Module 3 NUCLEAR POWER PLANT

Nuclear Power Plants - Introduction

- Need for Nuclear power plant: high energy demand, booming increase o populations, depleting fossil fuel, oil & gas.

- A generating station in which nuclear energy is converted into electrica energy is known as nuclear power plant.

- Huge amount of energy can be released from small quantity of radio activ material (Nuclear fuels).

- Energy from 1kg of U235 = Energy from 4500tons of high grade coal.

- Nuclear reactor is the main component of nuclear power station.

Nuclear Power Plants – Introduction (contd.)

- U235, Th232 etc are called as nuclear fuels. These elements are subjecte
  to nuclear fission in Nuclear reactor.

- Nuclear reaction (Nuclear fission) is taking place in the nuclear reactor.

- The breaking up of nuclei of heavy atoms into two nearly equal parts wit
  release a huge amount of energy is known as nuclear reaction or nuclea
  fission.

- A neutron is strikes on uranium atom, uranium atoms splits into tw
  components & huge amount of heat energy is released.

Economics of Nuclear Power Plants

Capital Costs

- The total operating costs per kWh generated in a nuclear power plants are quite lower than those in case of conventional steam power plants.
- Capital cost of nuclear power plant is more, however operating cost is cheap.
- Energy from 1kg of U235 = Energy from 4500 tonnes of high grade coal.

Economics of Nuclear Power Plants (contd.)

❑ Capital Costs (contd.)

- The capital costs of a nuclear power plant includes cost of land, cost of design & planning, cost of building, cost of nuclear reactor, heat exchangers, steam turbines, alternators etc.

- Nuclear reactors are very heavy & impose bearing pressure of about 50 tons per square metre. Therefore, the site should have strong foundation.

- The capital cost of nuclear reactors, cooling requirements, foundation of nuclear power plants are very high.

Economics of Nuclear Power Plants (contd.)

❑ Operating Costs

- The quantity of fuel placed in a nuclear reactor during any period, say one month, has little relationship to the kilowatt hours generated.

- Therefore, the fuel costs are calculated on the basis of "target irradiation".

- The quantity of fuel consumed in the reactors is calculated from the electrical output of the plant & operating fuel cost allocation is based on this calculation.

Economics of Nuclear Power Plants (contd.)

❑ Operating Costs (contd.)

- Nuclear fuel may remain in a reactor for more than 5 years. Therefore, the cost of fuel injected initially is considered as capital cost.

- The other operating costs include salaries & wages of operating & maintenance staff, oil, water, material for maintenance etc.

- The total operating costs per KWH of a nuclear plant are less than that of a coal fired thermal plant.

Merits of Nuclear Power Plants

- The amount of fuel requirement is quite small.
- There is a considerable saving in the cost of fuel transportation & storage.
- A nuclear power station requires less space as compared to any other types of the same size.
- It has low running charge (operating cost).
- Small amount of fuel can produce large electrical Energy.
- Output control is extremely flexible.
- There are large deposit of nuclear fuel available in the world.

Merits of Nuclear Power Plants (contd.)

- This plant is very economical for producing large electrical power.
- The cost of primary distribution is reduced.

  Reasons - it can locate near to the load centre because it doesn't require large quantity of water & needn't near to the coal mine.
- Large deposits of nuclear fuels are available all over the world. So it can ensure continued supply of electrical energy for thousands of year.
- It ensure the reliable operation.
- Low CO_2 emission.

Demerits of Nuclear Power Plants

- The fuel used is expensive & difficult to recover.
- The capital cost of nuclear power plant is very high as compared to other types of plants.
- The erection & commissioning of the plant requires greater technical knowledge.
- The fission by product are generally radioactive & may cause a dangerous amount of radio active pollution.
- Maintenance charge & salary of maintenance employees are high.

Demerits of Nuclear Power Plants (contd.)

- Maintenance charge is more due to the lack of standardization. Moreover high wages of specially trained employee reason for further raise of cost.
- Nuclear power plant is not well suited for varying loads as the reactor doesn't respond to the load fluctuation efficiently.
- The disposal of the by-products which are radioactive is a big problem. They have either to be disposed of in a deep trench or in a sea away from sea – shore.
- The cooling water requirement of a nuclear power plant is very heavy.

Selection of Site - Nuclear Power Plants

- **Water availability**

  Sufficient water is required for cooling purpose & plant site near to the river or sea side.

- **Disposal of waste**

  The waste produced by fission in a nuclear power station is generally radioactive which must be disposed properly to avoid health hazard. The waste can deposit in a deep trench, disposed away from seashore & selected plant should have disposal arrangement. Therefore, the site selected for such power plants should have adequate space & arrangement for the disposal of radio active waste.

Selection of Site - Nuclear Power Plants

- Distance from the populated area

  A reasonable distance should be maintained from populated area. The nuclear plant should be located away from populated area because of the presence of radio activity in the atmosphere near the plant. However as precautionary a dome is used in the plant which does not allow the radio activity to spread.

- Transportation facility

  A nuclear plant requires very little fuel, hence it does not require direct rail facilities for fuel transport. However, transportation is to be needed during construction stage. For transporting heavy equipments rail and rail facilities are needed.

Nuclear Reaction

- Nuclear reaction is associated with a release or absorption of energy.

- There are four types of nuclear reactions taking place in nature- Elastic scattering, Inelastic scattering , Capture or absorption ,Nuclear fission.

- In nuclear reaction, we need to consider the interaction between a projectile which may be a neutron, a proton or an α particle and a target nucleus which is usually heavy element.

- In nuclear, the atomic numbers & mass numbers must balance on both sides of the equation.

Nuclear Reaction (contd.)

- The masses of isotopes do not balance on both sides of the equation i.e. there is a increase or decrease in mass between reactants and products. Thus nuclear reaction is associated with a release or absorption of energy.

- If there is a decrease in total mass after the reaction, then there will be release of energy and vice versa.

- The interaction between projectile and target nucleus may result in elastic scattering, scattering and capture or absorption.

- If a neutron collides with a nucleus, and the nucleus remains unchanged in its isotopic composition & the neutron undergoes a change in its direction of motion then the process is called Scattering.

Nuclear Reaction (contd.)

- If neutron disappears from the system, the process is called Capture or absorption.

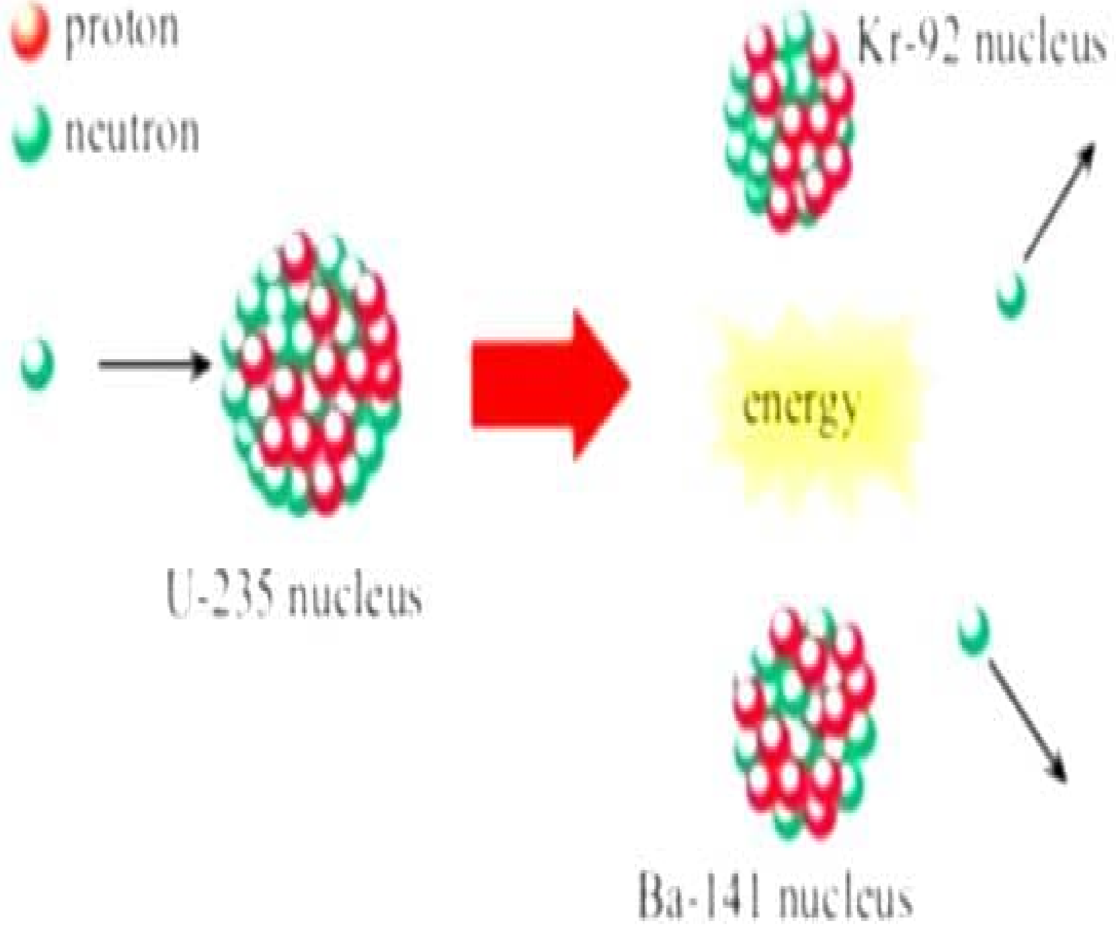
- Elastic scattering describes a process where the total kinetic energy of the system is conserved. There is neither release nor absorption of energy, there being only redistribution of kinetic energy of the colliding particles.

- Inelastic scattering is a fundamental scattering process in which the kinetic energy of an incident particle is not conserved.

- There is neither absorption nor release of energy and the identical particles and the ejected particles are identical.

