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Power Generation and Economics (15EE361) (PGE)

Module-3

Nuclear Power Plants

* Introduction :

- A generating station in which nuclear energy is converted into electrical energy is known as a nuclear power station.
- In nuclear power station, heavy elements such as Uranium (U^{235}) or Thorium (Th^{232}) are subjected to nuclear fission in a special apparatus known as reactor. The heat energy thus released is utilised in raising steam at high temperature & pressure. The steam runs the steam turbine which converts steam energy into mechanical energy. The turbine drives the alternator which converts mechanical energy into electrical energy.
- The most important feature of a nuclear power station is that huge amount of electrical energy can be produced from relatively small amount of nuclear fuel as compared to other conventional types of power plants. It has been found that complete fission of 1kg of Uranium (U^{235}) can produce as much energy as can be produced by burning of 4500 tonnes of high grade coal. Although the recovery of principal nuclear fuels (i.e Uranium & Thorium) is difficult & expensive, yet the total energy content of the of the estimated world reserves of these fuels are considerably higher than those of conventional fuels, viz, coal, oil & gas. At present energy crisis is gripping up and, therefore, nuclear energy can be successfully employed for producing low cost ~~cost~~ electrical energy on a large scale to meet growing commercial & industrial demands.

* Economics of Nuclear power plants :

- Nuclear power is cost competitive with other forms of electricity generation, except in regions where there is direct access to low-cost fossil fuels.
- The decreasing cost of fossil fuels in the past decade has eroded nuclear power's previous cost advantage in many countries.
- Fuel costs for nuclear plants are a minor proportion of total generating costs & often about one-third those for coal-fired plants.
- In accessing the cost competitiveness of nuclear energy, decommissioning & waste disposal costs are taken into account.

The relative costs of generating electricity from coal, gas & nuclear plants ~~are~~ vary considerably depending on location. Coal is, and will probably remain, economically attractive in countries such as India, USA and Australia with abundant and accessible domestic coal resources. Gas is also competitive for base-load ~~plants~~ power in many places, particularly with combine cycle plants. Nuclear energy is, in many places, competitive with fossil fuel for electricity generation, despite relatively high capital costs and the need to internalize all waste disposal & dicommissioning costs. If the social, health & environmental costs of fossil fuels are also taken into account, nuclear is outstanding. Nuclear energy averages 0.4 euro cents/kWh, much the same as hydro, coal is over 4.0 cents (4.1-7.3), gas ranges 1.3-2.3 cents and only wind shows up better than nuclear, at 0.1-0.2 cents/kWh average.

* Merits and Demerits of Nuclear Power Station:

Merits:

(i) The amount of fuel required is quite small. Therefore, there is a considerable saving in the cost of fuel ~~consumption~~ transportation.

(ii) A nuclear power plant requires less space as composed to any other type of the same size.

(iii) It has low running charges as a small amount of fuel is used for producing bulk electrical energy.

(iv) This type of plant is very economical for producing bulk electric power.

(v) It can be located near the load centres because it does not require large quantities of water & need not be near coal mines. Therefore cost of primary distribution is reduced.

(vi) There are large deposits of nuclear fuels available all over the world. Therefore such plants can ensure continued supply of electrical energy for thousands of years.

(vii) It ensures reliability of operation.

(viii) Very well suited for large power demands.

(ix) No atmospheric pollution as there is no combustible products.

(x) Generation of power is not affected by weather conditions.

(xi) These plants are neat & clean than other plants.

* Demerits of Nuclear power station :

(i) The fuel used is expensive and is difficult to recover.
(ii) The capital cost on nuclear plant is very high as compared to other type of plants
(iii) The erection & commissioning of the plant requires greater technical know-how.
(iv) The fission-by products are generally radiactive and may cause dangerous amount of radiactive pollution.
(v) Maintenance charges are high due to lack of standardisation. Moreover high salaries of specially trained personnel employed to handle the plant further raise the cost.
(vi) Nuclear power plants are not well suited for varying loads as the reactor does not respond to load fluctuations efficiently.
(vii) The disposal of the by-products, which are radioactive, is a big problem. They have either to be disposed off in a deep trench or in a deep sea away from sea-shore.
(viii) Failure of controls may lead to nuclear explosion.

* Selection of site for Nuclear Power Plant :

There are several factors, which are considered in selecting the site for nuclear power station. The selection of site is similar to the thermal power station as water is used as working fluid i.e steam.

(1) Availability of water : As in the case of steam power stations, nuclear power stations also requires ample amount of water for cooling & steam generation.
(2) Disposal of waste : It is one of the very important considerations in the nuclear power station due to dangerous waste/residue of the nuclear substances. Hence an extra care is needed in this respect. The storage of waste, which is to be disposed deep under the ground in sea so that radioactive effect is eliminated.
(3) Away from populated area : Although there is always tight safety but still there are chances of radioactive radiation, which affects the health of people. Therefore it must be away from the populated areas.
(4) Nearest to the load centres : Since the transportation & storage requirements are less compared to the coal fired plants. It is preferred to construct the nuclear power plant near the load centres so that transportation of energy at minimum cost can be achieved.

