiplication factor. If the rate of neutron production is equal to the rate at which neutrons disappear, the reproduction factor is one and the mass is said to be critical. It is shown in fig. (7.4).

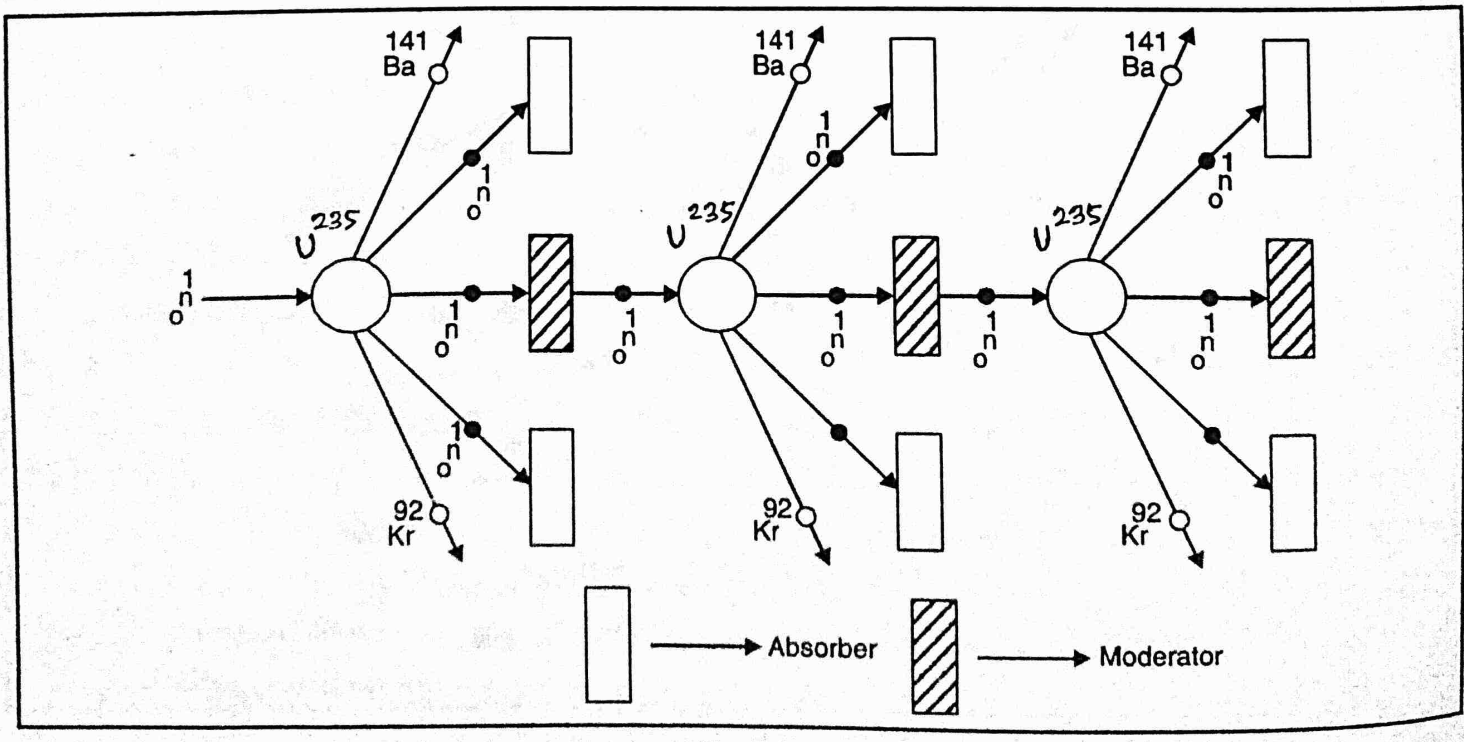

Fig. 7.4

7.9. II – NUCLEAR REACTOR

A nuclear reactor is a device based on controlled nuclear chain reaction wherein the nuclear energy produced is utilised for constructive purposes.