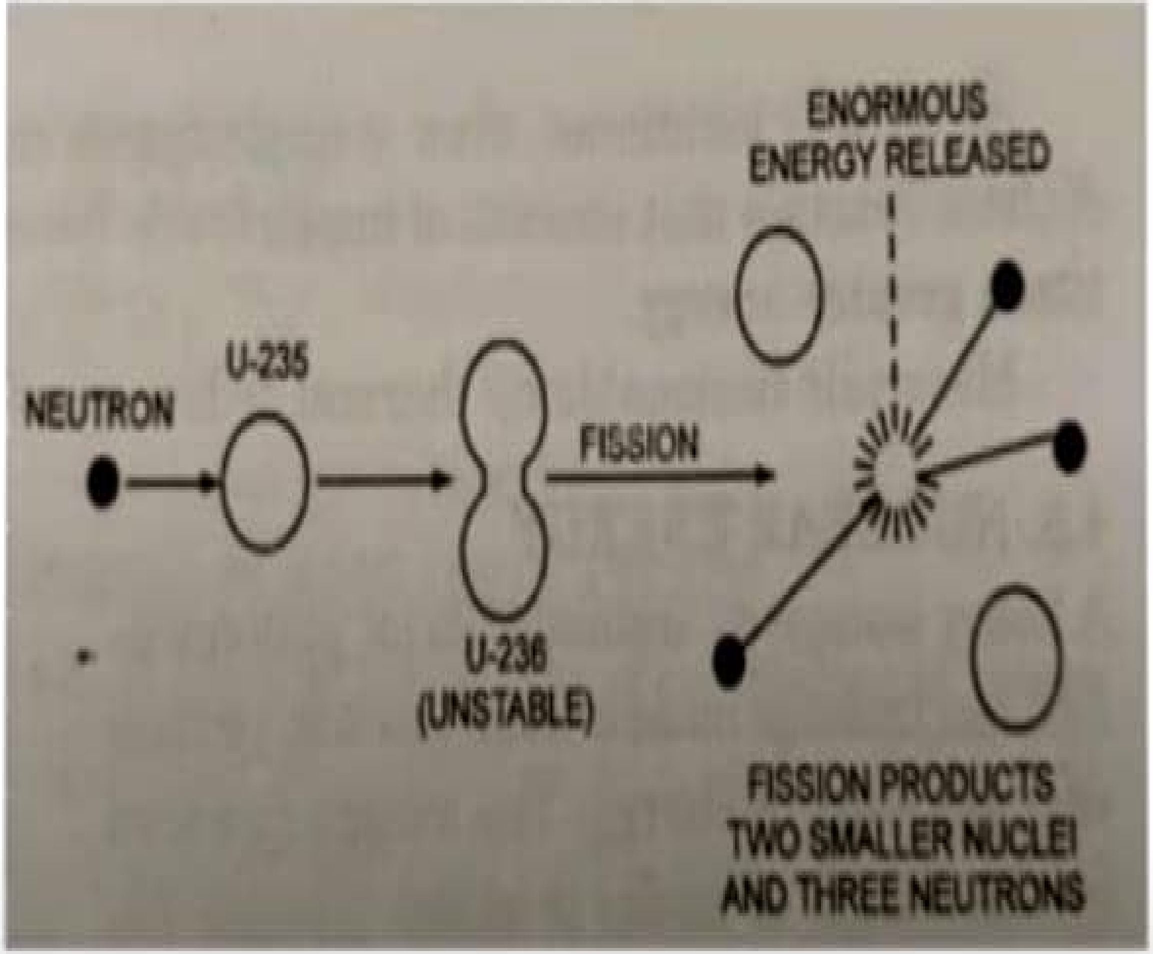
Nuclear Fission Process

The splitting of heavy nucleus into two or more smaller nuclei is termed nuclear fission.



Nuclear Fission Process (contd.)

Nuclear Fission Process - This is the process in which heavy nucleus is split when it is bombarded by certain particles such as neutron or proton or electron or X-ray.



Nuclear Chain Reaction

- Chain reaction is a fission reaction where the neutrons from a previous step continue to propagate & repeat the reaction.
- Chain reaction continues till most of the original nuclei in the given sample are fashioned.
- All the neutrons are not used for propagating the chain reaction. Some of these will be lost to the surroundings.,
- Thus for chain reaction to occur, the sample of the fissionable material should be large enough to capture the neutron internally.

ear Chain Reaction (contd.)

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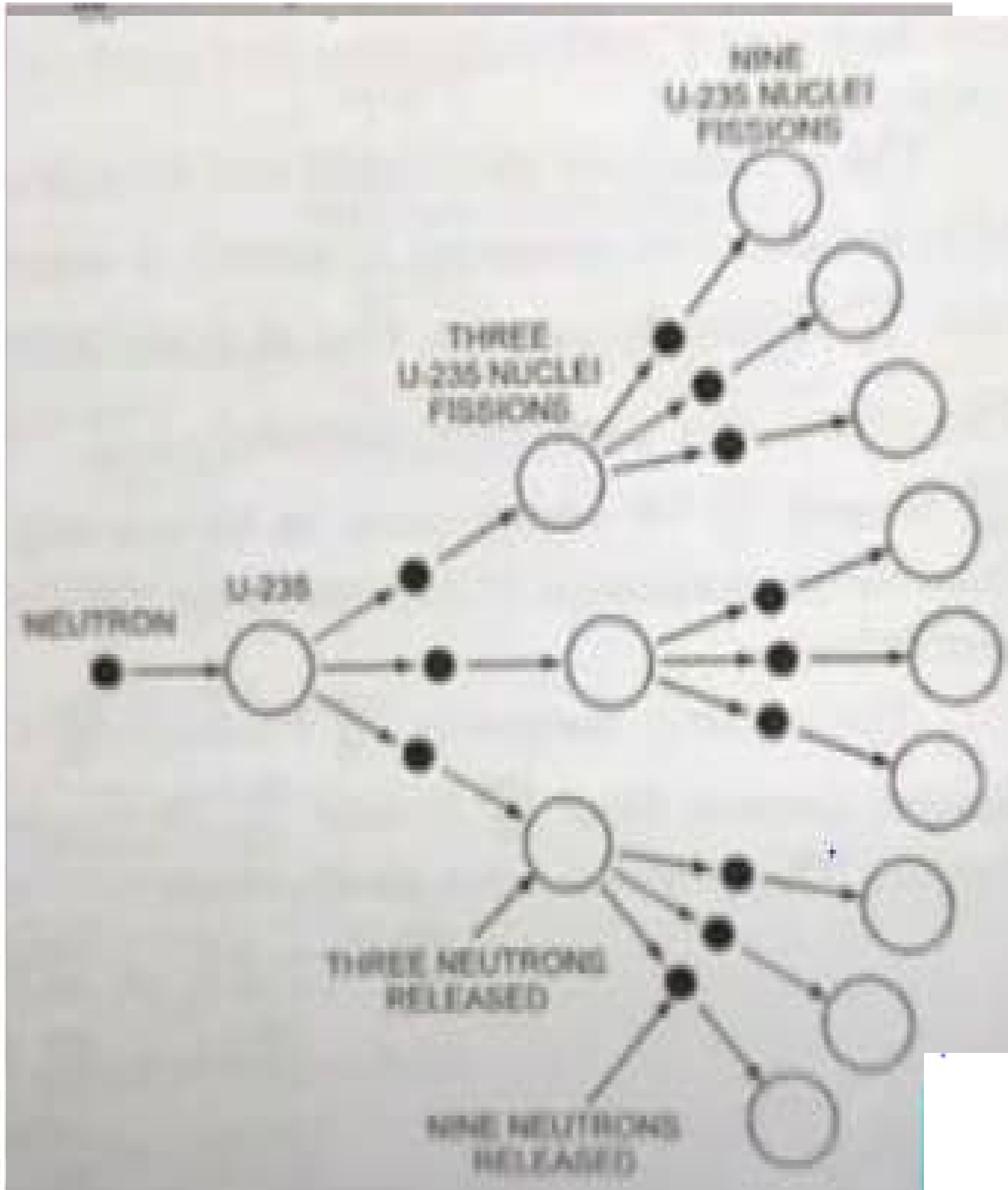


Nuclear Chain Reaction (contd.)

- If the sample is too small, most neutrons will escape from its surface, thereby breaking chain reaction.

- The minimum mass of fissionable material required to sustain chain reaction is called the critical mass.

- A chain reaction that consists of innumerable fission reactions will, therefore, generate many times greater energy.

Nuclear Fuels

- The fuels mainly used are natural uranium (U-235), enriched uranium, plutonium (Pu-239) & U-233.

- Natural uranium is the parent material.

- The material U-235, U-233 & Pu-239 are called as fissionable materials.

- U-235 is best among the fuels because of its higher fission percentage.

Nuclear Fuels (contd.)

- The only fissionable nuclear fuel occurring in nature is uranium, of which 99.3% is U-238 and 0.7% is U-235, U-234 and is only a trace.

- Out of three isotopes only U-235 will fission in a chain reaction.

- The other two fissionable materials (Pu-239 and U-233) can be produced artificially from U-238 and Th-232which occur in nature are called fertile materials.

Nuclear Energy

- The energy released by the fission of nuclei is called nuclear fission energy or nuclear energy.
- Heat energy & radiation liberated after nuclear fission reaction.
- If the nuclear reaction is uncontrolled, it causes explosion (Atomic bomb).
- Controlled chain reaction can be done in nuclear reactor & generate electricity.

Nuclear Energy (contd.)

- A heavy isotope as uranium 235 (or plutonium 239) can undergo nuclear chain reaction yielding vast amount of energy.

- The fission of U 235 or Pu 239 occurs instantaneously producing incomprehensible quantities of energy in the form of heat and radiation.

- If the reaction is uncontrolled, it is accompanied by explosive violence & can be used in atomic bombs.