Accessibility by rail and road : Accessibility to the road and rail are the general consideration of almost all the power plants as heavy equipments are to be transported to the sites during the construction. The fuels are also required to transport from the mines during the operation.

* Nuclear Reaction : Nuclear fission Process, Nuclear chain Reaction :

- Types : There are four types of nuclear reactions taking place in nature. These are ① Inelastic scattering ② Elastic Scattering ③ Neutron Capture ④ fission.
- The last reaction (fission) is the most important from nuclear power engineering. This type of reaction possible only with heavy nuclei such as $^{232}_{92}U$, $^{235}_{92}U$ and $^{239}_{94}Pu$. The nuclei produced after reaction are lighter than original nuclei & since they are now having more binding energies per nucleon they release the energy. This release of energy is due to the increase of mass defect of the lighter nuclei.
- We may say that as a result of fission the target nucleus absorbs thermalised (slow neutron) and becomes highly excited. Therefore it splits into two different masses. The product masses will also be in excited state and they will try to become stable by emmitting neutrons.

Methods of producing nuclear reaction : There are a number of methods of starting a nuclear reaction. In one method neutrons are used as bombarding particles. The main advantage of neutrons is that they are neutral (having no charge) and therefore they can make their own way through the shells of electrons & then through the nucleus even at low energy. This is the practical method used in almost all modern fission reactors. Neutrons can be produced in a number of ways.

Chain Reaction : Neutral Uranium occurs in three isotopes, U-238 (99.3%), U-235 (0.7%) and U-234 (minute traces). Of these isotopes U-235 is very easily and readily fissionable. If a neutron enters a U-235 atom there is a probability that the nucleus will split and release the enormous amount of energy that binds the nucleus together. This will generate heat in the mass of the Uranium. Each fissioned nucleus ejects two or three neutrons which can again hit Uranium nuclei & accelerate the splitting process even if some of the neutrons are not fully absorbed. This reaction is known as Chain reaction.

Materials fissionable by thermal or low-speed neutrons are U-233, U-235, Pu-239 (plutonium).

Fertile Materials : There are some materials which are not fertile but can be converted to fissile materials. These are known as fertile materials. Pu-239 & U-233 are not found in nature but U-238 & Th-232 can ~~provide~~ produce them by nuclear reactions. When U-238 is bombarded with slow neutrons it produces $^{239}_{92}U$ (with half life of 23.5 minutes) which is unstable & undergoes two beta disintegrations. The resultant $^{239}_{94}Pu$ has half life of 2.44×10^{4} years & is a good alpha emitter. Thus

$$^{238}_{92}U + ^{1}_{0}n \rightarrow ^{239}_{92}U + \gamma$$

$$^{239}_{92}U + ^{0}_{-1}e \rightarrow ^{239}_{93}Np$$

$$^{239}_{93}Np + ^{0}_{-1}e \rightarrow ^{239}_{94}Pu$$

During conversion the above noted reactions will takes place. The other isotopes of neptunium such as 2.1 day Np-238 and plutonium can also be produced by the bombardment of heavy particles accelerated by the cyclotron.

The nuclear transformations to convert $^{232}_{90}Th$ to U-233 are expressed as under

$$^{232}_{90}Th + ^{1}_{0}n \rightarrow ^{233}_{90}Th + \gamma$$

$$^{233}_{90}Th + ^{0}_{-1}e \rightarrow ^{233}_{91}Pa$$

$$^{233}_{91}Pa + ^{0}_{-1}e \rightarrow ^{233}_{92}U$$

U-235 isotope of uranium is the source of neutrons required to derive Pu-239 and U-233 and U-238 & Th-232 respectively. This process of conversion is performed in the breeder reactors.

* Nuclear Energy :

In nuclear physics the energy is expressed in Mega electron volt (MeV) & mass is in atomic mass unit (amu). One electron volt is the energy gained by an electron passing through the potential difference of one voltage. Since the charge of electron is 1.602×10^{-19} C.

$$1\,eV = 1.602\times10^{-19}\ \text{Joule}$$

$$1\,MeV = 10^{6}\times1.602\times10^{-19} = 1.602\times10^{-13}\ J$$

According to Einstein Mass-Energy relation ($E = MC^2$, where m is mass in Kg, E is Energy in joules & C is the velocity of light in metre/second), the energy corresponding to 1 amu is ($= 1.66 \times 10^{-27}$ Kg) will be as follows.

$$1 \text{ amu} = 1.66 \times 10^{-27} \times (3 \times 10^8)^2 = 1.494 \times 10^{-10} J$$

$$1 \text{ amu} = \frac{1.494 \times 10^{-10}}{1.602 \times 10^{-13}} \text{ Mev} = 931 \text{ Mev}$$