In a reactor, small pieces of uranium are spread throughout the material called moderator, which can slow down the neutrons to thermal energies. These slow (thermal) neutrons can cause fission in other nuclei. When a thermal neutron strikes $_{92}U^{235}$ nucleus it breaks up in $_{56}Ba^{141}$ and $_{36}Kr^{92}$ nuclei and three fast neutrons are produced. These fast neutrons strike the moderator and loose their kinetic energies due to repeated collisions and become thermal neutrons. These thermal neutrons produce fission in other nuclei of uranium. Thus a chain reaction is set up. Whenever a chain reaction is to be stopped (or brought under control), some material which is a strong absorber of neutrons is inserted in between so that neutrons are absorbed and rate of reaction is slowed down. Fig. (7.5) shows a schematic diagram of a nuclear reactor.

Nuclear reactor basically consists of following parts :

(*i*) A core of nuclear fuel (*ii*) Reflector (*iii*) Moderator (*iv*) Control rods (*v*) Coolant (*vi*) Radiation shielding.

(i) Reactor Core : This is main part of reactor which contains the fissionable material called reactor fuel. Thus nuclear fuel is a material that can fissioned by thermal neutrons. Commonly used fuels in a reactor are U^{233}, U^{235}, Pu^{239} etc. Generally, pure U^{235} is taken inside the sealed aluminium cylinders piled in fissionable chamber. When slow neutrons interact the fuel, the fission starts and energy is released. In general, the reactor core have fuel elements, moderator, control rods and coolant material housed in a pressure vessel.

(ii) Reflector : It is a region surrounding the reactor core collector reflector. The function of this reflector is to reflect back some of the neutrons that leak out from the surface of the core. The material of the reflector is the same as that of moderator.