Nuclear Reactor and its components

- Nuclear Reactor is the part of nuclear power plant where nuclear fuel is subjected to nuclear fission and the energy released in the process is utilized to heat the coolant which may in turn generate steam.

- Continuous Nuclear fission process leads to chain reaction.

- Controlled chain reaction takes place in nuclear reactor.

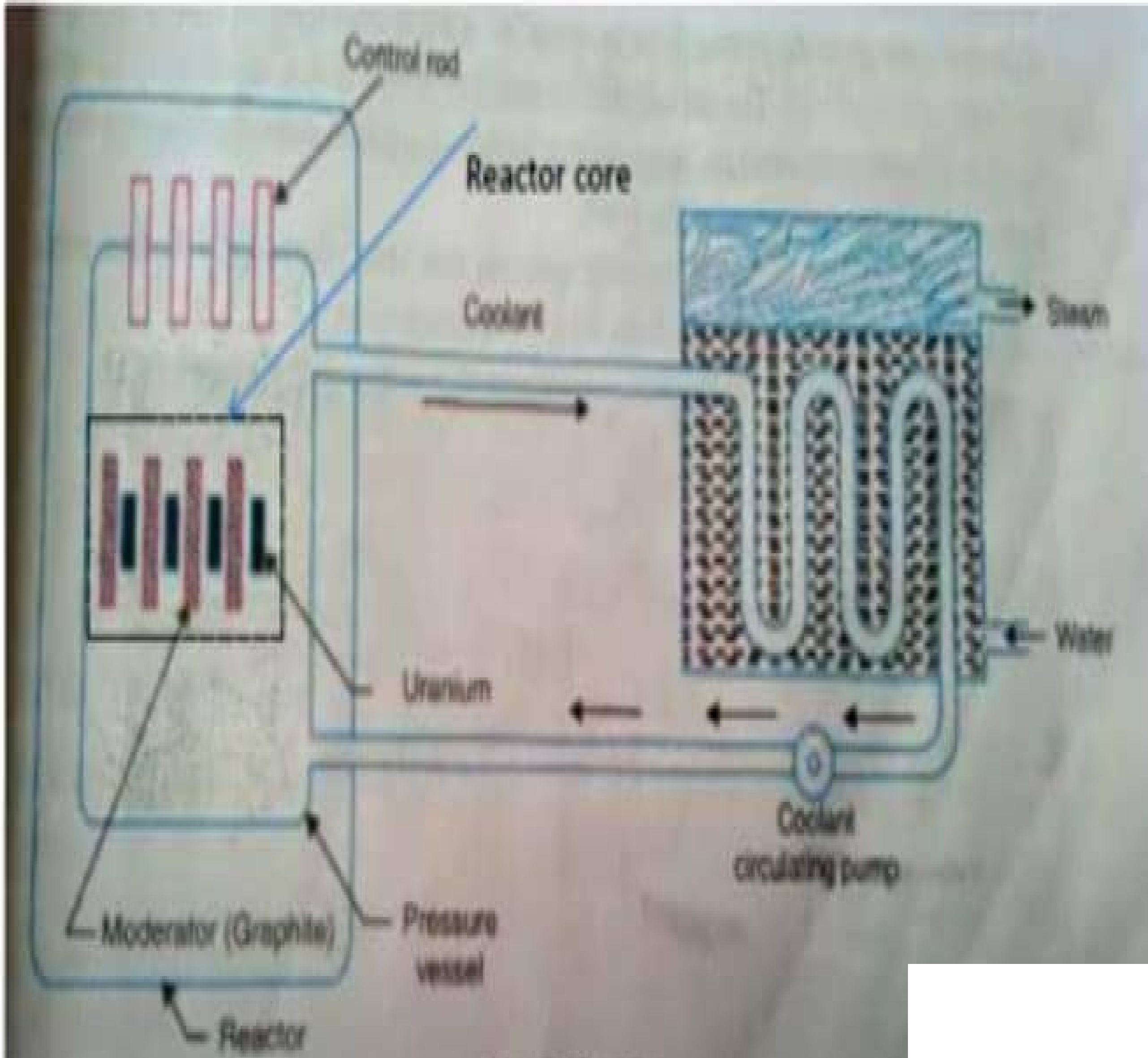
- Uncontrolled chain reaction leads explosion.

- The main function of the nuclear reactor is to control the emission and absorption of neutrons.

Nuclear Reactor and its components (contd.)

The main parts of nuclear reactor are

- Reactor Core
- Moderator
- Fuel Rods
- Control Rods
- Coolant
- Reflector
- Thermal Shielding
- Reactor Vessel
- Biological Shield



Nuclear Reactor

Nuclear Reactor and its components (contd.)

- Nuclear reactor is a cylindrical stout pressure vessel & house fuel roads of uranium, moderator & control rods.

- The fuel rods constitute the fission material & release huge amount of energy when bombard with slow moving neutrons.

- The moderator consists of graphite rods which enclose the fuel rods. The moderator slows down the neutrons before they bombard with the fuel rods.

- The control rods are of cadmium & inserted into the reactor. Cadmium is strong neutron absorber regulate the supply of neutron for fission

Nuclear Reactor and its components (contd.)

- Control rods can push in deep enough, they absorb most of fission neutrons & hence a few are available for the chain reaction & therefore chain reaction stops. Control rods regulate the intensity of chain reaction.

- Pulling out the control rods increase the power of nuclear reactor & vice versa.

- The heat produced in the nuclear reactor is removed by the coolant. Generally sodium metal is used as a coolant.

- D_2O (Heavy water) is also suitable as a coolant. Coolant carries heat to the heat exchanger.

Nuclear Reactor and its components (contd.)

Reactor Core

- The reactor core mainly comprises of a number of rods made of fissile materials.

- In a view to have better control of the fission reaction, it is usually to clad the fuel with aluminium or zirconium or stainless steel.

- The fuel is finely powdered and shaped into a form which facilitates uniform production of heat.

- It is then enclosed inside the cladding material, and the cladded fuel is suitably placed inside the reactor.

Nuclear Reactor and its components (contd.)

❑ Moderator

- The purpose of moderator is to slow down the fast moving secondary neutron so that chain reaction is sustained. The moderator surrounds the fuel rods.
- As soon as fast moving neutrons are given out, as a result of chain reaction the collide against the moderator and slow down.
- They are now capable of causing further fission, and thus the chain reactio continues.
- Materials used as moderators are ordinary water, heavy water, beryllium an graphite.
- Graphite, Boron, Lithium, Carbon , Nitrogen etc are suitable for Moderator

Nuclear Reactor and its components (contd.)

Control Rods

- Control rods are meant for controlling the rate of fission of U 235.
- Control rods are rods, plates, or tubes containing a neutron absorbing material
- These are made of boron 10, cadmium or hafnium, that absorb some of the slowed neutrons.
- The materials used for control rods must have very high absorption capacity for neutrons.
- It reacts with graphite so special steps to be taken in the design of reactor so as to inhibit the reaction between CO_2 and graphite.

Nuclear Reactor and its components (contd.)

Control Rods (contd.)

- In a nuclear reactor, nuclear chain reaction has to be initiated when started from cold, and the chain reaction is to be maintained at a steady value during the operation of reactor.

- Also the reactor must be able to shut down automatically under emergency conditions.

- All this requires a control of reactor so as to prevent the melting of fuel rods, disintegration of coolant & destruction of reactor the release of energy is enormous.

- When dry, it doesn't react with mild steel of the pressure vessel.

Nuclear Reactor and its components (contd.)

❑ Control Rods (contd.)

- Chain reaction is controlled either by removing the control rods or by inserting neutron absorbing materials.

- The control rods are inserted from top of the reactor core from the top of the reactor vessel.

- These rods regulate the fissioning in the reactor by absorbing the excess neutrons. These can be moved in and out in the reactor core.

- If the fissioning rate of the chain reaction is to be increased, the control rods are moved out slightly so that they absorb less number of neutrons & vice versa.

Nuclear Reactor and its components (contd.)

❑ Coolant

- It is a medium through which the heat generated in the reactor is transferred to the heat generator for further utilization of power generation.

- If water is used as coolant it takes up heat & gets converted into steam in the reactor which is directly used for driving the turbine.

- A good coolant should not absorb neutrons, should be non oxidizing, non toxic & non corrosive and have high chemical and radiation stability and good heat transfer ability.

- Gases: Air, helium, hydrogen & CO_2. Liquids: Light & heavy water.
  Metals: Molten sodium & Lithium are used as coolants.

Nuclear Reactor and its components (contd.)

- Coolant (contd.)
  - Ordinary water is used both as coolant & moderator in boiling water reactors.
  - Pressurized water is used as coolant & moderator in Pressurized water reactors.
  - Water has good thermal capacity and good heat transport medium.
  - Liquid metals are used as coolant in fast reactors which have large heat release from, a small core.
  - They have high heat transfer capability & low vapour pressure.
  - CO_2 is colourless & odorless & has low neutron absorption cross section.

Nuclear Reactor and its components (contd.)

Reflector

- A neutron reflector is placed around the core and used to avoid the leakage o neutrons from the reactor core.

- Reflector sends back any slow moving secondary neutron which tries to escap out of the reactor core.

- The reflector surrounds the reactor core completely.

- It is made of the same material as the moderator, and possesses the sam characteristic feature as the moderator.

- The reflector helps to conserve the nuclear fuel by preventing the escape of the neutrons.

Nuclear Reactor and its components (contd.)

❑ Reactor Vessel

- The reactor core, reflector and thermal shielding are all enclosed in the main body of the reactor and is called the reactor vessel.

- It is strong walled container and provides the entrance and exit for the coolant and also passages for its flow through and around the reactor core.

- The reactor core is usually placed at the bottom of the vessel.

Nuclear Reactor and its components (contd.)

Thermal Shielding

- The shielding is usually constructed from iron and help in giving protection from the deadly ά and β particle radiations and Υ rays as well as neutrons given off by the process of fission with the reactor.