The sum of masses of the protons and neutrons exceeds the mass of the atomic nucleus. This difference in mass is called as Mass defect. The ~~ne~~ energy associated with the mass defect is known as the binding energy of the nucleus, which is a direct measure of nuclear stability. The energy can be released in two ways:

1. By Combining the light nucleus and the energy released, known as Fusion.
2. By breaking the heavy nucleus and the energy released, known as Fission

Fission is most widely used in nuclear power stations. The materials fissionable by thermal or low speed neutrons are $_{92}U^{233}$, $_{92}U^{235}$ & $_{94}Pu^{239}$

* Nuclear Fuels :

- The ~~energy to~~ Fuels mainly used are natural uranium (0.7% U-235), Enriched Uranium, Plutonium (Secondary fuel) and U-233 (Secondary fuel available from breeder reactor), Natural uranium is the parent material
- In order to use a naturally occurring uranium as fuel, it must go through the purification process.

* The materials U-235, U-233 and Pu-239 are called fissionable materials. The fissionable nuclear fuel occurring in nature is uranium, of which 99.3% is $^{238}_{92}U$ and 0.7% is $^{235}_{92}U$ and $^{234}_{92}U$ is only a trace amount, out of these isotopes only $^{235}_{92}U$ cause fission in a chain reaction.

* Fissionable materials $^{239}_{94}Pu$ and $^{233}_{92}U$ are formed in the nuclear reactors during fission process from $^{238}_{92}U$ and $^{232}_{90}Th$ respectively due to absorption of neutrons without fission.

16, 43, 45, 61, 63, 64,

The process is given as below.

$$^{238}_{92}U + ^{1}_{0}n \longrightarrow ^{239}_{92}U + \gamma$$

$$^{239}_{92}U \longrightarrow ^{239}_{93}Np + ^{0}_{-1}e$$

$$^{239}_{93}U \longrightarrow ^{239}_{94}U + ^{0}_{-1}e$$

The above process is called conversion. Absorption of a neutron by U-238 produces U-239, which is unstable with life period of 23 minutes and decays into neptunium with emission of an electron.

^{239}Np which has half life period of 2.3 days & transformed into Pu-239 which is long life fissionable isotope of plutonium.

Fissionable U-233 is produced in the following way

$$^{232}_{90}Th + ^{1}_{0}n \rightarrow ^{233}_{90}Th + \gamma$$

$$^{233}_{90}Th \xrightarrow{23.3\,min} ^{233}_{91}Pa + ^{0}_{-1}e$$

$$^{233}_{91}Pa \xrightarrow{27.4\,day} ^{233}_{92}U + ^{0}_{-1}e$$ process is known as breeding.

* Nuclear power plant layout

The concept of Nuclear power generation is much more similar to that of the conventional steam power generation. The difference are in the steam power plant, coal or oil burning furnace is replaced by the nuclear reactor and heat exchanger in nuclear power plant.

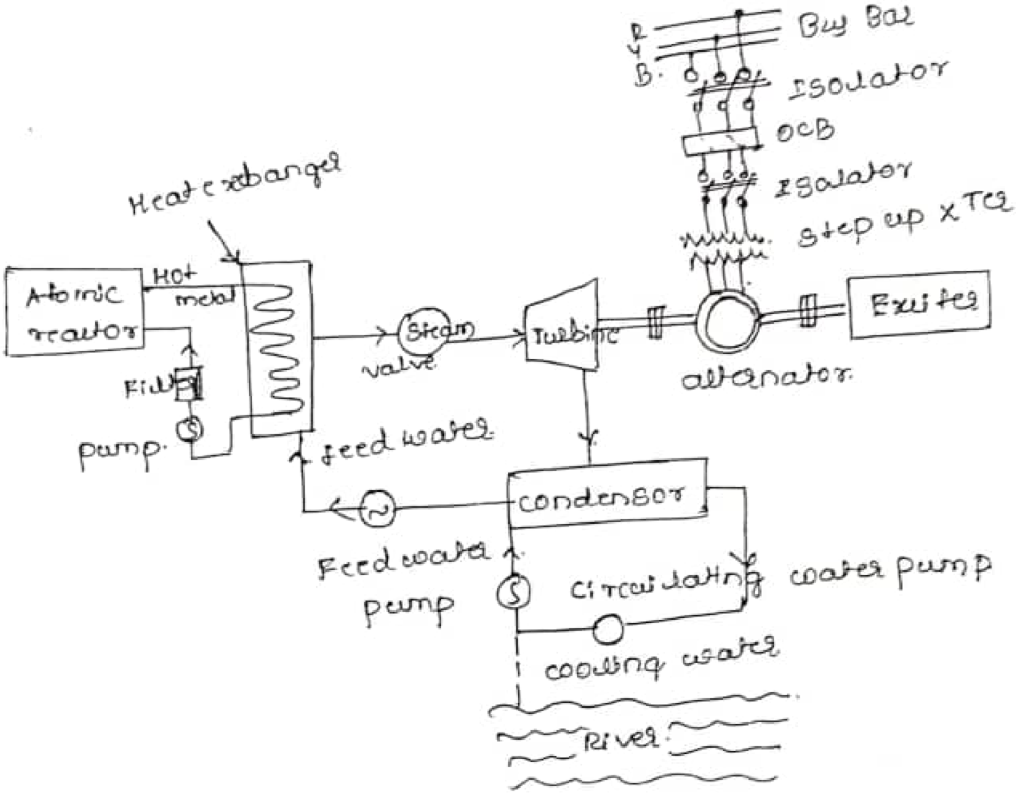

fig- Schematic arrangement of Nuclear power plant.

