Year & Sem. – IV Year (VII Sem.)

Subject – Power Generation Sources (7EE6-60.2)

Unit – II

Topic: Conventional Energy Generation Methods

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VISSION AND MISSION OF INSTITUTE

Vision:

To become a renowned center of outcome based learning, and work towards academic, professional, cultural and social enrichment of the lives of individuals and communities.

Mission:

M1: Focus on evaluation of learning outcomes and motivate students to inculcate research aptitude by project based learning.

M2: Identify, based on informed perception of Indian, regional and global needs, areas of focus and provide platform to gain knowledge and solutions.

M3: Offer opportunities for interaction between academia and industry.

M4: Develop human potential to its fullest extent so that intellectually capable and imaginatively gifted leaders can emerge in a range of professions.

VISSION AND MISSION OF DEPARTMENT

Vision:

The Mechanical Engineering Department strives to be recognized globally for excellent technical knowledge and to produce quality human resource, which can manage the advance technologies and contribute to society through entrepreneurship and leadership.

Mission:

M1: To impart highest quality technical knowledge to the learners to make them globally competitive mechanical engineers.

M2: To provide the learners ethical guidelines along with excellent academic environment for a long productive career.

M3: To promote industry-institute linkage.

Thermal Power Plant

- A Thermal Power Plant converts the heat energy of coal into electrical energy. Coal is burnt in a boiler which converts water into steam. The expansion of steam in turbine produces mechanical power which drives the alternator coupled to the turbine.Thermal Power Plants contribute maximum to the generation of Power for any country.

- Thermal Power Plants constitute 75.43% of the total installed captive and non-captive power generation in India.

- In thermal generating stations coal, oil, natural gas etc. are employed as primary sources of energy.

Classification of power stations

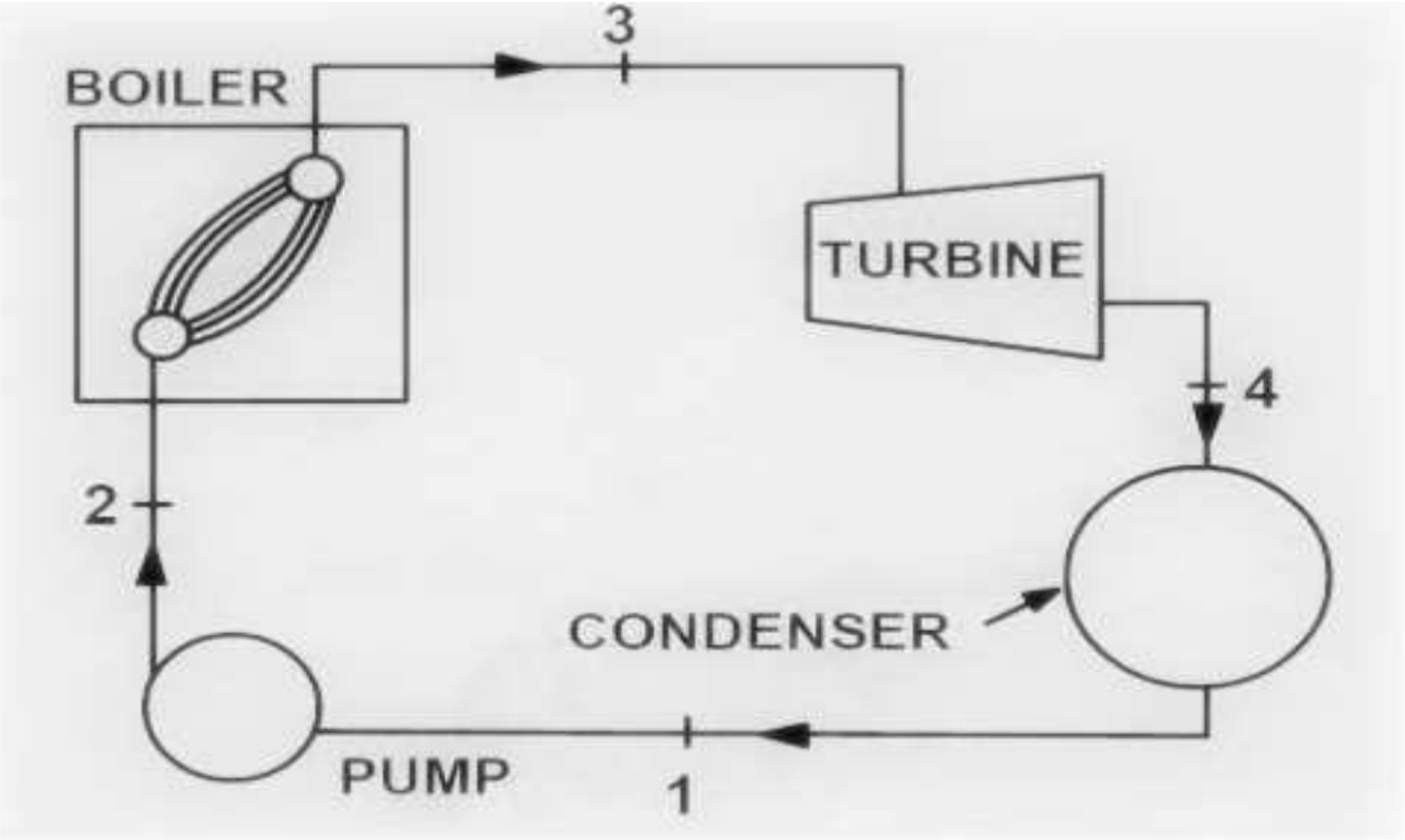
- By fuels ➡ Fossil fuel power stations, nuclear power plants, geothermal power plants, biomass power plants,

- By prime mover ➡ Steam turbine plants, gas turbine plants, combined cycle plants,

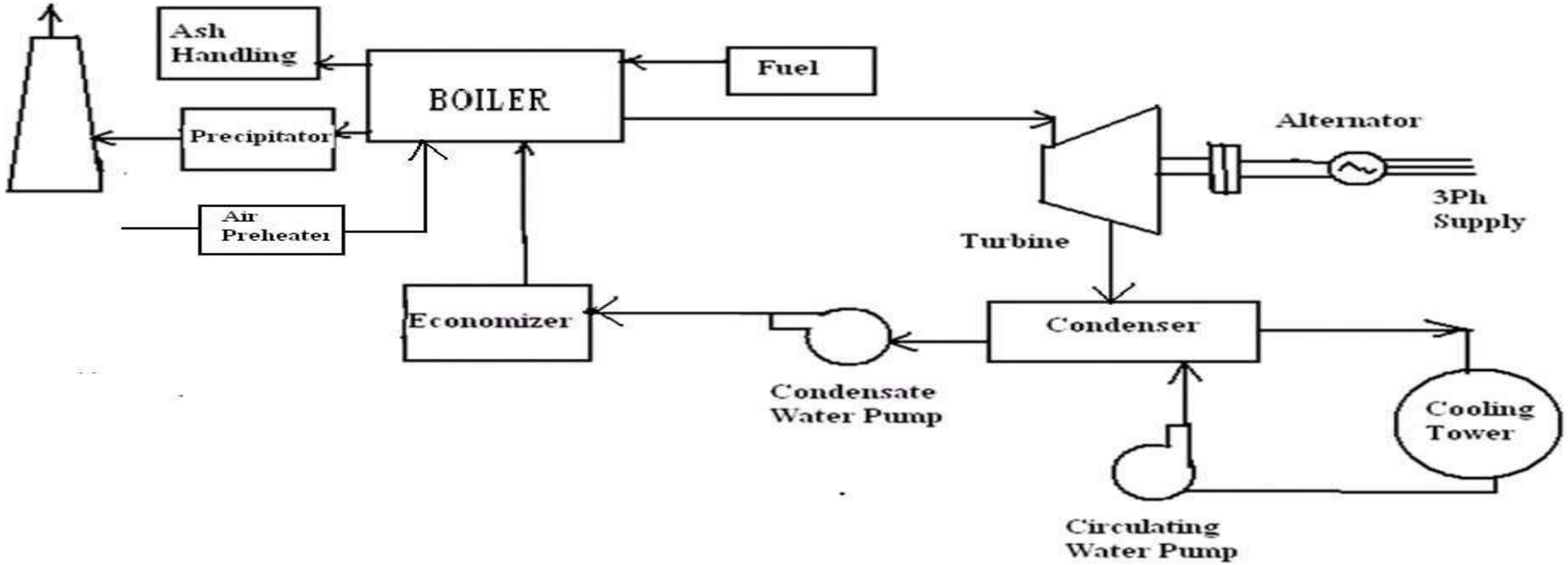
WORKING PRINCIPLE

- Firstly the water is taken into the boiler from a water source. The boiler is heated with the help of coal.
- The increase in temperature helps in the transformation of water into steam. The steam generated in the boiler is sent through a steam turbine.
- The turbine has blades that rotate when high velocity steam flows across them. This rotation of turbine blades is used to generate electricity.
- A generator is connected to the steam turbine. When the turbine turns, electricity is generated and given as output by the generator, which is then supplied to the consumers through high-voltage power lines.