- In this manner it gets heated and prevents the reactor wall from getting heated.

Biological Shield

- The whole of the reactor is enclosed in a biological shield to prevent the escape or leak away of the fast neutrons, slow neutrons, β particles and Υ rays as theses radiations are very harmful for living organisms.

- Lead iron or dense concrete shields are used for this purpose.

Nuclear Reactor Control

- All the plant reactors are provided with the means to regulate the fission process so that energy is generated according to the load requirements and in emergency reactor can shutdown immediately.

- Fission control is affected by regulating the neutron population or flux as per power requirement by providing for absorption of excess neutrons through such substances which have high neutron absorption coefficient. These are called poisons.

- Cadmium and Carbon are two such substances which are inserted with the help of adjustable rods.

Nuclear Reactor Control (contd.)

- The position of control rods are regulated by electrochemical & electronic sensing objects.

- We know that all neutrons released are not used in chain reaction but some of these are lost to surroundings.

- In order to maintain chain reaction, it is essential that the number of neutrons after the fission should be slightly more than the number before leak of neutrons from reactor core.

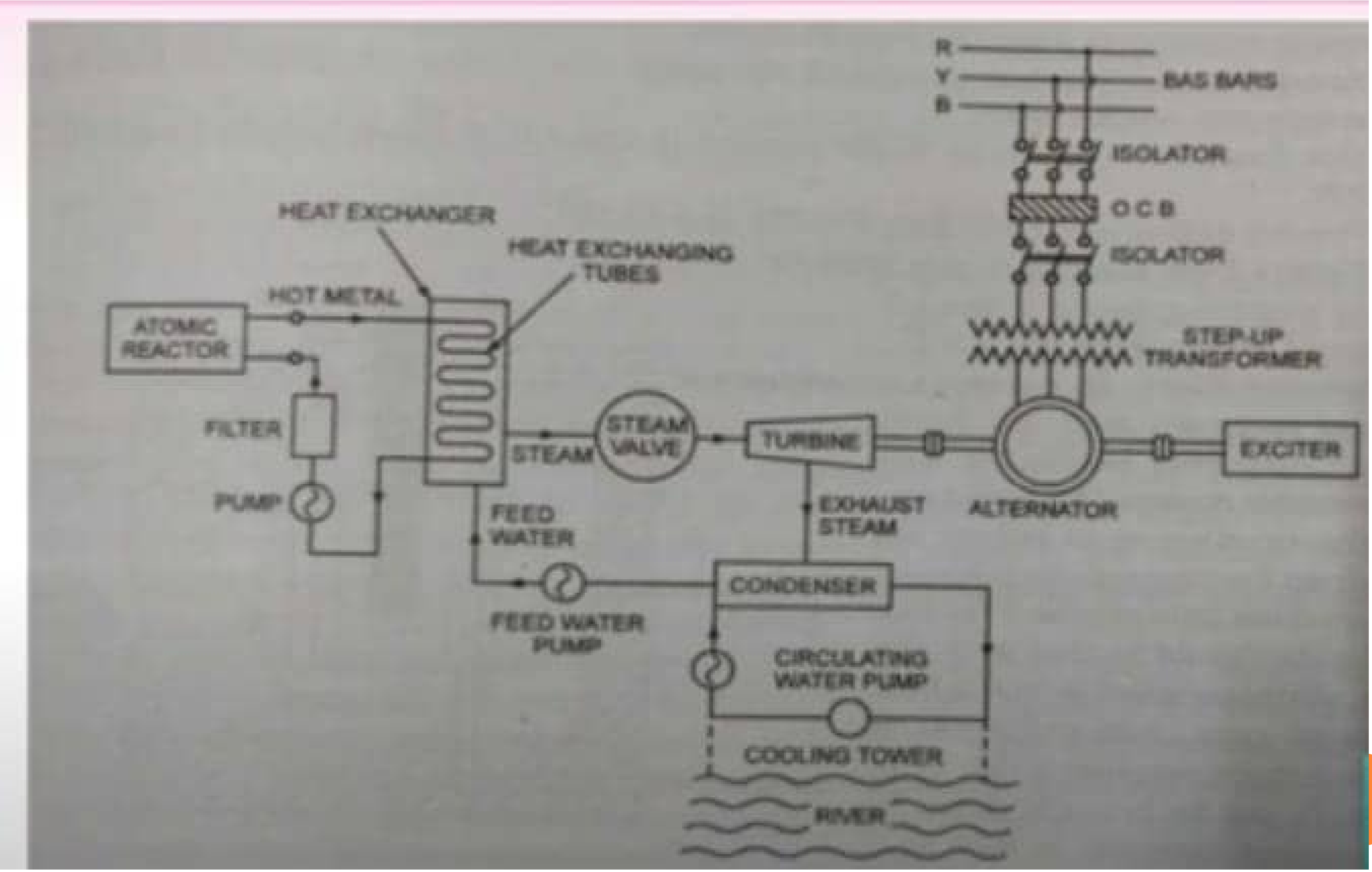
Nuclear Reactor Control (contd.)

- The multiplication factor (K) for any reactor is defined as the number of neutrons produced in one generation to the number of neutrons produced in the preceding generation.

$$K = \frac{\textit{Number of neutrons produced in one generation}}{\textit{Number of neutons produced in preceding generation}}$$

- K= 1 ; Desirable requirement of power station called as critical condition
- K <1 ; stop chain reaction - 'Subcritical condition'
- K >1 ; Chain reaction build up again - 'Super critical condition'

Nuclear plant layout



Nuclear Power Plant Layout - Explanation

- Nuclear power plant consists of a Nuclear Reactor, Heat exchanger, steam turbine, Alternator, Condenser etc.

- Nuclear reaction is taking place in Nuclear Reactor & generates heat.

- Function of hot metal (pumping fluid) is to exchange (transfer) the heat energy generated from atomic reactor (Nuclear Reactor) to the Heat exchanger.

- Liquid sodium can be used as hot metal.

Nuclear Power Plant Layout - Explanation

- Heat exchanger converts water into steam.
- The heated metal is allowed to exchange its heat to the heat exchanger by circulation.
- The generated steam from heat exchanger utilised to drive the steam turbine (gas turbine) which is coupled to an alternator thereby, generating electrical energy.

Components of Nuclear Plant Layout

- ❑ Nuclear Reactor and its Components
- ❑ Heat Exchanger
- ❑ Steam Turbine
- ❑ Alternator

Components of Nuclear Plant Layout (contd.)

❑ Nuclear Reactor And Its Components

- Reactor is the part of nuclear power plant where nuclear fuel is subjected to nuclear fission and the energy released in the process is utilized to heat the coolant which may in turn generate steam.

- The main function of the reactor is to control the emission and absorption of neutrons.

- The main parts of reactor are Reactor core, Moderator, Control rods, Coolant, Reflector, Thermal Shielding, Reactor vessel, Biological shield.

Components of Nuclear Plant Layout (contd.)

❑ Heat Exchanger

- Coolant gives up heat to the heat exchanger which is utilized in raising the steam.
- After giving up the heat, the coolant is again fed to the reactor.

❑ Steam Turbine

- Produce mechanical energy.
- The steam produced in the heat exchanger is led to the steam turbine through a valve.
- After doing a useful work in a turbine , a steam is exhausted to condenser.

Components of Nuclear Plant Layout (contd.)

❑ Alternator

- The steam turbine drives the alternator which converts mechanical energy into electrical energy.

- The output from the alternator is delivered to the busbar through transformer, Circuit breaker & isolators.

Power Reactors in use

❑ Boiling Water Reactor (BWR)

- The boiling water reactor (BWR) is a type of light water nuclear reactor used for the generation of electrical power.
- The BWR reactor core heats water, which turns to steam and then drives a steam turbine.
- No separate heat exchanger.

Power Reactors in use

❑ Boiling Water Reactor (contd.)

- This is the simplest type of water reactor.
- It has a steel pressure vessel surrounded by a concrete shield.
- Fuel used is enriched uranium oxide.
- Ordinary water is used both as moderator and coolant.
- The steam is generated in reactor itself.

Power Reactors in use

❑ Boiling Water Reactor (contd.)