The schematic arrangement of Nuclear power plant is as shown in the above fig., A nuclear power plant consists of Nuclear reactor, Heat exchanger, Steam turbine, alternator, condensor, water pumps etc.

* The large amount of heat energy is produced in breaking of atoms of uranium or other similar metals of large atomic weight into metal of lower atomic weight by fission process in a atomic reactor.
* Now the generated heat energy is extracted by pumping fluid or molten metal like liquid Sodium or gas through the pipe.
* The Hot metal or gas is then allowed to exchange its heat with the help of Heat exchanger as shown

above In heat exchanger the gas is heated or Steam is generated which is used to drive gas or Steam turbine coupled to the alternator, thereby generating electrical energy.

* While deciding the layout of nuclear power plant, care must be taken that, the operation of plant must be safe, operating convenience & capital economy.

* Nuclear reactor & its control.

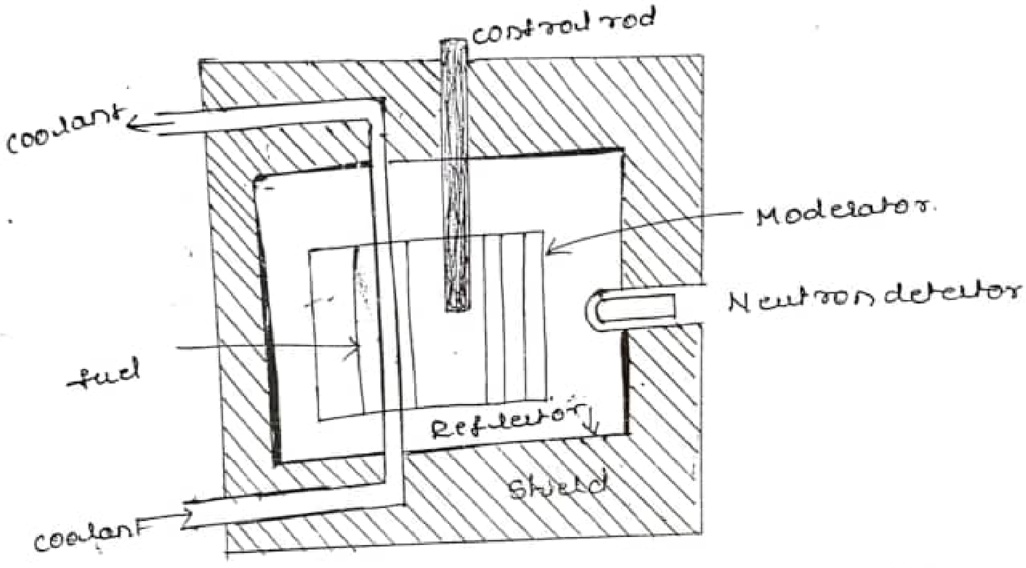

fig a. Basic components of a Nuclear reactor.

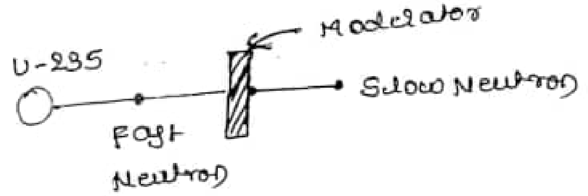

fig-b) Moderator slows down a Fast Neutron.

Nuclear reactor is a part of Nuclear power plant where fuel is subjected to nuclear fission process and energy is released.

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

Nuclear reactor is consisting of →

① Fuel rods ② Reactor core ③ moderator
④ Shielding ⑤ control rods ⑥ Reflector ⑦ coolant
⑧ Reactor vessel.

* **Fuel rods :-** A fuel rod is a tube, filled with pellets of uranium, normally used fuels in a reactor are $^{235}_{92}U$, $^{235}_{92}Pu$, $^{233}_{92}U$, among three $^{235}_{92}U$ is naturally available upto 0.7 % in the uranium ore.

* **Reactor core :-** It contains a number of fuel rods which are made up of fissile material; they may be diluted with non-fissionable material for better control of the reaction or to reduce the damage from fission product poison.

It is desirable to use reactorcore as cubical or cylindrical in shape rather than spherical.

* **moderator :-** The purpose of moderator is to moderate or to reduce the neutron speed to a value that increases the probability of fission occuring.
The Graphite, heavy water or beryllium can be used as moderator with natural uranium. However the ordinary water is used as moderator with enriched uranium.