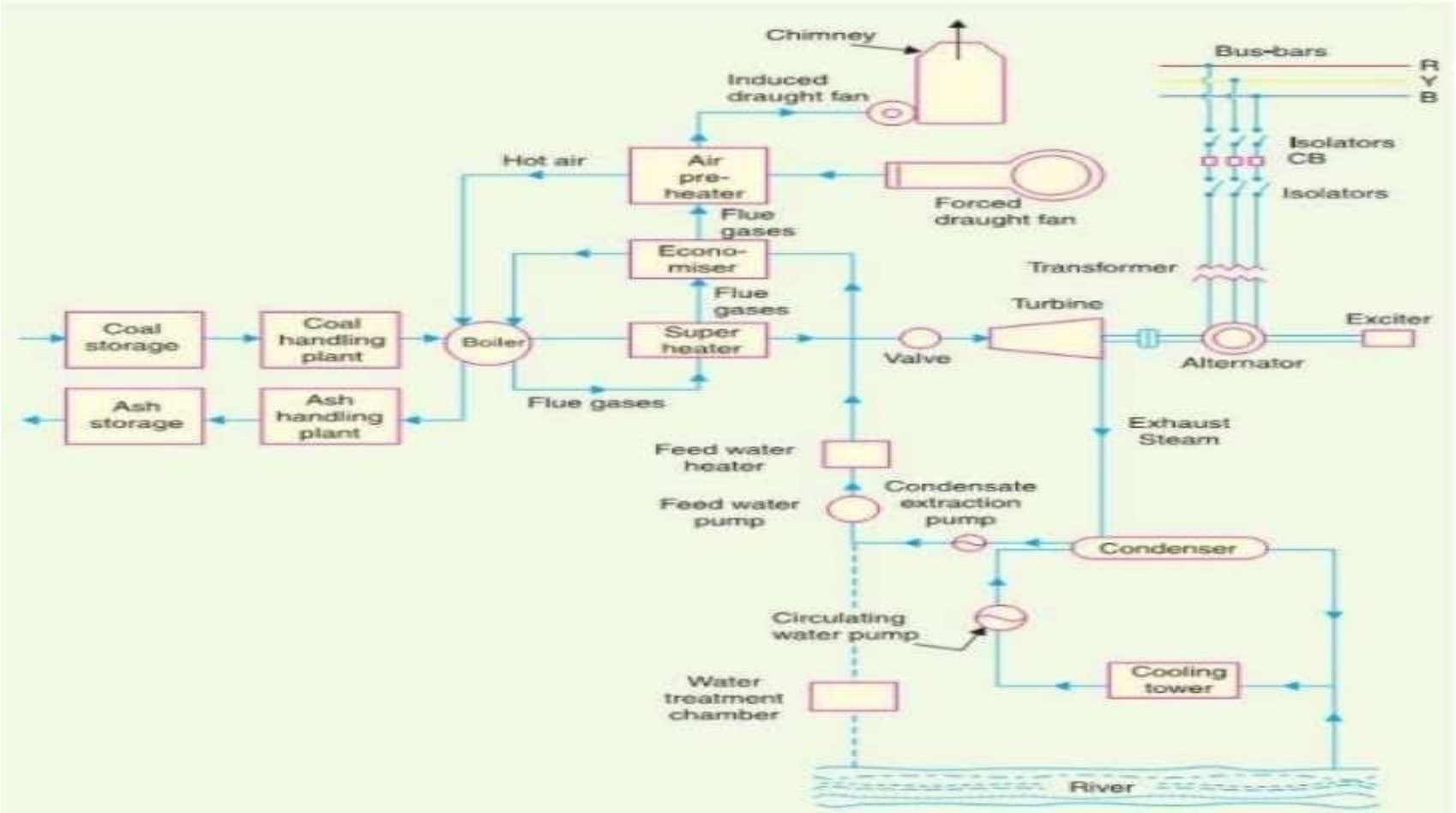
Working on Rankine cycle



GENERAL LAYOUT OF THERMAL POWER PLANT



Layout of steam power plant



Schematic arrangement of Steam Power Station

Comprises of following circuits

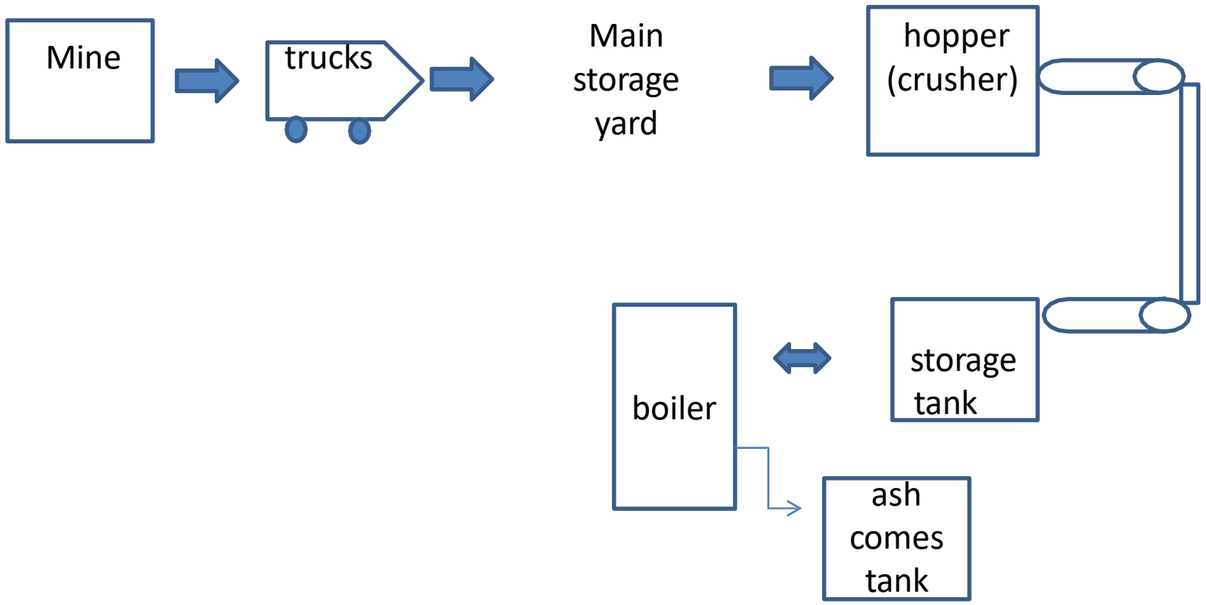
- Coal and ash circuit
- Air and gas circuit
- Feed water and steam flow circuit
- Cooling water circuit

Main and auxiliary Equipment

- Coal handling plant
- Pulverizing plant
- Draft fans
- Boiler
- Ash handling plant
- Turbine
- Condenser
- Cooling tower and ponds
- Feed water heater
- Economizer
- Superheater and reheater
- Air preheater

Coal and handling

- Coal is transported to power station by rail or road and stored in coal storage plant and then pulverized.



Ash handling plant

- The ash from the boiler is collected in two forms-
- 1 Bottom ash(slurry): it's a waste which is dumped into ash pond
- 2 fly ash: fly ash is separated from flue gases in esp.

Pulverizing plant

- In modern thermal power plant, coal is pulverized i.e. ground to dust like size and carried to the furnace in a stream of hot air. Pulverizing is a means of exposing a large surface area to the action of oxygen and consequently helping combustion.
- Pulverizing mills are further classified as:
- 1 contact mill
- 2 Ball mill
- 3 Impact mill

Boiler

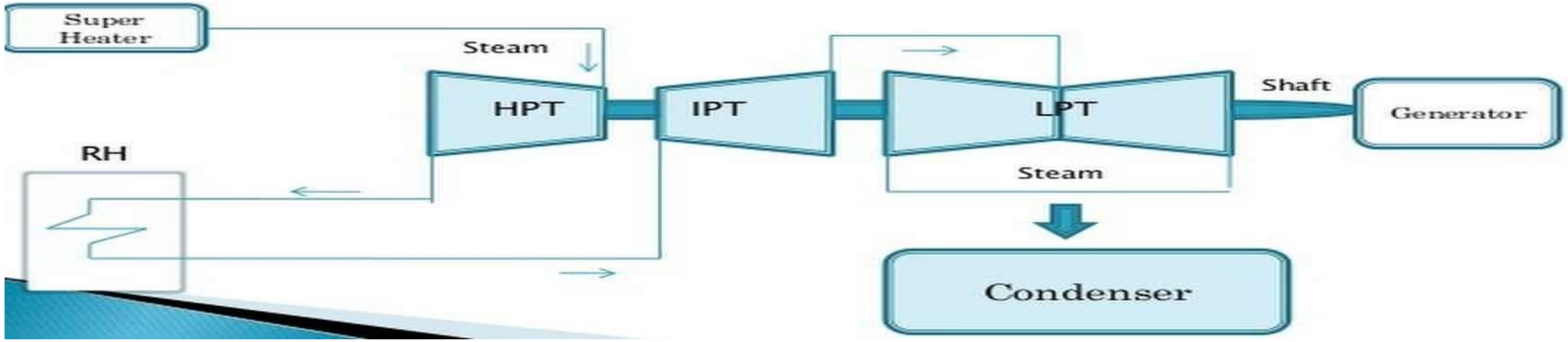
- The function of boiler is to generate steam at desired pressure and temperature by transfering heat produced by burning of fuel in a furnace to change water into steam.
- The boiler is fed with HFO and LDO initially to ignite the coal in boiler.
- Types of boiler

a. Water tube boiler

b. Fire tube boiler

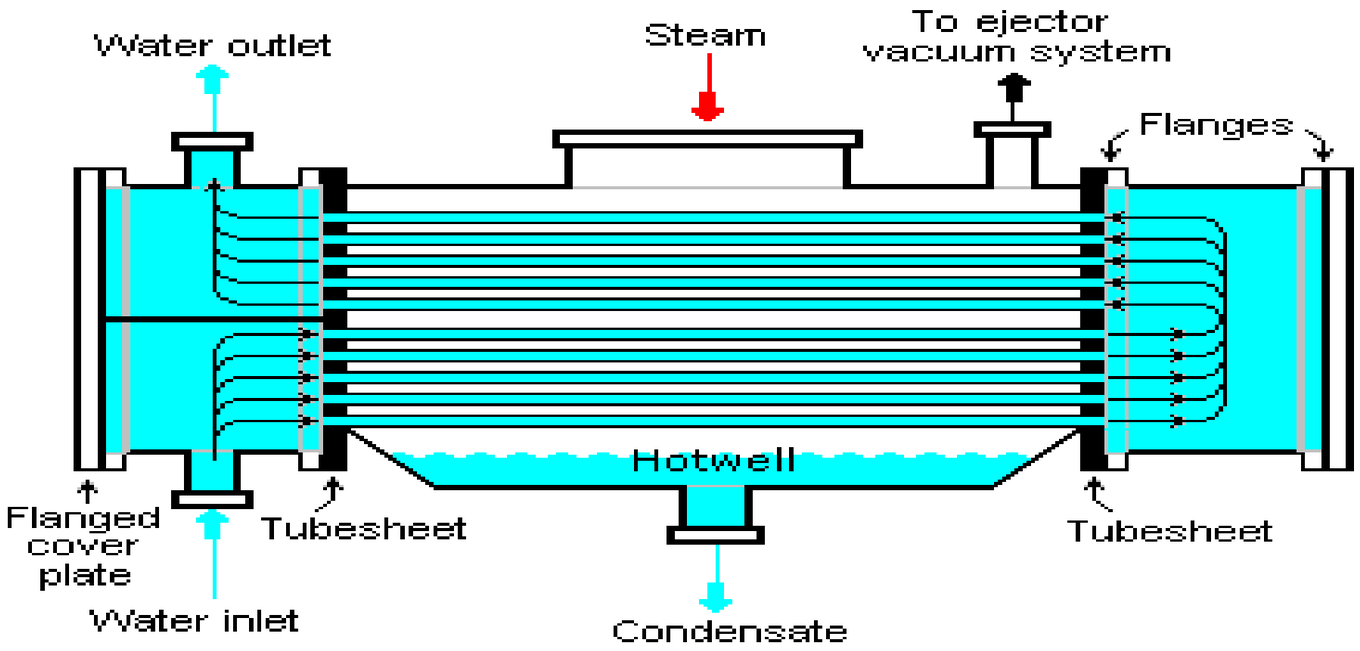
TURBINE

- In thermal power plants generally 3 turbines are used to increases the efficiency.
- 1 high pressure turbine
- 2 intermediate pressure turbine
- 3 low pressure turbine