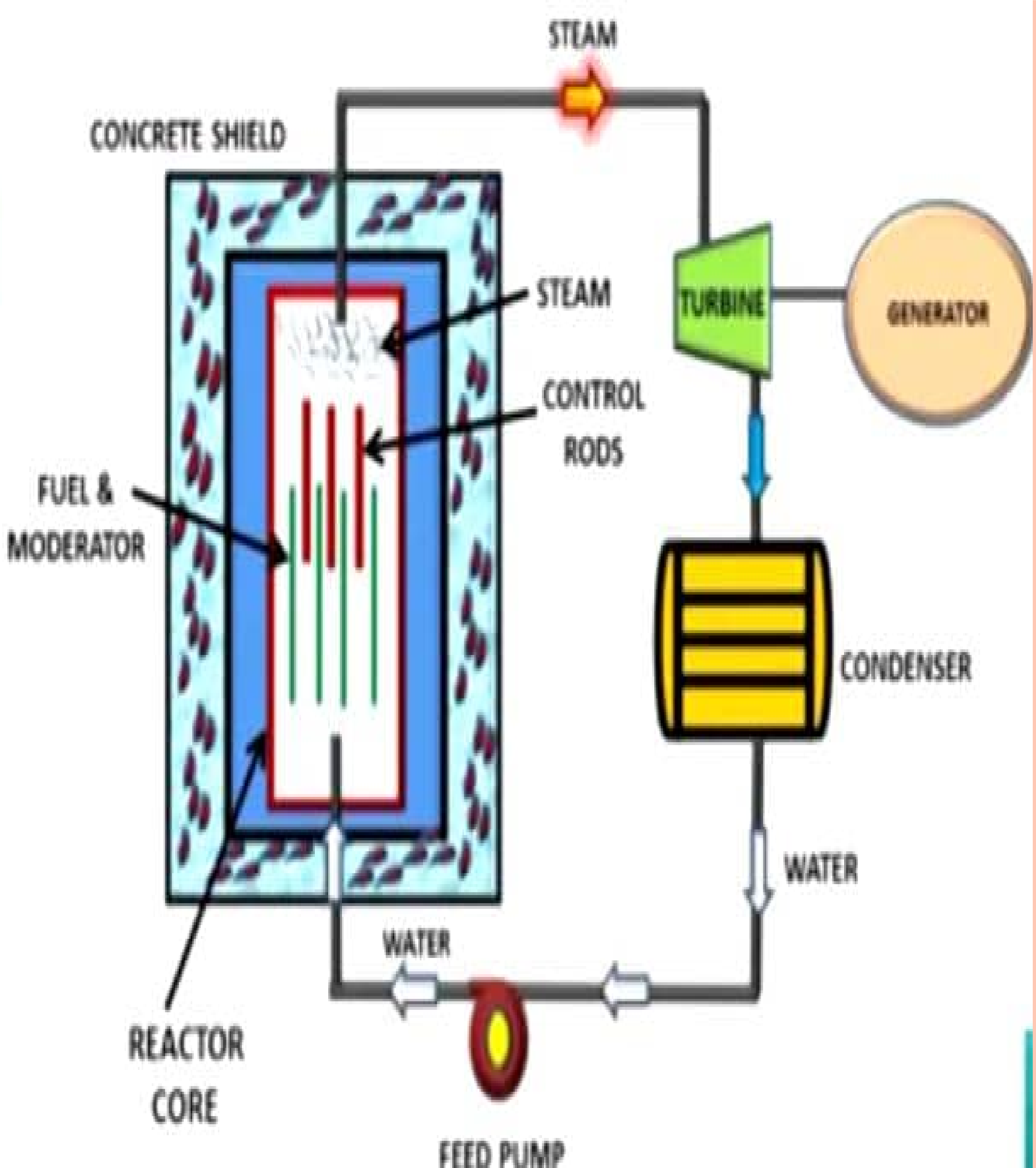
- Feed water enters the reactor vessel at the bottom and takes the heat produced due to fission of fuel and gets converted into steam.

- This steam leaves the reactor at the top and after passing through turbine and condenser returns to the reactor.

- Uranium fuel elements are arranged in a particular lattice form inside the pressure vessel containing water.

- A BWR assembly comprises 90-100 fuel rods and there are up to 750 assemblies in a core holding up to 140 tonnes of uranium.

Boiling Water Reactor (BWR)



Power Reactors in use

Advantages of BWR

- It has small size pressure vessel
- It has high steam pressure
- Simple construction
- Less cost
- High thermal efficiency
- Elimination of heat exchanger resulting in reduction in cost & gain in thermal efficiency

Power Reactors in use

Disadvantages of BWR

- Its impossible to increase power for sudden load demand.
- In view of direct cycle, there is a danger of radioactive contamination of steam, therefore more safety measures are provided for piping and turbine.
- It cannot meet sudden increase in load.
- Because of the danger of small amounts of fissile materials passing through along with the coolant, more biological protection is needed.

Classification of Nuclear Reactors

- According to the applications
- According to the type of fission
- According to the type of fuel used
- According to the state of fuel
- According to the fuel cycle
- As per arrangement of fissile & fertile material
- According to the arrangement of fuel & the moderator
- On the basis of moderator material used
- Power reactors in common use
- On the basis of cooling system
- On basis of coolant used

Classification of Nuclear Reactors (contd.)

- According to the applications
  - ✓ Research & Development Reactors - These reactors are used for testing new reactor designs and research.
  - ✓ Production Reactors - converts fertile material & fissile material
  - ✓ Power Reactors - These reactors are used for generation of electrical energy

- According to the type of fission
  - ✓ Fast Reactors - Neutron kinetic energy 1 MeV or more
  - ✓ Slow Reactors - Neutron kinetic energy is less than 0.1 eV
  - ✓ Intermediate Reactors - Neutron kinetic energy is between 0.1 eV and 0.1 MeV

Classification of Nuclear Reactors (contd.)

- According to the fuel cycle
  - ✓ Burner Reactors (Thermal Reactor) - Designed for producing heat only without any recovery of converted fertile material.
  - ✓ Converter Reactors - Such reactors convert fertile material into fissile material different from the one initially fed into the reactor core.
  - ✓ Breeder Reactors - Such reactors convert fertile material into fissile material at a higher rate, which is similar top one initially supplied to the reactor core.

Classification of Nuclear Reactors (contd.)

- **As per arrangement of fissile & fertile material**
  - ✓ One region reactors - Fissile & fertile material are mixed
  - ✓ Two region reactors - Fissile & fertile material are separated

- **According to the arrangement of fuel & the moderator**
  - ✓ Homogeneous Reactors - Nuclear fuel and moderator represent uniform mixture in the fluid form, including gases, liquids and slurries (mixture of an insoluble substance, as cement, clay with liquid).
  - ✓ Heterogeneous Reactors - Separate fuel rods are inserted in the moderator in some sort of regular arrangement forming a so called lattice.

Classification of Nuclear Reactors (contd.)

- On the basis of moderator material used
  - ✓ Graphite Reactors
  - ✓ Heavy water Reactors
  - ✓ Ordinary water Reactors
  - ✓ Beryllium Reactors
  - ✓ Organic Reactors

- According to the type of fuel used
  - ✓ Natural Uranium Reactors
  - ✓ Enriched Uranium Reactors
  - ✓ Plutonium Reactors

Classification of Nuclear Reactors (contd.)

- Power reactors in common use
  - ✓ Boiling Water Reactors (BWR)
  - ✓ Pressurized Water Reactors (PWR)
  - ✓ Gas cooled Reactors
  - ✓ Heavy Water Cooled & Moderated (CANDU Type) Reactors
  - ✓ Liquid Metal Cooled Reactors
  - ✓ Fast Breeder Reactors

- According to the state of fuel
  - ✓ Solid Reactors
  - ✓ Liquid Reactors

Classification of Nuclear Reactors (contd.)

- On the basis of cooling system
  - ✓ Direct Reactors -The liquid fuel circulated from the reactor to heat exchanger where steam is generated.
  - ✓ Indirect Reactors - Coolant passed through the reactor and then through the heat exchanger for steam generation

- On basis of coolant used
  - ✓ Gas
  - ✓ Water
  - ✓ Heavy Water
  - ✓ Liquid Metal Reactors

Power Reactors in use

❑ Pressurized Water Reactor (PWR)

- Pressurized water reactors (PWRs) constitute the large majority of the world's nuclear power plants.

- In a PWR, the primary coolant (water) is pumped under high pressure to the reactor core where it is heated by the energy released by the fission of atoms.

- Enriched uranium is used as nuclear fuel.

Power Reactors in use

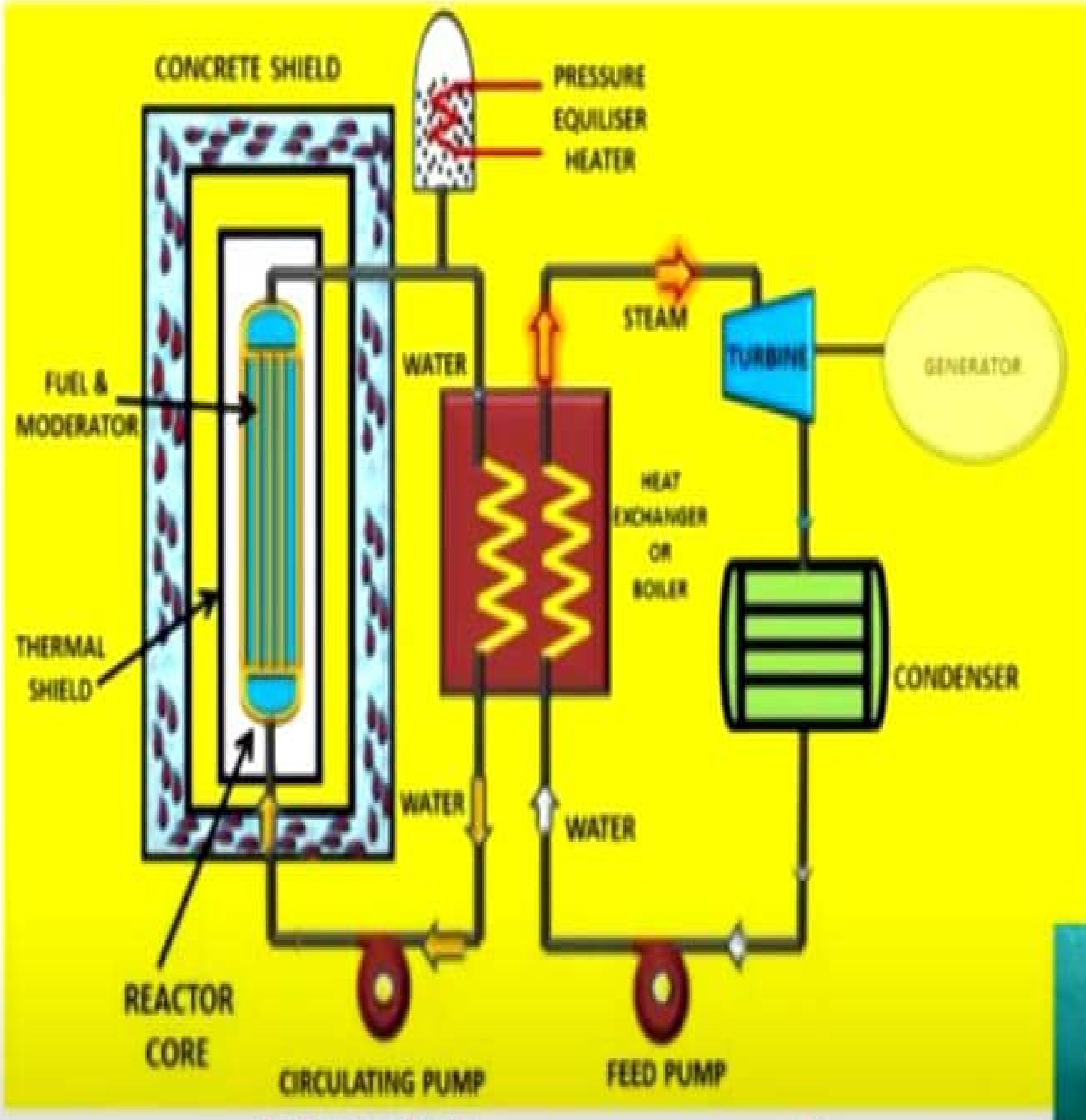
❑ Pressurized Water Reactor (contd.)