* **Shielding :-** Its purpose is to provide the protection from the α and β particle radiations, and γ-rays as well as neutrons which are produced due to the nuclear fission process. & it helps to prevent the reactor wall from getting heated.

(4) control rods :- In a reactor, nuclear chain reaction has to be initiated, when started from cold and chain reaction is to be maintained at steady value during the ~~chain~~ operation of reactor, also the reactor must be able to shut down automatically under emergency conditions.

chain reaction can be controlled either by removing fuel rods or either by inserting neutron absorbing materials, which are known as control rods. The control rods must have very high absorption capacity for neutrons. The commonly used control rods are cadmium, boron or hafnium.

(5) reflector :- The reflector surrounds the reactor core within the thermal shielding. & it helps to bounce escaping neutrons back into the core.

(6) coolant :- A coolant transfers heat produced inside the reactor to a heat exchanger ~~from~~ for further utilization in power generation.

(7) Reactor vessel :- This encloses the reactor core, reflector, and shield. It is a strong walled container which also provides entrance and exit passages for directing the flow of coolant.

* Reactor control

once nuclear fission process is initiated, the neutrons released during nuclear fission process are not used up in propagating the chain reaction & Some of these neutrons are lost to the surrounding.

In order to maintain the chain reaction, it is essential that, the no of neutrons after nuclear fission should be slightly more than the no of neutrons before nuclear fission. The ratio is known as multiplication factor.

The multiplication factor k for any reactor is defined as

$$k = \frac{\text{No of neutrons produced in one generation}}{\text{No of neutrons produced in the proceeding generation}}$$

value of $k = 1$, for as multiplication factor, indicates that the chain reaction will continue at a steady state. $k > 1$, indicates that chain reaction will be building up. $k < 1$ shows the chain reaction will be dying down.

* disposal of Nuclear waste & effluent

The waste associated with nuclear power are as follows.

1. Solid radioactive waste arises from filters
2. pieces of discarded fuel element cans.
3. splitters
4. control rods
5. sludge from cooling ponds.
6. Gaseous effluents.

There are many ways for disposal of solid fission products, the products can be stored in shielded storage vaults, it consists of fixing the solid waste in boro-silicate glass & then storage of this glass in leak tight capsules or vaults.

* Sometime a suitable containers are filled with radioactive waste & sunk to the bottom of seas & oceans.

* However the above method does not completely prevent the radioactivity from leading into the water
* Another way of disposal is the separation and transmission of long-lived isotopes to short-lived or stable products following neutron absorption in a breeder or fusion reactor.

* The sludge from the cooling ponds called as radioactive liquid effluent are first diluted enormously before discharging to sea.
* These radioactive effluents arise from laundry, personal decontamination etc, together with the activity accumulating from the corrosion of the irradiated fuel elements in the storge ponds.
* Before discharging to see enormous dilution takes place & final levels of any particular isotope is contained effluent is disposed well below the maximum level of drinking water

* Sometime the liquid radioactive waste is converted into clinkers of small volume & sealed in metal container & these containers are stored in deep salt mines.
* However it is safe to store radioactive waste under ground in the liquid form in a suitable tanks or the cin technology enables 1000 litres of highly radioactive liquid waste into less than 0.01 m3 of the solid waste.
* Gaseous effluents are filtered & discharged into atmosphere, the filtered gas is discharged at higher levels so that it is dispersed properly. The filtering & discharging areas are kept clean from fire materials.

* It is essential to monitor the loss of CO_2 from the reactor to ensure that the loss does not exceed about 1 tone/day. proper precautions against toxic & radiological hazards are necessary.

* Classification of Reactors

Nuclear reactors can be classified on the following basis

a) on the Basis of Neutron energy. the reactors are classified as - 1) Thermal reactors
2) Fast reactors.

b) on the basis of Fuel used
1) Natural uranium
2) Enriched uranium

c) on the basis of Moderator used
1) Graphite reactors
2) Beryllium reactors
3) water reactors.

d) on the basis of coolant used.
1) water cooled reactors
2) Gas cooled reactors
3) Liquid metal cooled reactors
4) organic liquid cooled reactors

e) on the basis of type of core used
1) Homogenous reactors
2) Heterogenous reactors.

* Boiling water reactor (BWR) :-

The below fig shows boiling water reactor In this reactor enriched uranium is used as fuel. water is used as both coolant and moderator.

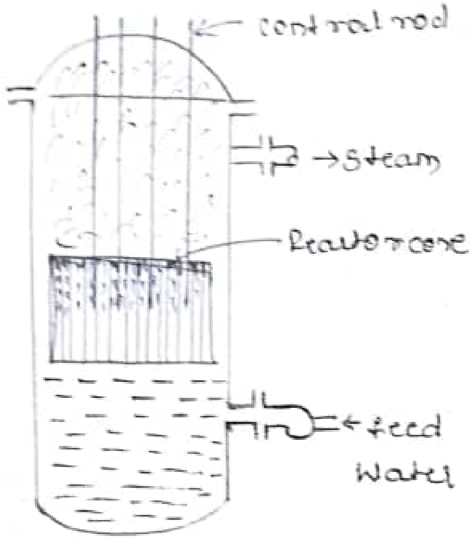

fig - A boiling water reactor.