Condenser

- The surface condenser is a shell and tube heat exchanger where cooling water flows through tubes and exhaust steam fed into the shell surrounds the tubes. as a result, steam condensed outside the tubes



Feed water heater

- ADVANTGES

1. Feed water heating improves overall plant efficiency.
2. The dissolved oxygen and carbon dioxide which known as Deaeration.
3. Thermal stresses due to cold water entering the boiler drum are avoided.
4. Quantity of steam produced by the boiler is increased.

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- ADVANTGES

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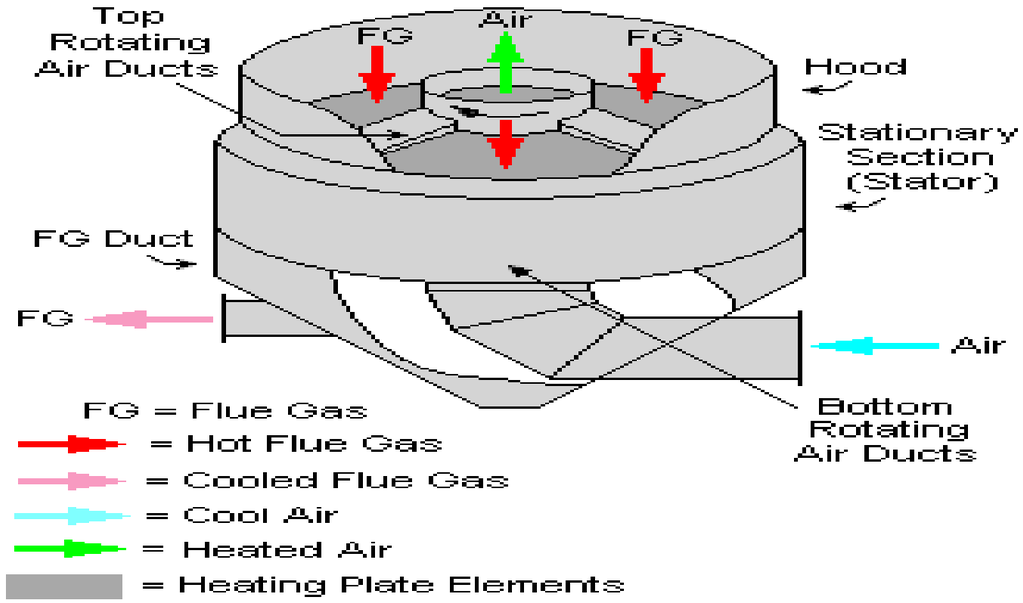
Economizer

- Flue gases coming out of the boiler carry lot of heat. An economizer extracts a part of this heat from flue gases and uses it for heating feed water.
- Advantages

1. Saving coal consumption and higher boiler efficiency

Air preheater

- The function of air preheaters is to preheat the air before entering to the furnace by utilizing some of the energy left in the flue gases before exhausting them to the atmosphere



Typical Stationary Plate Air Preheater

Advantages and disadvantages

Steam Power Station (Thermal power Station)

A generating station which converts heat energy of coal combustion into electrical energy is known as a **steam power station.**

Advantages

(*i*) The fuel (*i.e.,* coal) used is quite cheap.
(*ii*) Less initial cost as compared to other generating stations.
(*iii*) It can be installed at any place irrespective of the existence of coal. The coal can be transported to the site of the plant by rail or road.
(*iv*) It requires less space as compared to the hydroelectric power station. **(*v*)** The cost of generation is lesser than that of the diesel power station

Disadvantages

(*i*) It pollutes the atmosphere due to the production of large amount of smoke and fumes

Selection parameters of power plant

- Supply of fuel
- Availability of water
- Transportation facilities
- Cost and type of land
- Nearby to load centers
- Distance from populated area

limitations

- Generally The power plant limitations must be established so that they do not exceed the corresponding limits for which the engines or propellers are type certificated
- Takeoff operation. The power plant takeoff operation must be limited by—

1. The maximum rotational speed (rpm);
2. The maximum allowable manifold pressure (for reciprocating engines);
3. The maximum allowable gas temperature (for turbine engines)

- Continuous operation.
- Fuel grade or designation. The minimum fuel grade (for reciprocating engines), or fuel designation (for turbine engines), must be established so that it is not less than that required for the operation of the engines within the limitations .

Thermal plants in Rajasthan

- Kota thermal power plant
- Suratgarh super thermal power plant
- Giral lignite thermal power plant
- Chhabra thermal power station
- Kalisindh thermal power project
- Ramgarh gas thermal power station
- Dholpur combined cycle power station

Gas Turbine Power Plant

Working principle :

- Air is compressed(squeezed) to high pressure by a compressor.
- Then fuel and compressed air are mixed in a combustion chamber and ignited.
- Hot gases are given off, which spin the turbine wheels.

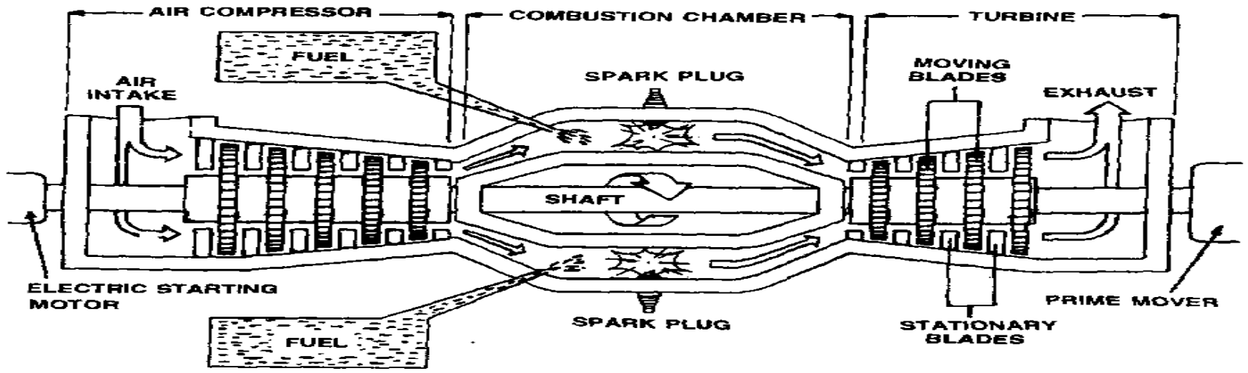


Fig. 2.28: HOW A GAS TURBINE SYSTEM WORKS

Introduction

- Gas turbines burn fuels such as oil, nature gas and pulverized(powdered) coal.
- Working fluid is compressed AIR.

Consist of :

- COMPRESSOR
- COMBUSTION CHAMBER
- GAS TURBINE
- ALTERNATOR
- STARTING MOTOR

Air compressor

The air compressor and turbine are mounted at either end on a common shaft, with the combustion chamber between them.

¬Gas turbines are not self starting. A starting motor is used.

¬The air compressor sucks in air and compresses it, thereby increasing its pressure.

Combustion chamber

In the combustion chamber, the compressed air combines with fuel and the resulting mixture is burnt.

¬The greater the pressure of air, the better the fuel air mixture burns.

¬Modern gas turbines usually use liquid fuel, but they may also use gaseous fuel, natural gas or gas produced artificially by gasification of a solid fuel.

Turbine

Hot gases move through a multistagegas turbine.

¬Like in steam turbine, the gas turbine also has stationary and moving blades.

¬The stationary blades

⎫ guide the moving gases to the rotor blades

⎫ adjust its velocity.

¬The shaft of the turbine is coupled to a generator.

Applications of gas Turbine

¬drive pumps, compressors and high speed cars.

¬aircraft and ships.

¬ Power generation (used for peak load and as stand- by unit).