- The secondary circuit consists of water at high pressure in the gaseous state.

- In secondary circuit, generated steam is used to run the turbine-alternator arrangement.

- The point of interaction between these two circuits is the heat exchanger (or) the boiler wherein heat from the superheated high pressure water converts the water in the secondary circuit to steam.

Pressurized Water Reactor (PWR)



Power Reactors in use

Advantages of PWR

- Since the two circuits are independent of each other, it makes very easy for the maintenance staff to inspect the components of the secondary circuit without having to shut down the power plant entirely.

- A PWR has got a high power density and this, combined with the fact that enriched Uranium is used as fuel instead of normal Uranium, leads to the construction of very compact core size for a given power output.

- Much fewer control rods are required in a PWR. In fact for a typical 1000 MW plant just around 5 dozen control rods are sufficient. Water can be used as coolant and moderator. Possibility of breeding plutonium.

Power Reactors in use

Disadvantages of PWR

- The primary circuit consists of high temperature, high pressure water which accelerates corrosion. This means that the pressure vessel should be constructed of very strong material such as stainless steel which adds to construction costs of PWR.

- The pressure in the secondary circuit is relatively quite low as compared to the primary circuit hence the thermodynamic efficiency of PWR reactors is quite low.

- High losses from heat exchanger. Formation of low temperature steam (250 C). High power consumption by auxiliaries.

Breeder Reactors

- Reactors which are designed so that breeding will take place is known as breeder reactor.

- Breeder reactors are capable of producing more fissile material.

- Fissile material can produce from the fuel itself.

- These fissile materials can consume during fission.

- High efficient fuel consumption. Less fuel consumption.

Breeder Reactors (contd.)

- A breeder reactor is a nuclear reactor capable of generating more fissile material than it consumes.

- In breeder reactor, maximum amount of Uranium will be burnt.

- These devices are able to achieve this feat because their neutron economy is high enough to breed more fissile fuel than they use from fertile material like uranium-238 (or) thorium-232.

- Breeders were at first considered attractive because of their superior fuel economy compared to other nuclear reactors.

Breeder Reactors (contd.)

- Fast breeders do not require moderation since the neutrons need to be moving fast, whereas thermal breeders make us of moderation to achieve slower-moving neutrons.

- Fuel can be recycled in the breeder reactor. Increase the fuel efficiency. Largest breeder reactor – super phoenix in France.

- Types of Breeder Reactors
  - Liquid Metal Cooled Fast Breeder Reactor
  - Gas Cooled Fast Breeder Reactor
  - Molten Salt Breeder Reactor
  - Light Water Breeder Reactor

Power Reactors in use

Gas Cooled Reactors (GCR)

- These type of reactors uses gas (CO_2 or helium) in place of water as coolant and graphite as moderator. The advantage of using gas as coolant is that it is safe, easy to handle and it can be heated up to any temperature without change of phase at any pressure. This reactor uses Uranium dioxide as fuel.

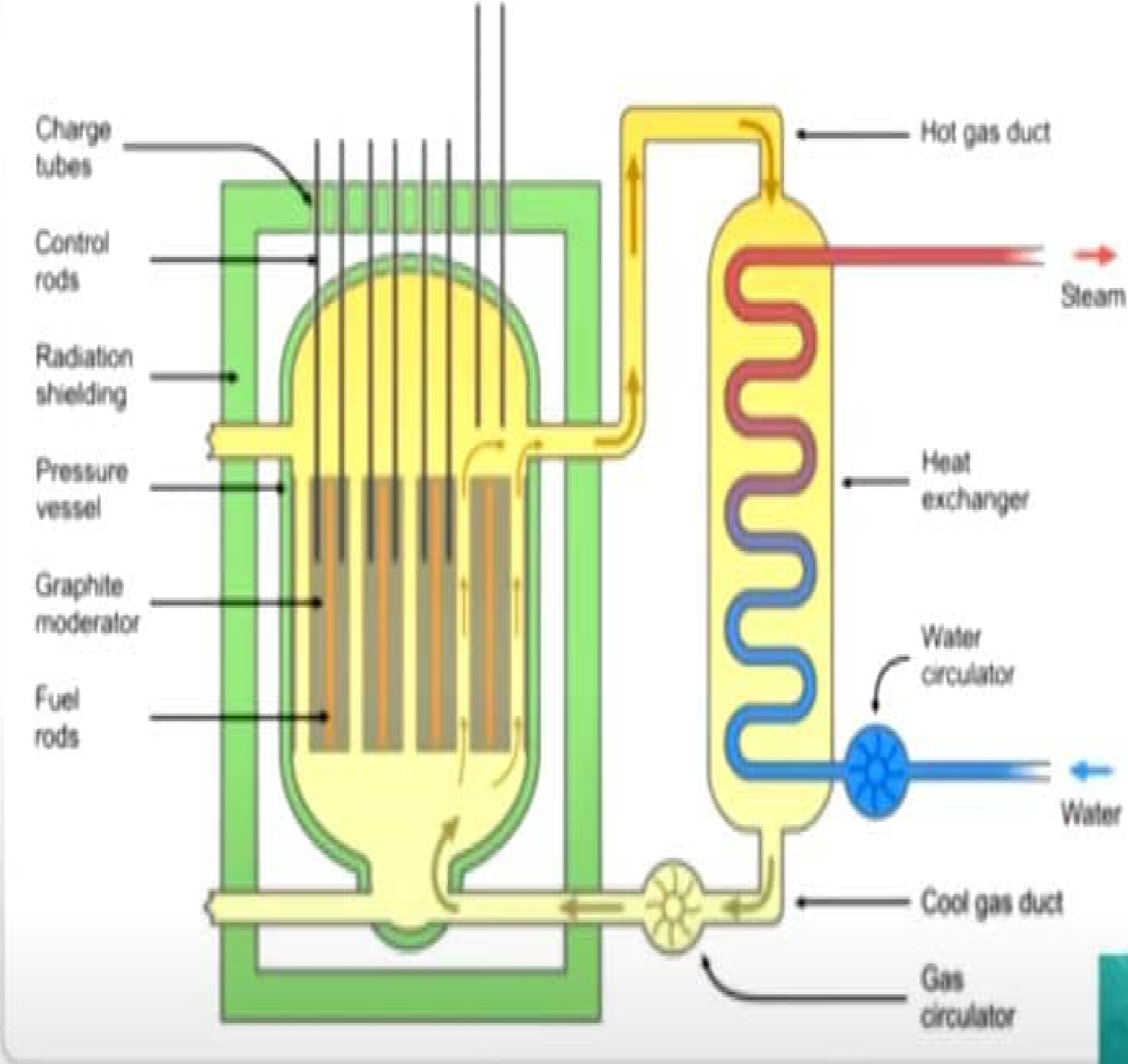
- A concrete shield covers up the core to avoid radiation leak, and all the essential components are contained in a pressure vessel, in which there are four bars of uranium fuel elements wrapped by graphite moderators, with a number of charge tubes sticking into them in order to load fuel elements.

Power Reactors in use

Gas Cooled Reactors (contd.)

- Two ducts run out of the reactor to form a gas duct circle with the heat exchanger. A heat exchanger is necessarily required.
- Gas is circulated through the reactor core and the heat exchanger by means of a blower (or) gas compressor.
- The steam pressure is around 150 atmosphere and temperature around 550 C.
- The tubes in the heat exchanger through which water is circulated should have fins on their surface so as to improve the rate of heat transfer.

Gas Cooled Reactors (GCR)



Power Reactors in use

Advantages of Gas Cooled Reactors

- It has no corrosion problems.
- Greater safety in comparison with water cooled reactors, because gases are easy to handle.
- Contamination problems are moderate.
- These can be operated at high temperatures.
- Gases can be pressurized easily.
- Graphite remains stable at high temperatures and radiation problems are minimum.

Power Reactors in use

Disadvantages of Gas Cooled Reactors

- Relatively large size of reactor because of use of natural fuel and graphite moderator.
- Extremely low power density.
- Low steam pressure and temperature.
- Fuels have to be operated at high temperatures.
- If helium is used in the case of an HTGC reactor, leakage is a major problem.
- Gases have a lower heat transfer coefficient thus it requires large heat exchangers.
- A large amount of fuel loading is required.
- More power is needed for coolant circulation compared to water cooled reactors.

Heavy Water Cooled and Moderated Reactors (CANDU Type Reactors)

- It is also called as Pressurized Heavy Water Reactor (PHWR). The word CANDU stands for Canadian Deuterium Uranium.

- The CANDU reactor was designed by Atomic Energy Canada Limited (AECL) as an alternative to other reactor designs which use slightly enriched uranium (2-5% U-235).

- The CANDU allows more local input that do not have the capability to cast a pressure vessel.

- The CANDU fuel contains uranium dioxide with natural uranium (0.7% U-235). As a result, the CANDU is cheaper to fuel and can theoretically give higher lifetime capacity factors.

Heavy Water Cooled and Moderated Reactors
(CANDU Type Reactors)

- The heavy water coolant is kept under pressure, allowing it to be heated to higher temperatures without boiling, much as in a typical pressurized water reactor.