& Steam is generated in the reactor itself.

* Initially the feed water enters into the reactor tank at the bottom & takes up the heat generated due to fission process and gets converted into the steam

* Steam leaves at the top of reactor and flows into the turbine uranium fuel elements are arranged in a particular lattice form inside the pressure vessel containing water.

* A BWR have 90-100 fuel rods & there are up to 750 assemblies in core holding up to 140 tonnes of uranium.

* advantages of BWR

1) Heat exchanger circuit is eliminated, which leads to the reduction in cost & increase in thermal efficiency.
2) As water is allowed to boil inside the reactor the pressure inside the reactor vessel is considerably lower than in case of pressurized water reactor (PWR)
3) The BWR cycle is more efficient than PWR cycle
4) A BWR is more stable than the PWR.

5) The metal surface temperature is lower than the PWR ~~cycle~~ since the boiling of water inside the reactor is performed.

* **disadvantages of BWR**

① In view of direct cycle there is a danger of radioactive contamination of steam, which leads to the failure of fuel elements, & it requires more number of safety measures therefore increase in cost.

② there is wastage of steam resulting in reduction in thermal efficiency on part load operation

③. power density of BWR is nearly half that of the PWR, & the size of vessel will be considerably large in comparison to that of the PWR.

④. A BWR can't meet, sudden increase in load.

* **pressurized water reactor (PWR)**

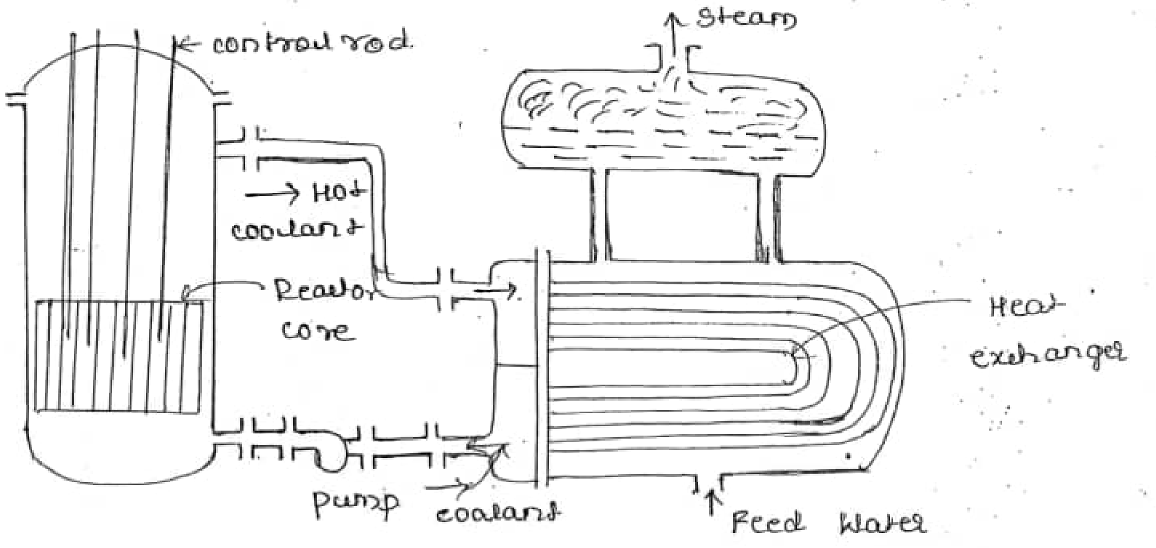

fig-a) A pressurized water reactor.

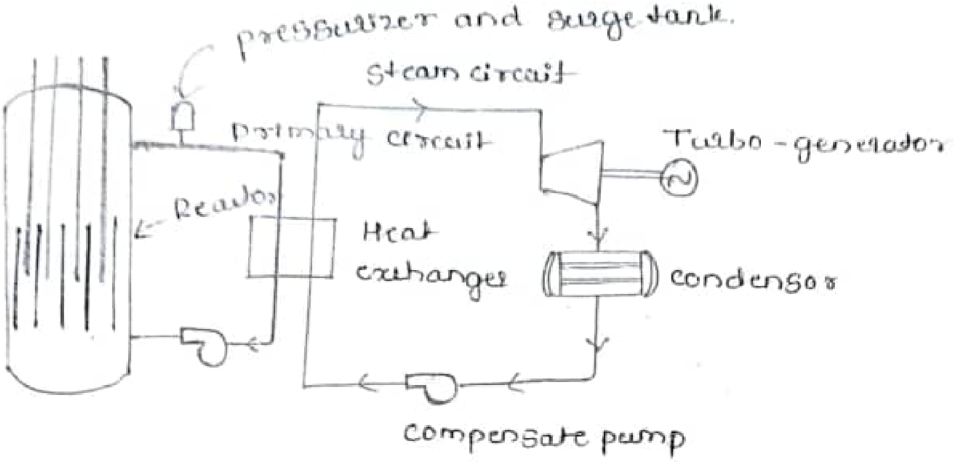

fig-b, Line arrangement of a PWR with heat exchanger inclu

A pressurized water reactor is as shown in fig a, & Line arrangement is as shown in fig b.