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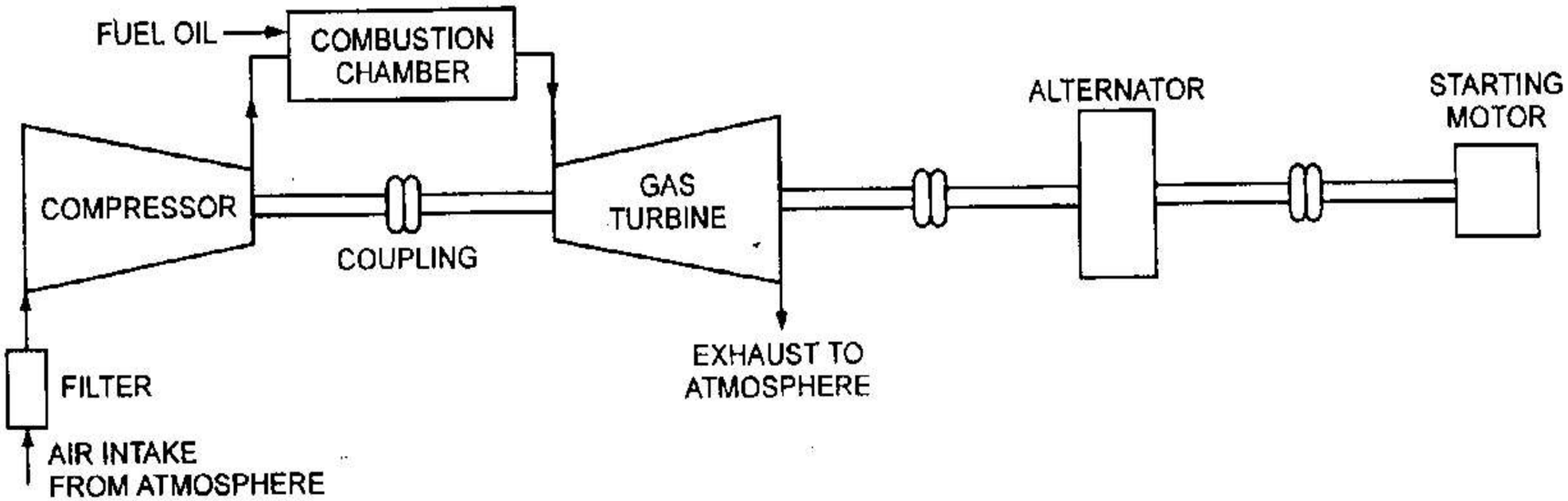
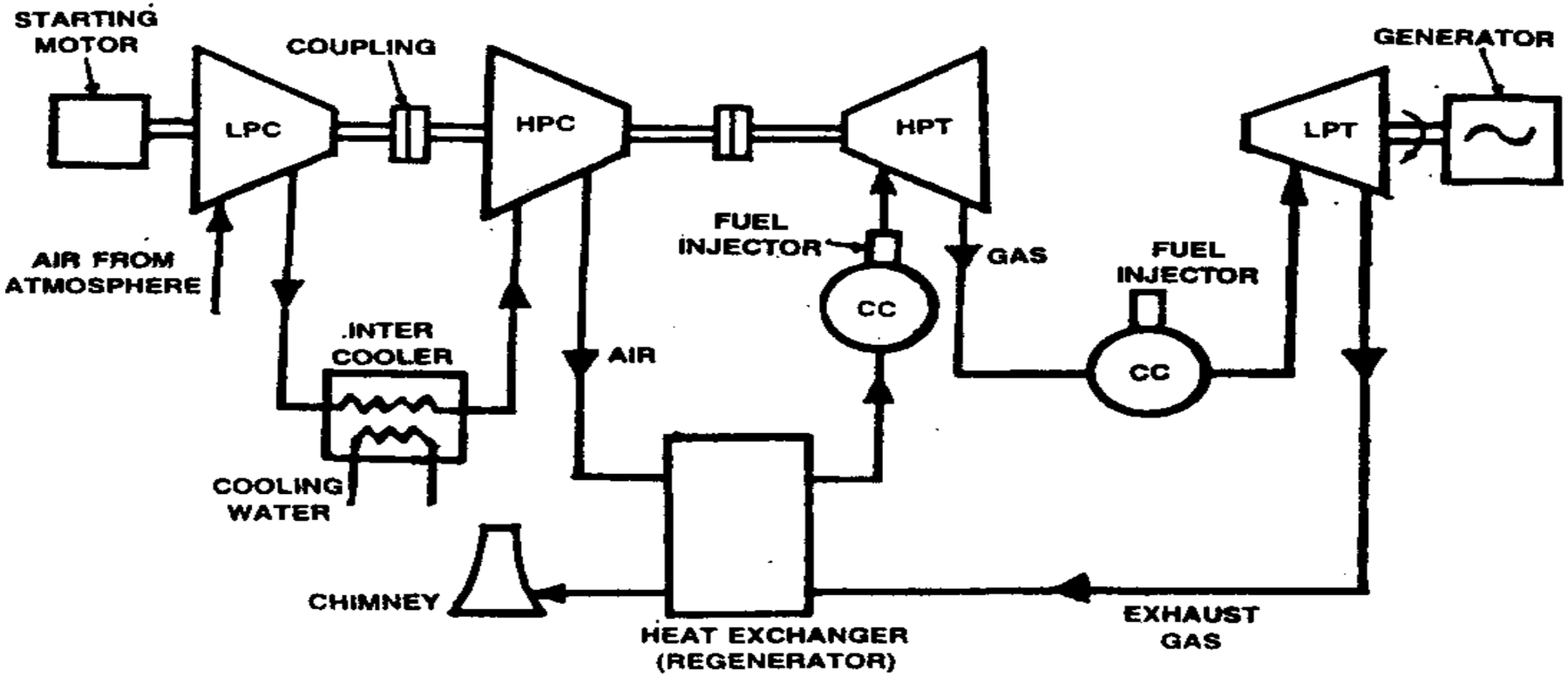
Layout of Gas Power Plants



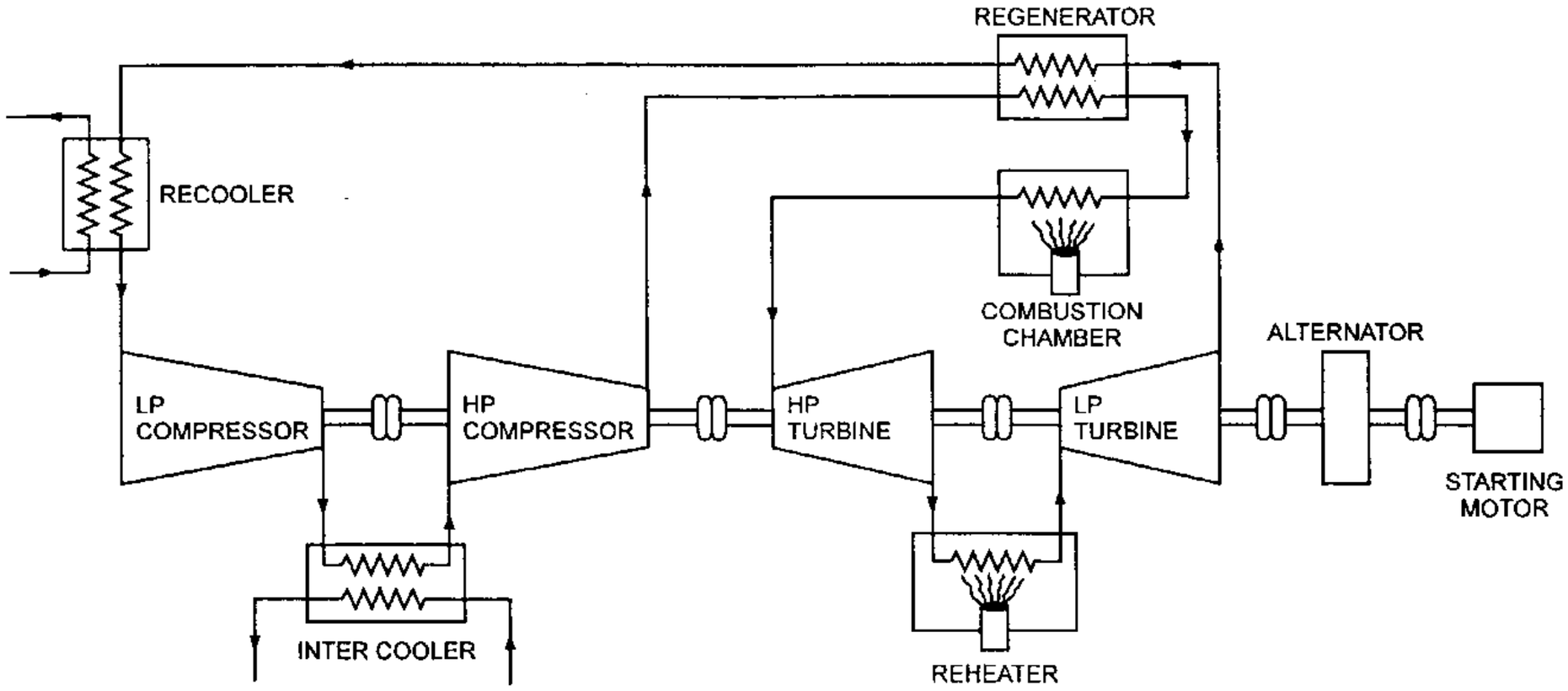
Layout of Gas Power Plants

- Takes air from the atmosphere through air filter.
- Compresses the air to very high pressure.
- Compressor is rotated with the help of starting motor
- FUEL OIL & COMPRESSED AIR is fed to combustion chamber.
- Fuel oil is burned inside the combustion chamber.
- This further increases the temperature and pressure of the compressed air to a high value
- Compressed air at high pressure is expanded inside the turbine.
- Turbine rotates the generator coupled to it
- Alternator produces electricity.
- Provides initial starting to the system.
- Rotates the compressor during the initial stage
- Mechanical isolation between alternator and compressor.
- Independent speed control for compressor.