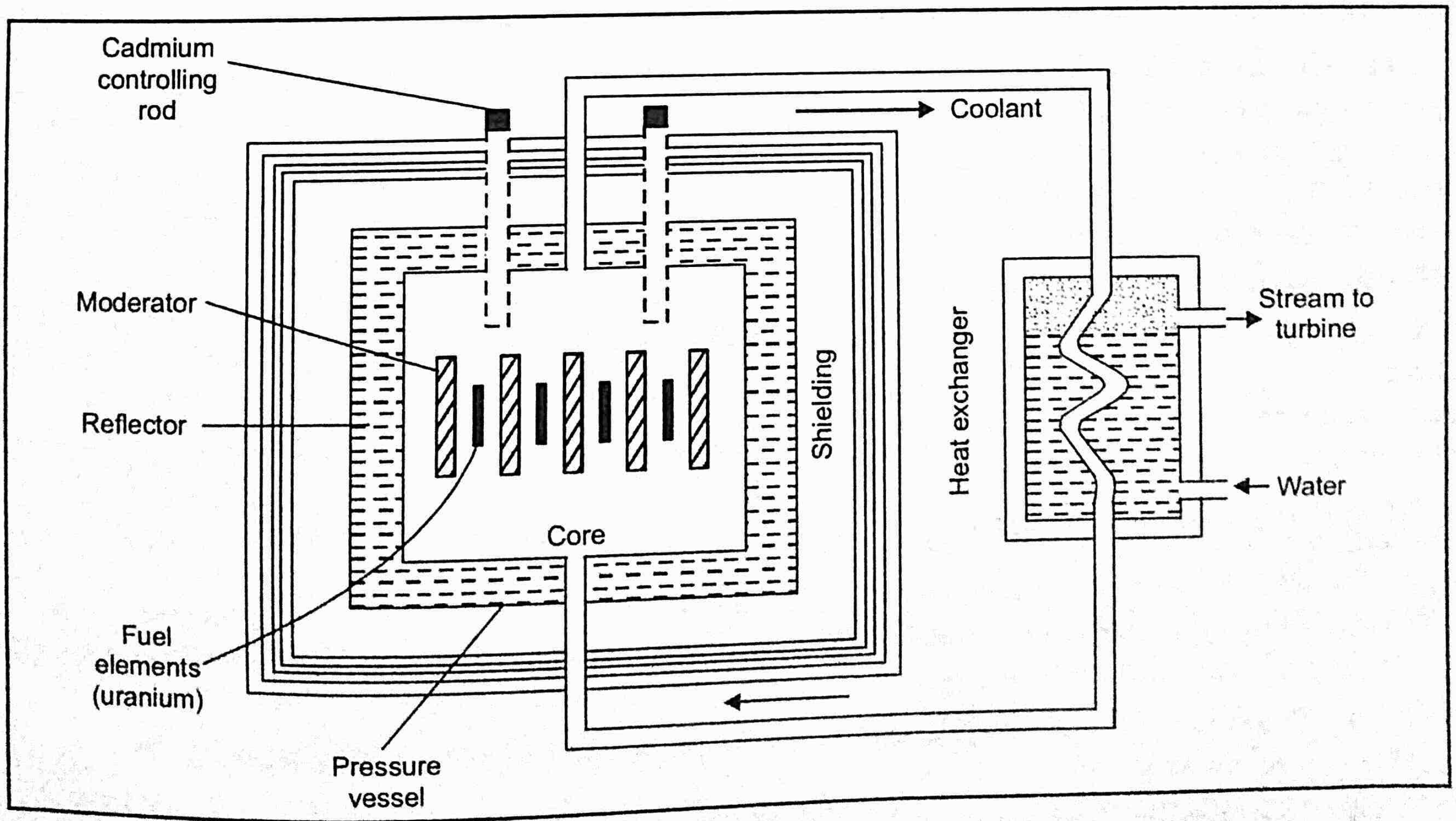

Fig. 7.5

(iii) Moderator : Moderator is used to slow down the fast neutrons produced in the fission process when thermal neutrons strike the nuclear fuel. The material of moderator (*i*) should be light and (*ii*) should not absorb neutrons. Usually graphite and heavy water are used as moderators. These moderators are rich in protons. When fast moving neutrons collide head on protons of moderator substances, their energies are interchanged and neutrons are slowed down. Such neutrons are called thermal neutrons, which cause fission of $_{92}U^{235}$ in the fuel.

(iv) Control rods : In a reactor it is necessary to control the fission process, otherwise the chain reaction may become explosive and damage the nuclear reactor. In order to remove this difficulty, we consider a quantity called **reproduction factor** K. It is defined as the ratio of rate of production of neutrons to the rate of loss of neutrons due to leakage or absorption.

$$\text{Reproduction factor (K)} = \frac{\text{Rate of production of neutrons}}{\text{Rate of loss of neutrons}}$$

(i) If $K = 1$, the chain reaction just proceed (*i.e.* the reactor is critical.)

(ii) If $K < 1$, the chain reaction stops (*i.e.* the reactor is sub critical.)

(iii) If $K > 1$, the reaction will accelerate (*i.e.* reactor is super-critical.)

In order to regulate the power level of the reactor, control rods are used. The control rods can be inserted into or drawn out of the reactor fuel core and consist of a material that absorbs neutrons *i.e.* cadmium, boron etc.

Initially, fission is started with external source of neutrons while controlled rods are partially pulled out of the core. Under these condition the system is super critical *i.e.* number of neutrons increases which in turn increases power level. As soon as the desired power level has been achieved, the control rods are pushed into the core until the system becomes critical.

(v) Coolant : The fission produces heat in the reactor core. The coolant transfers this heat from the core to the heat exchanger, where steam is produced. This steam produced at high pressure runs a turbine and electricity is obtained at the generator. The dead steam from turbine condenses into water and is returned to the heat exchanger. The process repeats and a continuous supply of electricity is obtained.

(vi) Radiation Shielding : In a nuclear reactor various types of rays are emitted which are very harmful for human being. The whole reactor is protected with concrete walls, 2 to 2.5 metres thick, so that radiations emitted by nuclear reactions may not produce harmful effects on the persons working on the reactor. The thick walls of cement and concrete constructed around the reactor are known as **shields.**

Uses of a Nuclear Reactor :

1. Nuclear reactors are used in electric power generator.
2. They are used to produce radioactive isotopes which in turn are used in medicine, industry and agriculture.
3. They are also used to produce neutron beams of very high intensity for use in nuclear research.
4. They can be used for propulsion of ships, submarines and craft.