* The fuel used is enriched uranium clad with stainless steel or zirconium alloy, ~~under~~ and water under pressure is used as both moderator and coolant.
* However this type of reactor is designed to prevent the boiling of water coolant in the uranium core.
* A pump circulates water at high pressure round the core so that the water in liquid form absorbs the heat from the uranium and transfers it into the secondary loop.
* The boiler consists of heat exchanger and a steam drum, as shown above a pressurizer and surge tank is tapped into the pipe loop to maintain constant pressure in the water slm throughout the load range.
* An electric heating coil in the pressurizer boils the water to form steam & it is collected at the dome water spray is used to condense the steam when pressure is desired to be reduced.

Since the water passing through the reactor becomes radio-active & entire primary circuit including heat exchanger has to be shielded.

* **Advantages**

1) A PWR is relatively compact in size compared with other types.
2) There is a possibility of breeding plutonium by providing a blanket of U-238.
3) The reactor has high power density.
4) It is cheap because the ordinary water is used as both moderator & coolant
5) Reactor takes care of load variation by using pressurizer & surge tank

* **disadvantages**

1) Low thermal efficiency
2) more heat loss due to the use of heat exchanger
3) due to high pressure, a strong pressure vessel is required.
4) Lack of flexibility in recharging.
5) More safety device is required
6) expensive cladding material is required to avoid corrosion.

* **Heavy water cooled & Moderated (CANDU) type reactor**

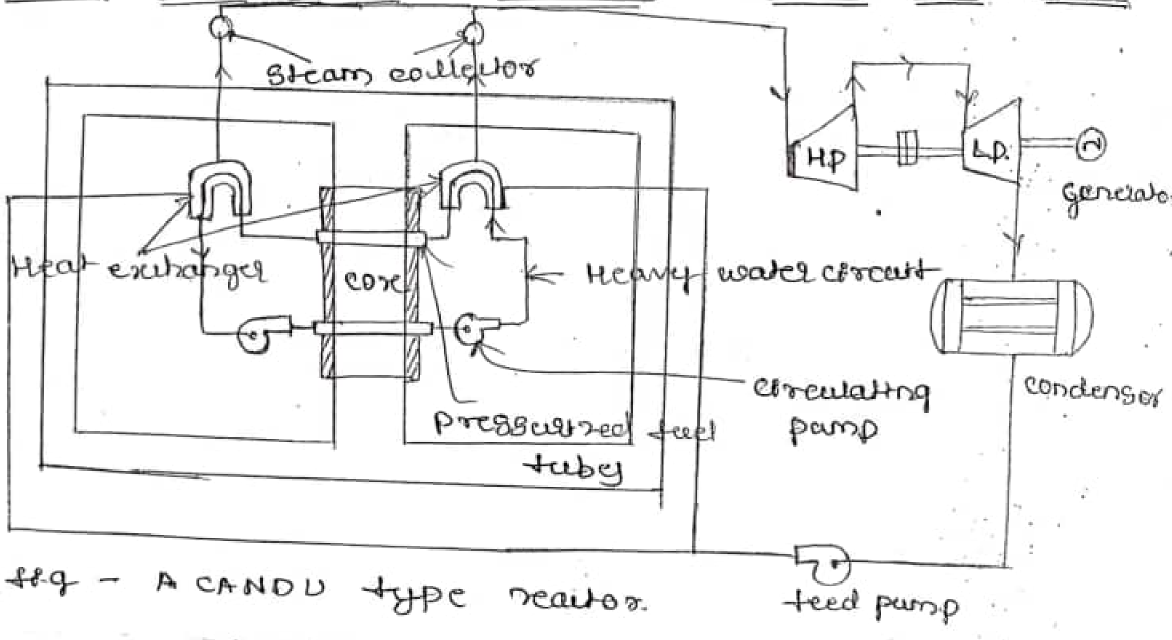

fig - A CANDU type reactor.

The word CANDU - stands for canadian deuterium Uranium. these type of reactors are used in those countries which do not produce enriched uranium.