Open cycle Gas Power Plants

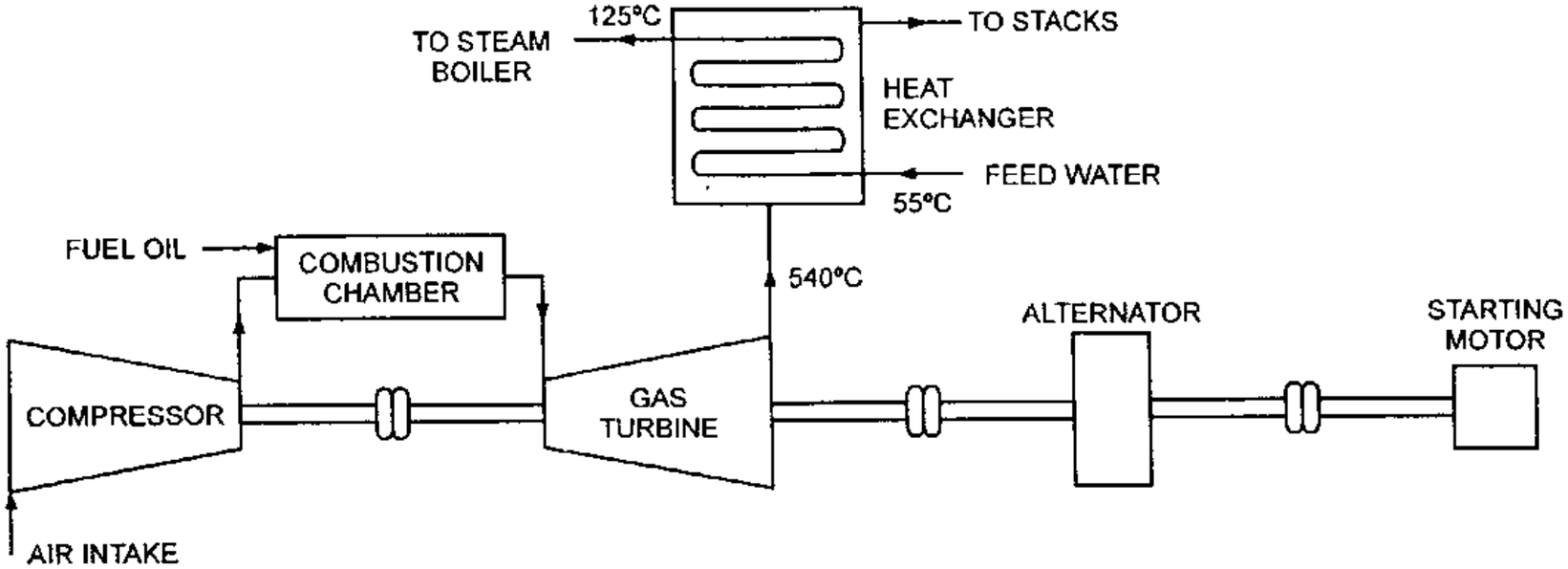


Closed Cycle Gas Power Plants



COMBINED STEAM & GAS POWER PLANTS

Use of Exhaust Gases of Gas Turbine Power Plant For Heating of Feed Water
Use of Exhaust Gases From Gas Turbine As Combustion Air in Steam Boiler
Use of Gases From a Supercharged Boiler For Expansion in Gas Turbine



Advantages of gas turbine power plant

- Storage of fuel requires less area and handling is easy.
- The cost of maintenance is less.
- It is simple in construction. There is no need for boiler, condenser and other accessories as in the case of steam power plants.
- Cheaper fuel such as kerosene , paraffin, benzene and powdered coal can be used which are cheaper than petrol and diesel.
- Gas turbine plants can be used in water scarcity areas.
- Less pollution and less water is required.

Disadvantages of gas turbine power plant

¬ 66% of the power developed is used to drive the compressor. Therefore the gas turbine unit has a low thermal efficiency.

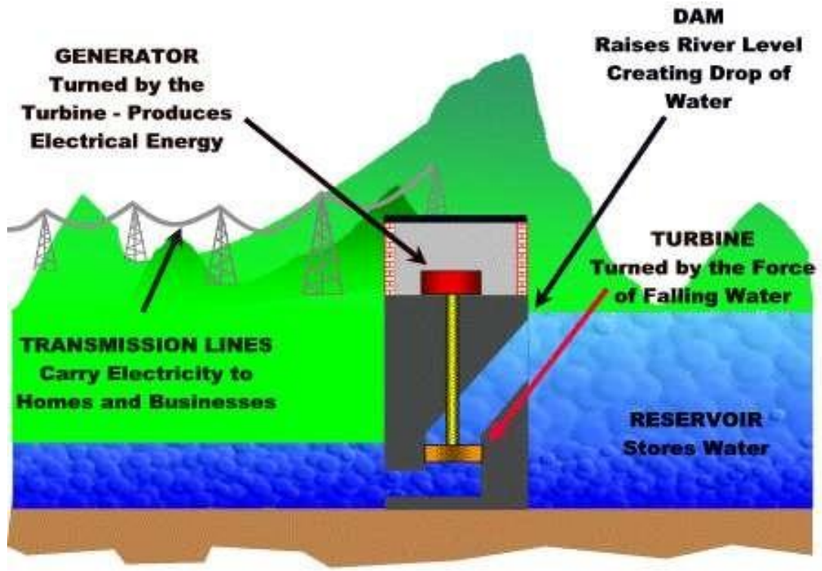
¬ The running speed of gas turbine is in the range of

- **(40,000 to 100,000 rpm) and the operating temperature is as high as 1100 – 1260^{0}C. For this reason special metals and alloys have to be used for the various parts of the turbine.**

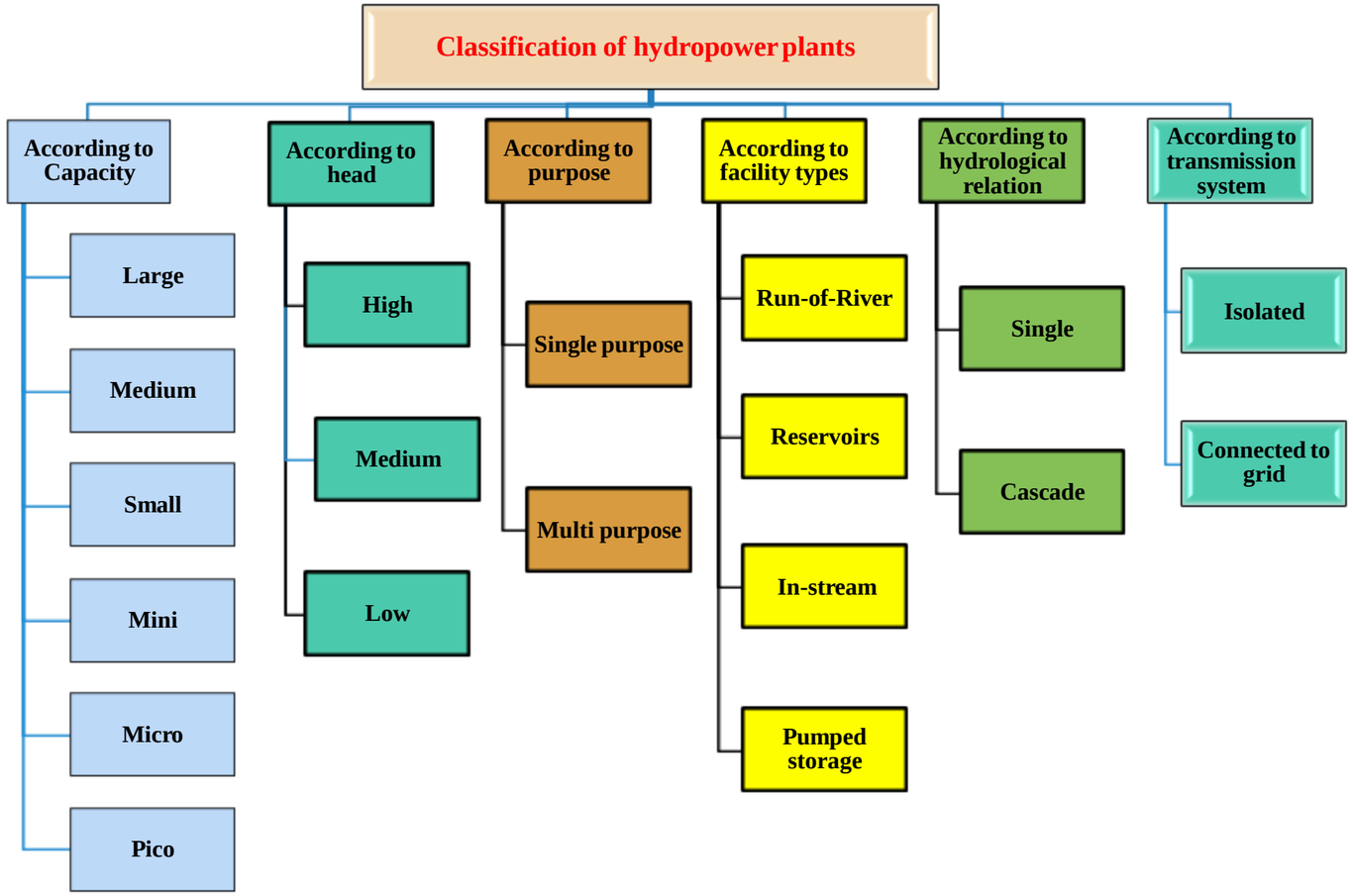
¬ High frequency noise from the compressor is objectionable.

HYDROPOWER PLANTS

- Hydropower transforms the potential energy of a mass of water flowing in a river or stream with a certain vertical fall (termed the "head")
- Hydroelectric power is the cheapest source of energy, renewable and environmentally benign during running.
- The potential annual power generation of a hydropower project is proportional to the head and flow of water
- In Hydro Power Plant the water is utilized to move the turbines which in turn run the electric generator's.
- The Potential energy of the water stored in the dam gets converted into the Kinetic Energy of the moving water in the penstock. And this Kinetic Energy gets converted into the Electrical Energy with the help of Turbine & Generator.
- Hydro Power Plant was invented by H.F. Rogers
- Hydro Power Plant fulfills the 30% of the total energy needs of the world.
- Total hydro potential of the world = 5000 GW.



CLASSIFICATION OF HYDROPOWER PLANTS



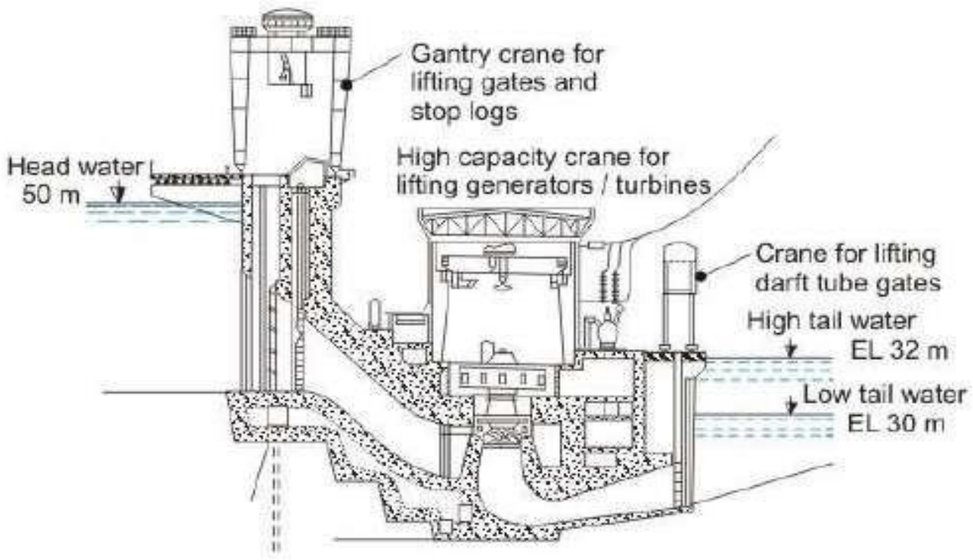
Classification According to capacity

- LARGE: >100 MW
- MEDIUM: 25 – 100 MW
- SMALL: 1-25 MW
- MINI: 100 KW - 1MW
- MICRO: 5 – 100 KW
- PICO: < 5 KW

Classification According to HEAD

LOW HEAD:

- Low head hydro power applications use river current or tidal flows of 30 meters or less to produce energy.
- These applications do not need to dam or retain water to create hydraulic head, the head is only a few meters.
- Using the current of a river or the naturally occurring tidal flow to create electricity may provide a renewable energy source that will have a minimal impact on the environment.