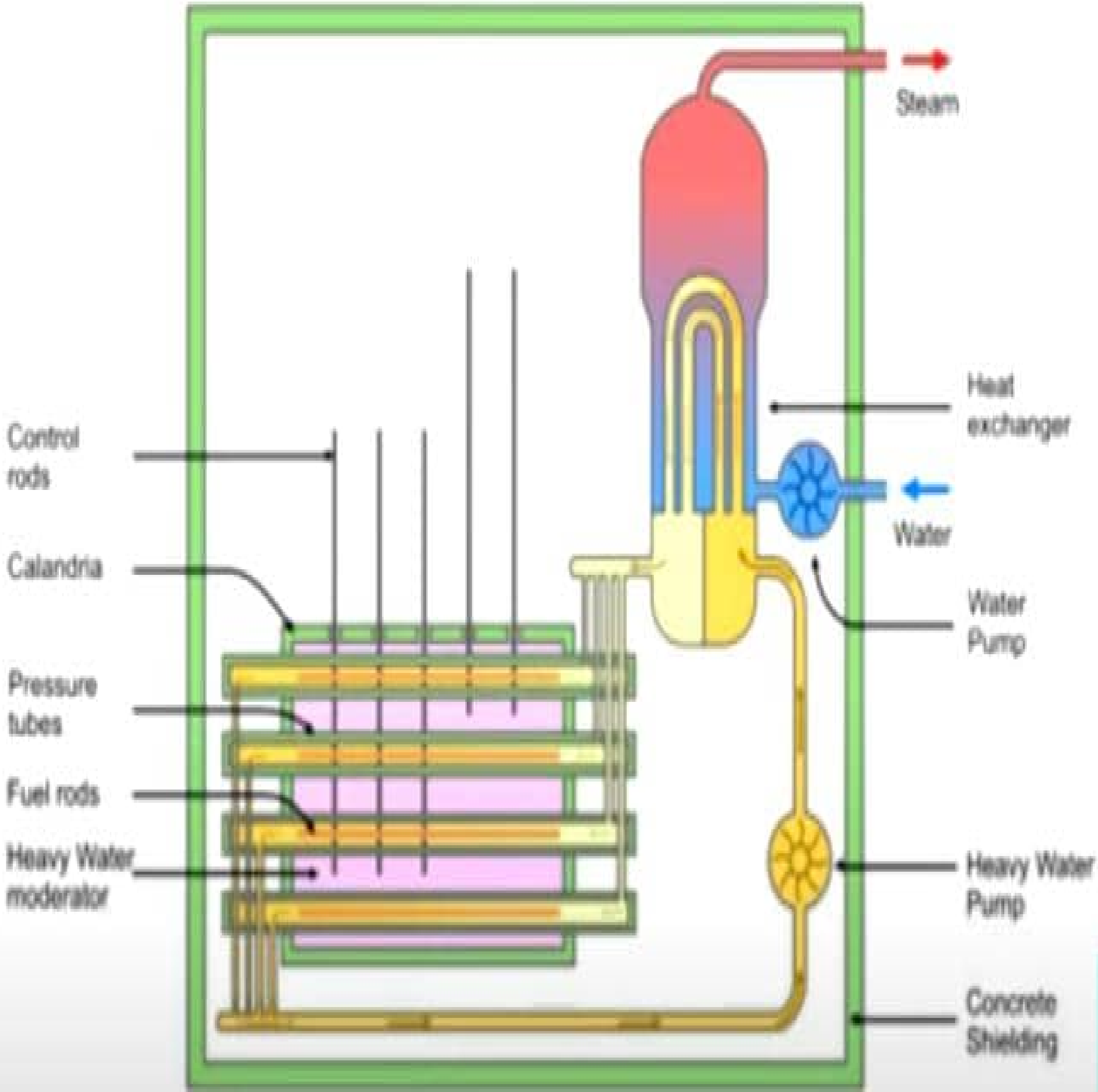
- While heavy water is significantly more expensive than ordinary light water, it yields greatly enhanced neutron economy, allowing the reactor to operate without fuel enrichment facilities (mitigating the additional capital cost of the heavy water) and generally enhancing the ability of the reactor to efficiently make use of alternate fuel cycles.

- It is used in countries where enriched uranium is not available.

Heavy Water Cooled and Moderated Reactors (CANDU Type Reactors)

- The primary and secondary circuits are similar to PWR.
- The coolant heavy water is circulated in the primary circuit and the steam is produced in secondary circuit transferring the heat in the heat exchanger.
- As in the case of the pressurized water reactor, reactor cooling pumps circulate heavy water through the reactor then to the steam generators in a closed loop.
- The moderator heavy water system has a separate heat exchanger with circulation system for cooling the moderator.

Heavy Water Cooled and Moderated (CANDU Type) Reactors)



Heavy Water Cooled and Moderated Reactors

(CANDU Type Reactors)

Advantages

- Simpler reactor control because absence of fuel rods.
- Low fuel consumption
- No Control Rods
- Low pressure vessel is used
- More effective in slowing down the neutrons because moderator being at low temperature

Disadvantages

- Heavy cost of heavy water
- Very high standard design
- There is no problem of leakage, therefore a proper safety design is needed

Liquid Metal Cooled Reactors (LMCR) or Sodium Graphite Reactors (SGR)

- Sodium-Graphite Reactor (SGR) is one of the typical liquid metal reactors.

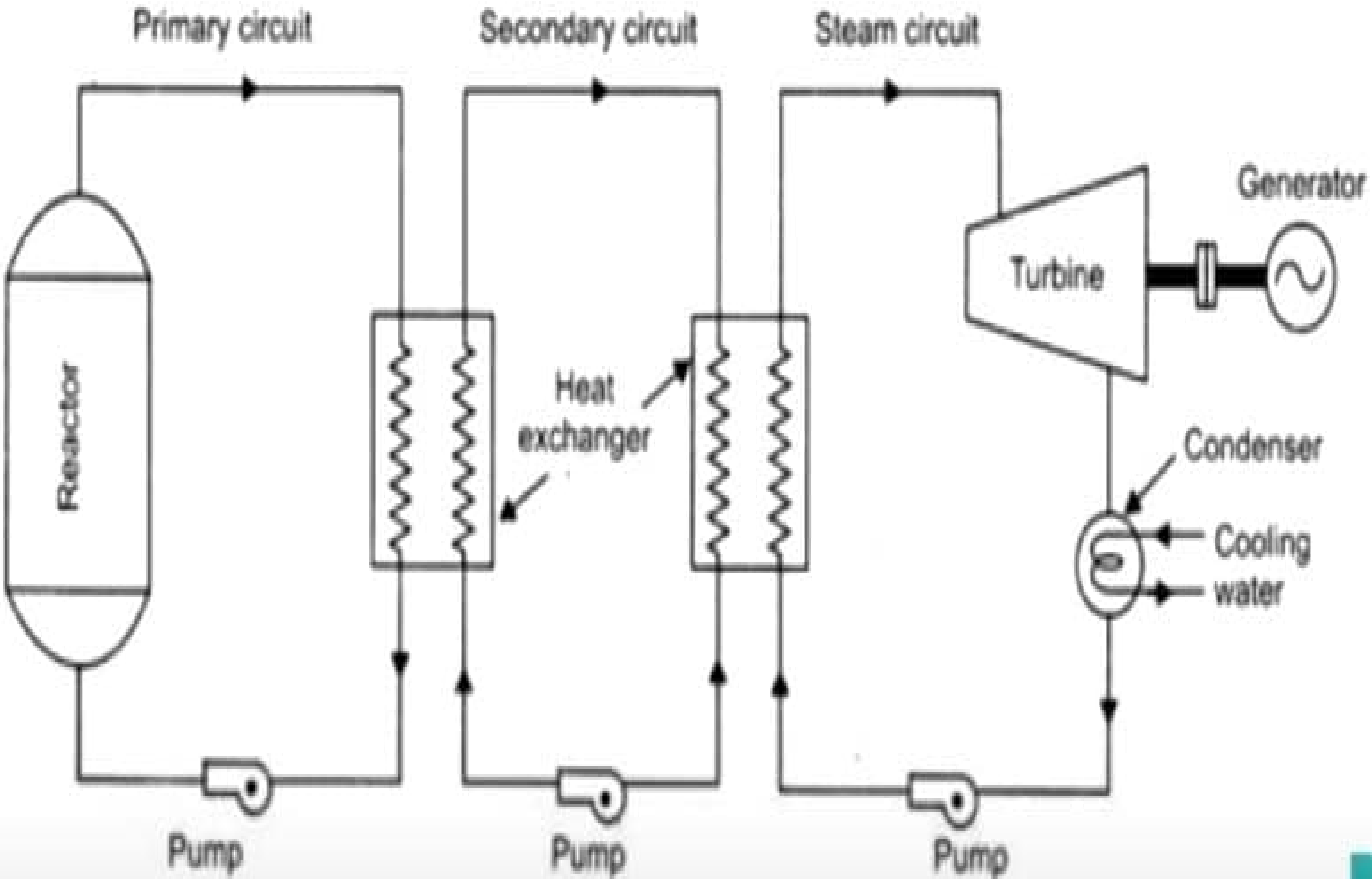
- In this reactor, sodium works as a coolant and graphite works as moderator.

- Here, sodium (Na) is used as primary coolant and sodium potassium (NaK) is used as secondary coolant.

- By using sodium as a primary coolant more electric energy can be produced.

- Because of low pressure in the primary and secondary coolant circuits. inexpensive pressure vessels can be used.

Diagram of Liquid Metal Cooled Reactors



Liquid Metal Cooled Reactors (contd.)

- Sodium boils at 880°C under atmospheric pressure and freezes at 95°C.

- Hence sodium is first melted by electric heating system and is pressurised to about 7 bar. The liquid sodium is then circulated by the circulation pump.

- At high temperatures sodium becomes radioactive and reacts with water. That's why a Intermediate Heat Exchanger (IHX) is used.