* Enrichment of uranium is costly & this reactor will make use of natural uranium as fuel & heavy water as moderator.
* The above fig shows arrangement of CANDU type reactor, Initially heavy water is passed through the pressurized fuel tubes & Heat exchanger.
* Heavy water is circulated in the primary circuit in the same as in PWR & steam is raised in the secondary circuit transferring the heat in the heat exchanger.
* the control rods are not required in this reactor, reactor control can be achieved by varying the moderator level in the reactor.
* The advantage of the reactor is that the fuel need not be enriched.
* other advantages are, as compared to BWR & PWR reactor vessel needs to be built to withstand low pressure.
* control rods are not required, therefore the control reactor is much simpler.
* The reactor has high multiplication factor & low fuel consumption.
* The disadvantage of the reactor is - high cost of heavy water, problem of leakage & high standard of design.
* Gas cooled reactor :- Gas cooled reactor uses a gas CO_2 or helium as a coolant instead of water & graphite as a moderator. A heat exchanger is required.

gas is circulated through the reactor core & heat exchanger by means of a blower or a gas compressor.

* Even though gas is inferior to water from the point of view point of heat transfer property, but it offers numerous advantages which are not available with H_2O.
* A large quantity of gas is required for circulation resulting in increased power consumption for auxiliary therefore overall plant efficiency is low.
* Graphite as moderator is less effective than water. The gas is circulated at a pressure of 14 – 28 kg/cm^2.

* <u>advantages of Gas cooled reactor</u>

1) Less severe corrosion problems
2) possibility of use of natural uranium as fuel.
3) Greater safety in comparison with water cooled reactors
4) contamination problems are moderate.
5) Low pressure coolant and relatively high reactor temperature.

* <u>The drawbacks of Gas cooled Reactor</u>

1) relatively large size of reactor because of use of natural fuel and graphite moderator.
2) extremely low power density.
3) low steam pressure & temperature.
4) large energy consumption by gas blowers because of poor heat transfer characteristics of gases.

* Introdution to Substation equipments

A Substation has several equipments:- transformers, circuit breakers, disconnecting switches, fuses, station buses, insulators, reactors, current & potential transformers, grounding s/m, Lightning arrestors, gaps, line traps, protective relay, station batteries etc.

* protective relay:- A protective relay is a type of protective device, which gives an alarm signals or to cause prompt removal of any element from service when the element behaves abnormally.

The functions of protective relay are

① The removal of component which is behaving abnormally by closing the trip circuit of circuit breaker or to sound an alarm.

② In order to disconnect the abnormally operating part to avoid damage or interference effective operation of ~~the~~ rest of the system.

③ To prevent the subsequent faults by disconnecting the abnormally operating part.

④ relays are helpful to disconnect the faulty part as early as possible to minimize the damage to the faulty part of the s/m itself.

⑤ to improve the s/m performance, s/m reliability, s/m stability & service continuity the relays are helpful.

* Circuit Breaker:- Circuit Breaker normally gets the signal from protective relays to operate, is an automatic switch which can interrupt the fault current. circuit breaker consists of two contacts one is fixed contact & other is moving contact. under normal operating condition both the contacts of CB are fixed, during abnormal running condition the arc is gets introduced b/n the contacts of CB & it trip to separate faulty & unhealthy part of power system.

The circuit breakers are classified on the basis of rated voltage such as low-voltage CB & high voltage CB. Based on the medium of arc extinction, the circuit breakers are also classified as follows.

a) Air break circuit Breaker (used upto 12kV) & miniature circuit breaker (up to 600V), & air is considered at the atmospheric pressure.

b) oil circuit Breaker

c) Minimum oil circuit Breaker (for 3.6 - 245kV)

d) Air blast circuit breaker (for 245 - 1100kV) where compressed air is used.

e) SF_6 circuit breaker (for 36-420kV) where SF_6 gas is used

f) vacuum circuit breaker (up to 36kV) where vacuum is used as arc quenching medium.

⇒ Based on the mode of arc extinction, circuit breakers can be classified as high - resistance interruption circuit Breaker & low resistance (zero point interruption CB.

The circuit breakers are decided based on voltage & fault current of the place where it is to installed.

The voltage rating of circuit Breaker is normally from 1.05 to 1.10 times more than the normal operating voltage. for example if the rating of CB for 400kV would be 420kV.

Most of the EHV circuit breakers are provided with auto reclosure.

* Reactors and capacitors:-

To limit the line charging c/n, long distance EHV lines are connected with line reactors at both the ends, These reactors are permanently connected to the line.

* Beside these, there are bus reactors & tertiary reactors which are connected with switches. These are used during light-loading conditions and at the line charging.

* Bus reactors are connected at the substation bus, where as tertiary reactors are connected in the tertiary winding of the transformers.

. By using these reactors Ferranti effect is reduced.

* Capacitors are normally connected in low-voltage systems during peak-load conditions, the system voltage falls & therefore capacitive reactive power is required.

* In EHV system, it is preferred to use Static VAr System because it takes care of reactive power which can supply both leading and lagging reactive powers.

* In distribution system or in Sub-transmission system, capacitors are connected to improve the power factor of the system.

* Lightning arrester:- It is also known as surge arrestor normally connected b/n the phase and ground at

at the substation, lightning arrester is used to protect the substation equipments due to lightning and switching surges.

* Surge arrestors offer low resistance to the high voltage surge for diverting to the ground.
* after discharging the surge energy to ground; it blocks the normal current flowing to ground by providing high resistance path.