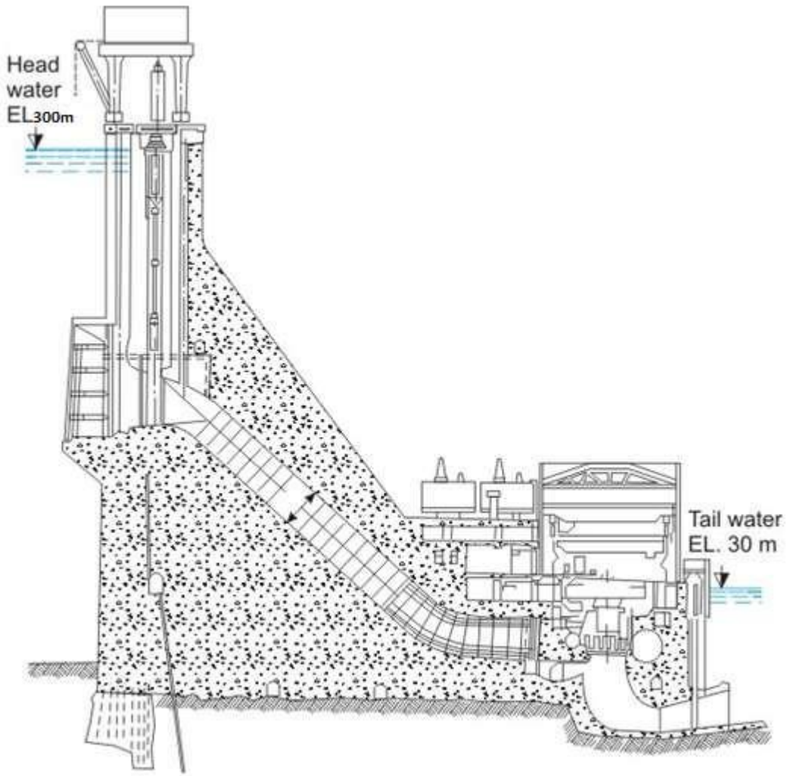


sectional view of low head hydropower plant

Classification According to HEAD

MEDIUM HEAD:

- A power station operating under heads from 30m to 300m.

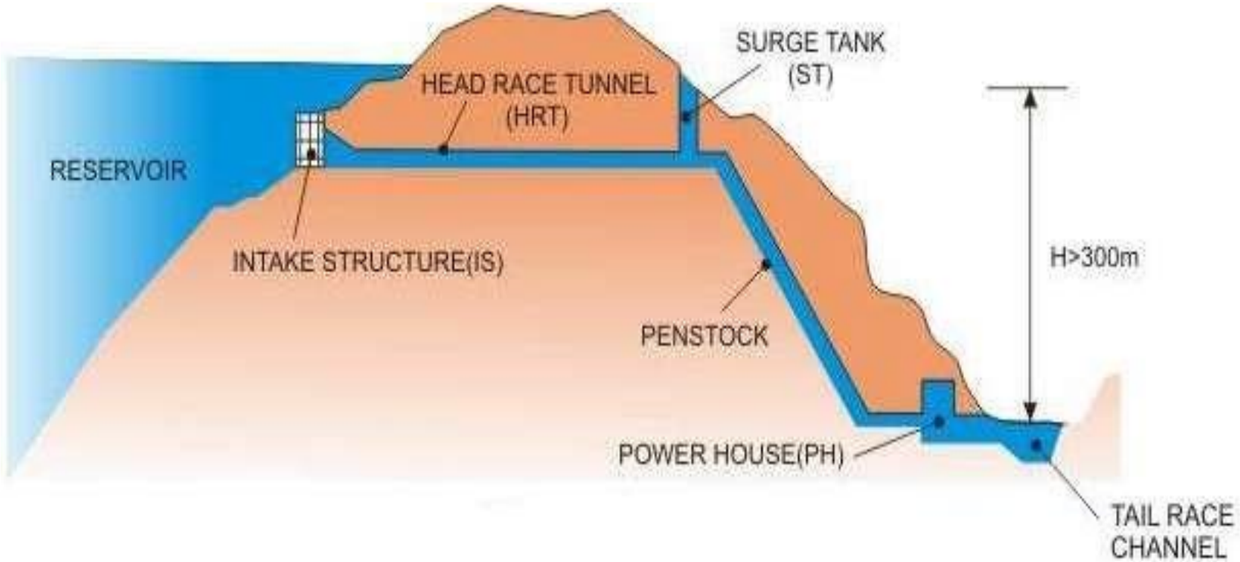


sectional view of medium head hydropower plant

Classification According to HEAD

HIGH HEAD:

- A power station operating under heads above about 300m.
- A head of 200m/250m is considered as the limit between medium and high head power stations

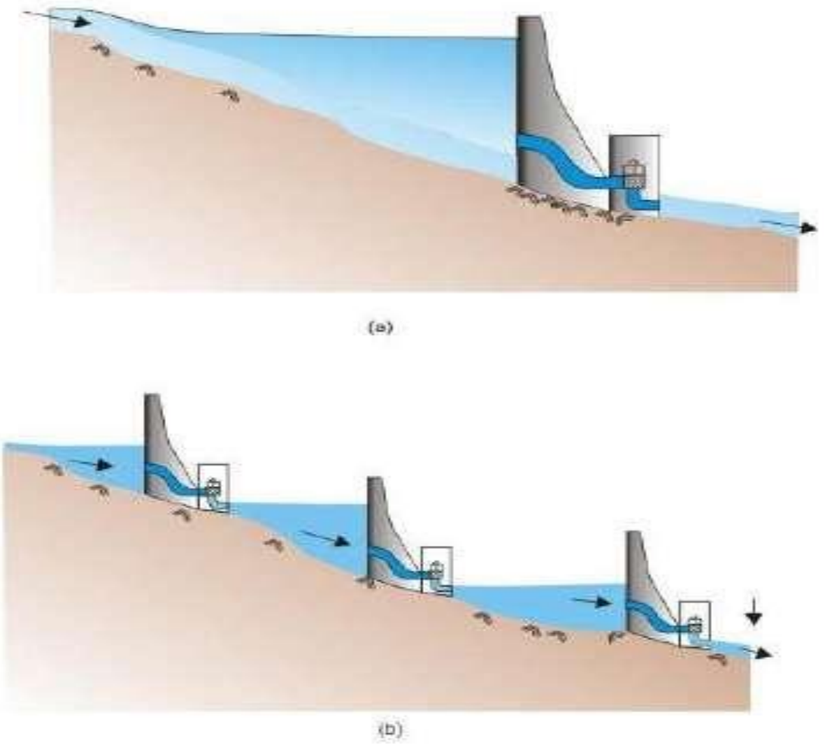


High head hydropowerplant

Classification According to Hydrological Relation

SINGLE STAGE- When the run off from a single hydropower plant is diverted back into river or for any other purpose other than power generation, the setup is known as Single Stage

CASCADE SYSTEM- When two or more hydropower plants are used in series such that the runoff discharge of one hydro power plant is used as the is a intake discharge of the second hydro power plant such a system is known as CASCADE hydropower plant.



a) single stage hydropower development scheme
(b) cascade or multistage hydropower system

Classification According to Purpose

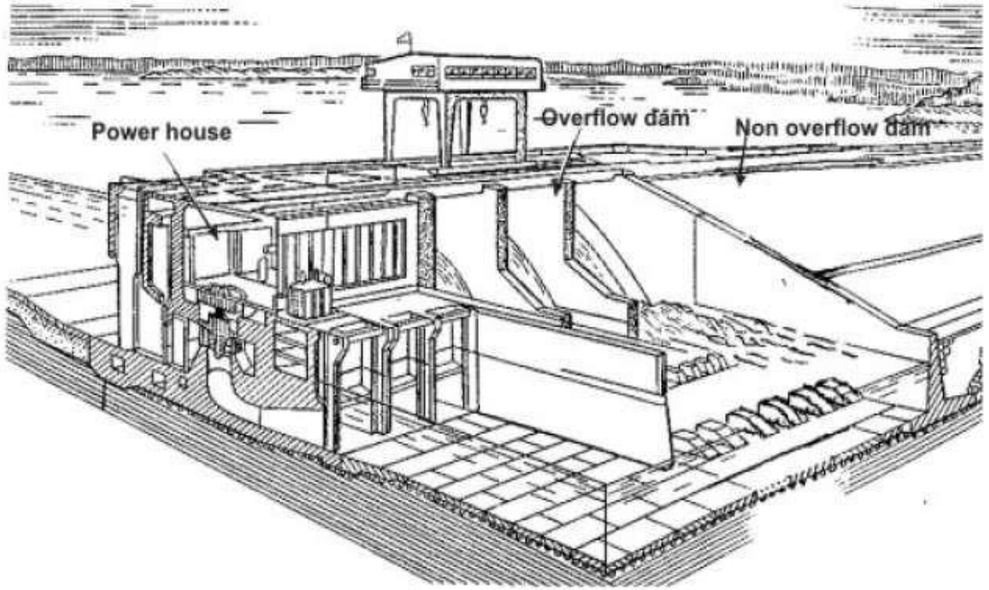
SINGLE PURPOSE: When the whole soul purpose of a project is to produce electricity then such a project is known as a Single Purpose Hydro Power Project.