- It transfers heat from Sodium to the secondary coolant NaK . This coolant goes to the steam generator heats the feed water to produce steam.

Liquid Metal Cooled Reactors (contd.)

- The reactor will have two coolant circuits (or) loops:

(i) The primary circuit has liquid sodium which circulates through the fuel core and gets heated by the fissioning of the fuel.
This liquid sodium gets cooled in the intermediate heat exchanger and goes back to the reactor vessel.

(ii) The secondary circuit has an alloy of sodium and potassium in liquid form.
This coolant takes heat from the intermediate heat exchanger which gets heat from liquid sodium of primary circuit.
The liquid sodium-potassium then passes through a boiler which is once through type having tubes only.

Liquid Metal Cooled Reactors (contd.)

- The liquid metal be handled under the cover of an inert gas, such as helium, to prevent contact with air while charging (or) draining the primary (or) secondary circuit/loop.

Advantages

- The high temperature of the steam can be obtained due to the use of liquid sodium as a coolant.
- Thermal efficiency is high.
- The system need not to be pressurized.
- The cost of the pressure vessel and piping system is reduced due to the use of low-pressure sodium in the primary circuit.

Liquid Metal Cooled Reactors (contd.)

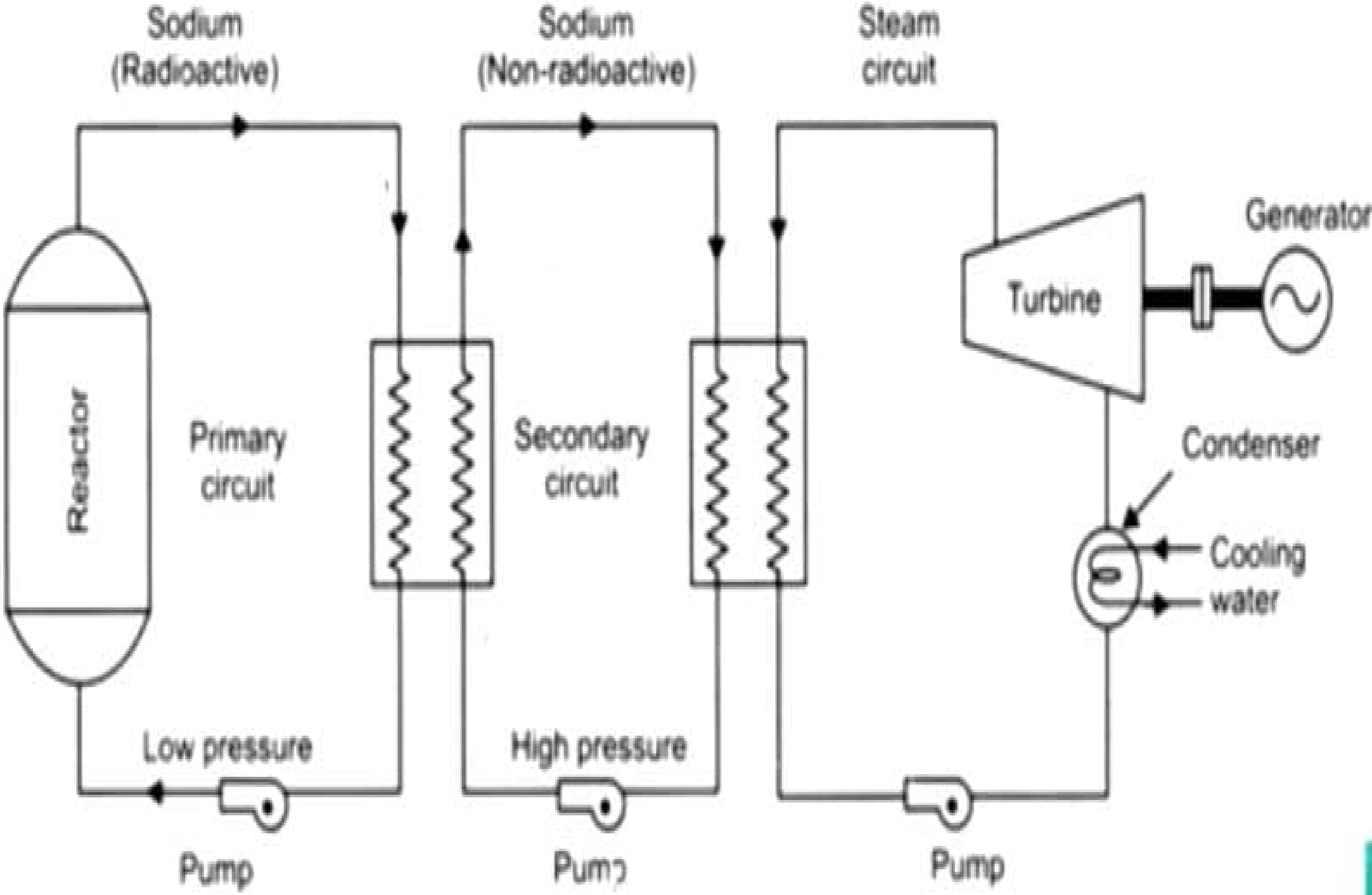
❑ Disadvantages

- Any leakage of sodium coolant is highly dangerous.
- Sodium is highly violent with air and water.
- Primary and secondary heat exchangers are needed to be shielded with concrete blocks against radiations.
- An intermediate heat exchanger is required to separate radioactive sodium with water and steam.

Fast Breeder Reactors (FBR) or Liquid Metal Fast Breeder Reactors (LMFBR)

- The most promising type of breeder reactor is the Liquid Metal Fast Breeder Reactor (LMFBR).
- This reactor is not only produce heat but also produce more secondary fissile fuels like plutonium more than fuel consumed in the reactor. This is known as Breeding.
- In this reactor, moderator is not used. The primary fuel U-235 is surrounded by a blanket of fertile material.
- One additional neutron available from the fission of U-235 is used to convert U-238 or Th-232 converted into U-233 as secondary fuels.
- Fertile material like U-238 is kept there. Here, fast speed electrons are absorbed by U-238 which produces Pu-239.

Diagram of Fast Breeder Reactors



Fast Breeder Reactors (contd.)

❑ Advantages

- High energy neutrons used in reactor
- The average neutron yield of a fission caused by a fast neutron is greater than in thermal reactors.
- The absorption cross sections are low
- Conversion factor is high
- Moderator is not required
- The absorption of the neutron is slow.
- Secondary fissile material by breeding is obtained.
- A small core is sufficient since it gives high power density as compared to other reactors.

Fast Breeder Reactors (contd.)

❑ Disadvantages

- It requires enriched uranium as fuel.
- The neutron flux is high at the center of the core.
- Thick shielding is necessary against radioactive radiations in primary and secondary circuits as in the case of sodium graphite reactors.

Effects of Nuclear Power Plants

- In nuclear power stations, the combustion fuel is low.
- Harmful effluents from such power stations in the atmosphere are too small.
- However, isotopes formed in nuclear power reactors have a high toxicity and their effect on living organisms may gradually increase.
- That is why, the problems of disposal, transport and storage of liquid radioactive waste are more significant.
- A nuclear reactor produces α rays, β rays, γ rays and neutrons which can disturb normal working of living organisms
- α rays are heavy particles carrying positive charge and can internal hazard.

Effects of Nuclear Power Plants (contd.)

- β rays have greater penetrating power, as compared to α rays due to smaller size. Over expose, they may cause skin problems.
- γ rays are electromagnetic radiations of very short wave length, have high energy and are very penetrating, they cause damage to organic materials.
- The biological effects of nuclear radiation depends on
  - Amount of dose absorbed
  - Time duration of exposure
  - Sensitivity and recovery of recipient organism
  - Distribution of active material within body.
- Nuclear power stations are surrounded by a sanitary protective zone to minimize the risk of irradiation of population within such zone.

Effects of Nuclear Power Plants (contd.)

- The first source is fission of nuclei of solid (or) gaseous nuclear fuels.
- Gaseous fission fragments which move likely to enter the air include inert gases, such as Xenon, Krypton etc and radioactive iodine.
- The second source is due to effort of neutron fluxes on the heat carrier in primary cooling system and on ambient air.
- Among the components of air, an inert gas, argon-40 is most prone to activation.
- The third source is damage of shells of fuel elements or in the presence of activated inert gases and aerosols in heat carrier leakages.

Disposal of Nuclear Waste and Effluent (contd.)

- Sometimes, suitable containers are filled with radioactive waste and sunk to the bottom of seas and oceans.

- Another way of disposal is the separation and transmutation of the long lived isotopes to short-lived or stable products following neutron absorption in a breeder or fusion reactor.

- It is safe enough to store radioactive waste underground in liquid form in suitable tanks or in reduction to clinker (Stony residue).

- Clinkering serves a two fold purpose of improving the protection and reducing the volume of waste.

Shielding

- Adequate shielding is necessary to guard personnel and delicate instruments.

- The various materials used for shielding are lead, concrete, steel and cadmium.
  - Lead is a common shielding material, has high density and is invariably employed due to its low cost.
  - Concrete is another shielding material having efficiency lesser than that of lead.
  - Steel is not an efficient shielding material but has good structural properties and is sometimes employed as an attenuating shield.
  - Cadmium is capable of absorbing slow neutrons by a nuclear reaction.

Shielding (contd.)

- No single material is effective in shielding against all types of radioactive radiations.

- A material containing hydrogen e.g. water or polythene is used to slow down fast neutrons

- Boron (or) Steel is employed for absorption of thermal neutrons.

- A heavy material like lead is required to act as a thermal shield and absorb gamma rays.

Shielding (contd.)

- In nuclear power reactors, a thermal shield of thickness of several cm of steel surrounded by about 3 m thick concrete is used.

- Water, in concrete, slows down fast neutrons.

- Iron, Barium or Steel turnings are mixed in concrete to attenuate gamma rays and absorb thermal neutrons.

- The effectiveness of a shielding material depends mostly on the density of the material.