MULTIPURPOSE : When the water used in hydropower project is to be used for other purposes like irrigation, flood control or fisheries then such a project is known as Multi Purpose Hydro Power Project.

Classification According to Facility Type

RUN-OF-RIVER TYPE

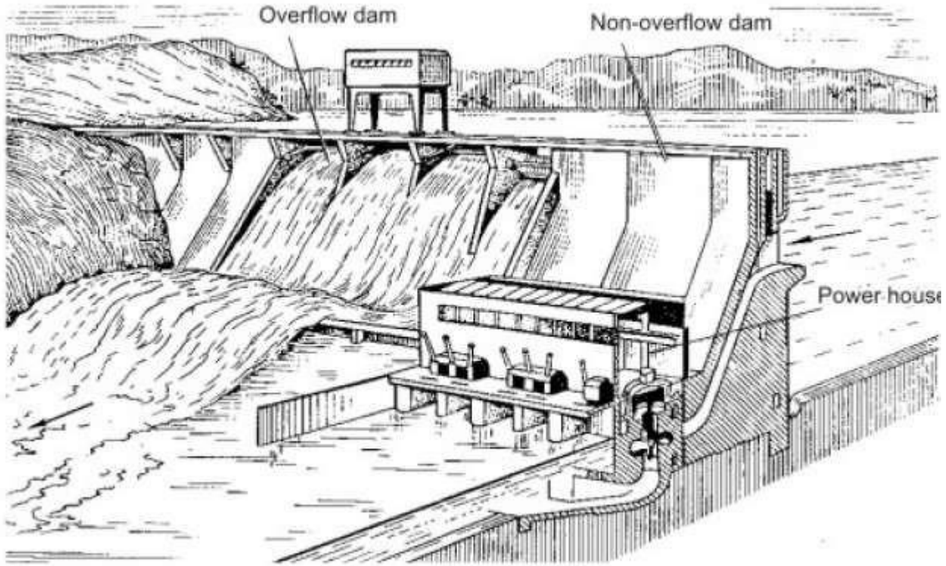
These are hydro power plants that utilize the stream flow as it comes , without any storage being provided



Classification According to Facility Type

STORAGE (RESERVOIR) TYPE

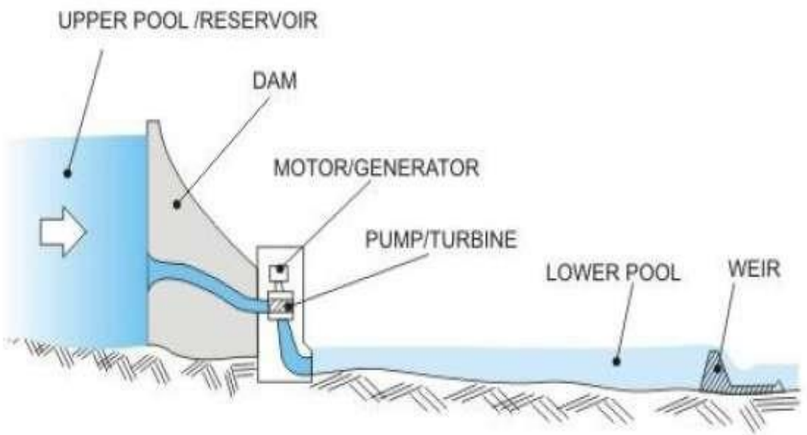
- Hydropower plants with storage are supplied with water from large storage reservoir that have been developed by constructing dams across rivers.
- Assured flow for hydro power generation is more certain for the storage schemes than the run-of-river schemes



Classification According to Facility Type

PUMPED STORAGETYPE

- Pumped storage type hydropower plants are those which utilize the flow of water from a reservoir at higher potential to one at lower potential.
- During off-peak hours, the reversible units are supplied with the excess electricity available in the power grid which then pumps part of the water of the tail-water pond back into the head-water pond



Classification According to Facility Type

IN-STREAM

When the velocity of water i.e kinetic energy flowing in the stream is used for conversion into electrical power, then the system is known as In- stream.

Classification According to Transmission System

ISOLATED: Whenever a hydropower plant is set up in a remote area in order to meet the local demands then such a hydropower plant is known as Isolated System.

CONNECTED TO GRID: Whenever the hydropower plant is set up to meet the demands of areas which are at a fair distance from the plant, then the transmission of power takes through the grid system. Such a setup is referred to as Connected to grid.

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Essential Elements Of Hydro Power Plant

PRIMARY ELEMENT'S

- CATCHMENTS AREA
- RESERVOIR
- DAM
- PRIME MOVERS
- DRAFT TUBES
- POWER HOUSE & EQUIPMENT

SAFETY DEVICE'S

- SPILL WAYS
- SURGE TANK
- TRASH RACK

Essential Elements Of Hydro Power Plant

1. CATCHMENTS AREA

The whole area behind the clam training into a stream as river across which the dam has been built at suitable place is called catchments area.

2. RESERVOIR

A reservoir is employed to store water which is further utilized to generate power by running the hydroelectric turbines.

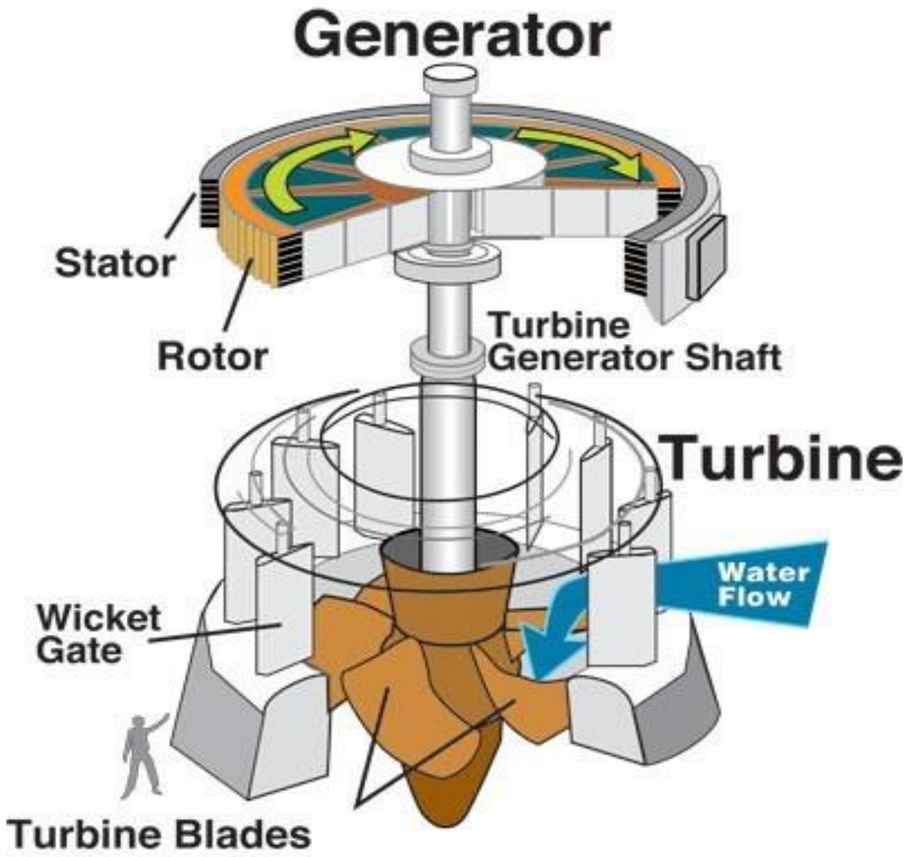
Essential Elements Of Hydro Power Plant

3. DAM

- A dam is a barrier which confines or raise water for storage or diversion to create a hydraulic head.
- Dam's are generally made of concrete, Stone masory, Rockfill or Timber

Essential Elements Of Hydro Power Plant

3. Generator



Essential Elements Of Hydro Power Plant

4. Turbine & Generator

Turbine & Generator is the most important part of any power plant This combination is known as **THE HEART OF THE**

POWER PLANT.

TURBINE :- Turbine is a very light fan like structure having many number's of blades . It has an ability to rotate on its axis when water passes through it.

GENERATOR :- Generator is a device in which when there is rotation of coil between the strong Magnetic Field then it produces an Alternating Current.

Essential Elements Of Hydro Power Plant

5. DRAFT TUBES

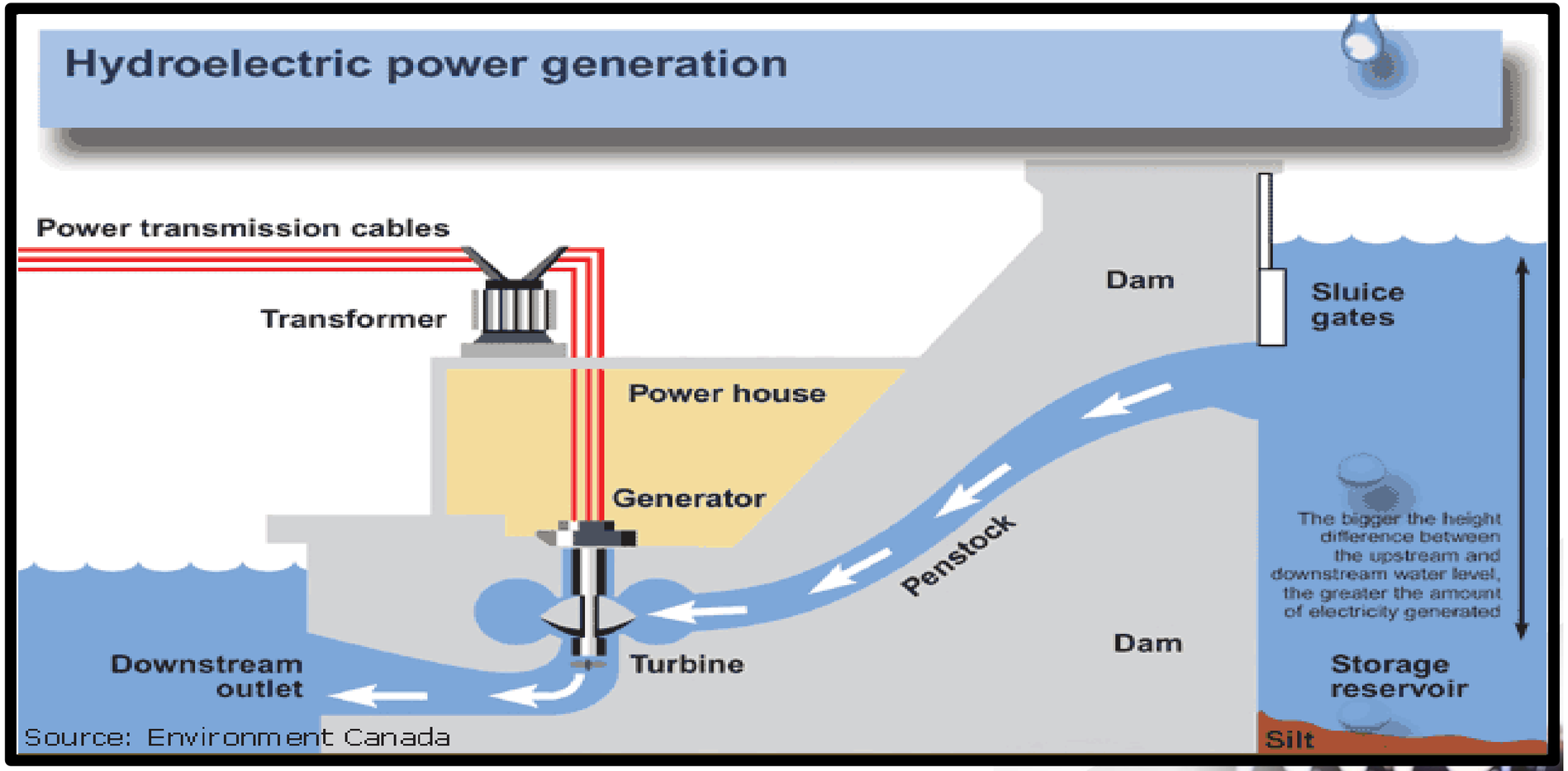
Draft Tube is an empty structure made beneath the Turbine. It serves in following 2 purpose's :

It allows the turbine to be set above tail water level without loss of head, to facilitate inspection and maintenance.

It regains by diffuser action , the major portion of the kinetic energy delivered to it from the runner.

It increases the output power.

It increases the efficiency of Hydro Power Plant.


Hydroelectric power generation
Power transmission cables
Transformer
Power house
Generator
Dam
Sluice gates
Penstock
The bigger the height difference between the upstream and downstream water level, the greater the amount of electricity generated
Dam
Downstream outlet
Turbine
Storage reservoir
Silt
Source: Environment Canada

WORKING OF HYDRO POWER PLANT

CATCHMENTS AREA TO TURBINE HOUSE

- Initially the water of the river is in Catchments Area. From catchments area the water flows to the dam.
- At the dam the water gets accumulated . Thus the potential energy of the water increases due to the height of the dam .
- When the gates of the dam are opened then the water moves with high Kinetic Energy into the penstock.
- Through the penstock water goes to the turbine house.
- Since the penstock makes water to flow from high altitude to low altitude, Thus the Kinetic Energy of the water is again raised.

WORKING OF HYDRO POWER PLANT

TURBINE HOUSE TO POWER HOUSE

- In the turbine house the pressure of the water is controlled by the controlling valves as per the requirements.
- The controlled pressurized water is fed to the turbine.
- Due to the pressure of the water the light weight turbine rotates.
- Due to the high speed rotation of the turbine the shaft connected between the turbine and the generator rotates .
- Due to the rotation of generator the ac current is produced. This current is supplied to the powerhouse .
- From powerhouse it is supplied for the commercial purposes.

Advantages

- No fuel charges.
- Less supervising staff is required. Maintenance & operation charges are very low. Running cost of the plant is low.
- The plant efficiency does not changes with age.
- It takes few minutes to run & synchronize the plant. No fuel transportation is required.
- No ash & flue gas problem & does not pollute the atmosphere. These plants are used for flood control & irrigation purpose.
- Long life in comparison with the Thermal & Nuclear Power Plant

Disadvantages

- The initial cost of the power plant is very high. Takes long time for construction of the dam.
- Generally, Such plant's are located in hilly area's far away from load center & thus they require long transmission lines & losses in them will be more.
- Power generation by hydro power plant is only dependant on natural phenomenon of rain .Therefore at the time of drought or summer session the Hydro Power Plant will not work.

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- Power generation by hydro power plant is only dependant on natural phenomenon of rain .Therefore at the time of drought or summer session the Hydro Power Plant will not work.

Nuclear Power Plant

Introduction:

- Nuclear fuel is any material that can be consumed to derive nuclear energy. The most common type of nuclear fuel is fissile elements that can be made to undergo nuclear fission chain reactions in a nuclear reactor
- The most common nuclear fuels are 235U and 239Pu. Not all nuclear fuels are used in fission chain reactions
- Other fuels: 238Np(Neptunium), 239U(Uranium), 241Pu(plutonium)

NUCLEAR FISSION

When a neutron strikes an atomof uranium, the uranium splits into two lighter atoms and releases heat simultaneously.

Fission of heavy elements is an exothermic reaction which can release large amounts of energy both as electromagnetic radiation and as kinetic energy of the fragments.

Chain Reaction

A chain reaction refers to a process in which neutrons released in fission produce an additional fission in at least one further nucleus. This nucleus in turn produces neutrons, and the process repeats. If the process is controlled it is used for **nuclear power** or if uncontrolled it is used for **nuclear weapons**

A chain reaction is that process in which number of neutrons keep on multiplying rapidly(in GP) during fission till whole of the fissionable material is disintegrated.
Chain reaction will continue if, for every neutron absorbed, at least one fission neutron becomes available for causing fission of another nucleus.

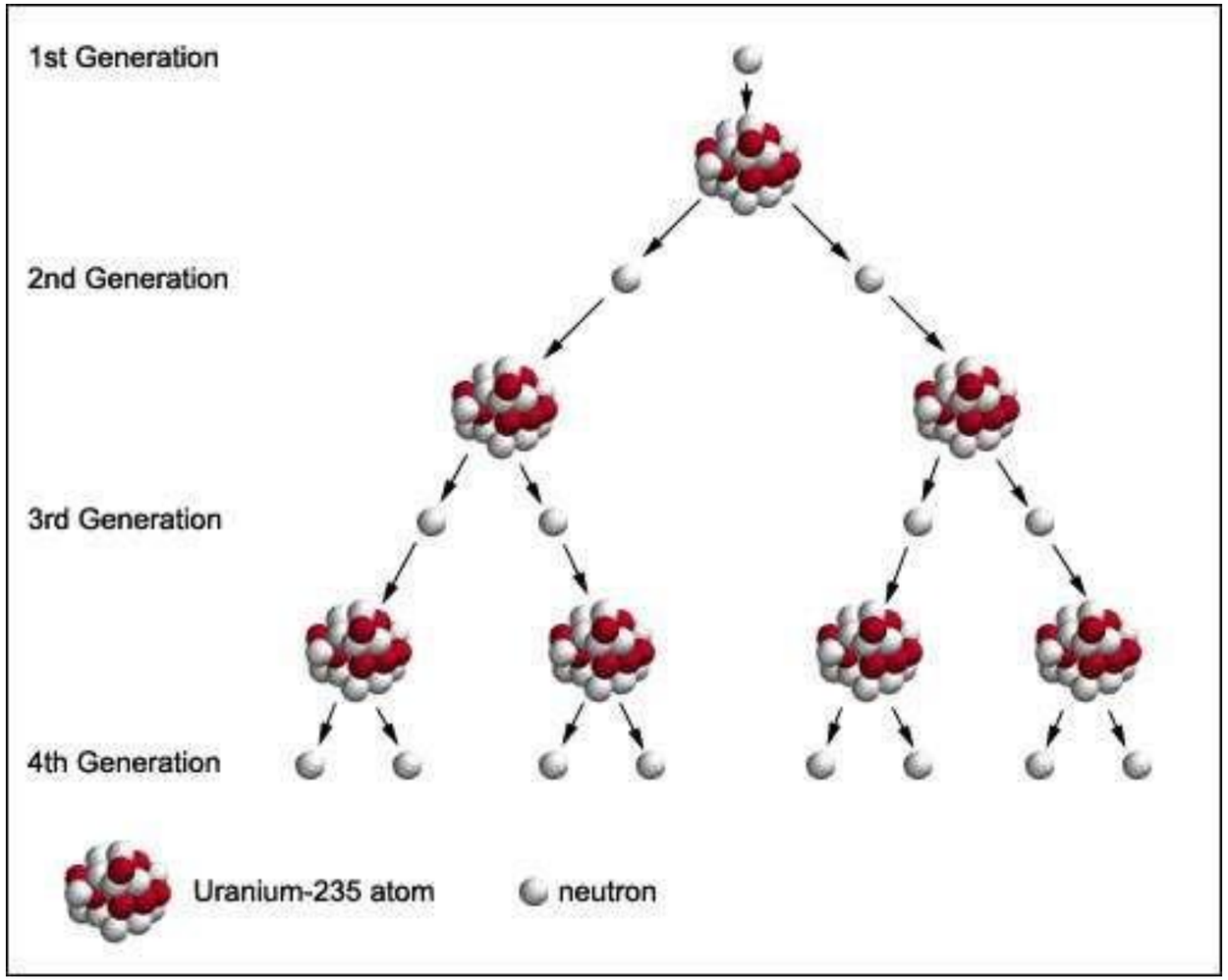
Expressed by **multiplication factor**
K= No. of neutrons in any particular generation/No. of neutrons in the preceding generation.

If K>1, chain reaction will continue and if K<1 , cant be maintained

Requirements of Fission Process

- The neutrons emitted in fission should have **adequate energy** to cause fission of another nuclei.
- The produced number of neutrons must be able not only to sustain the fission process but should be able to **increase the rate of fission**.
- The process must be followed by **liberation of energy**.
- It must be able to **control the rate of fission** by some means.
- **Critical mass:** The minimum quantity of fuel required for any specific reactor system is called critical mass, and size associated with it is called critical size.

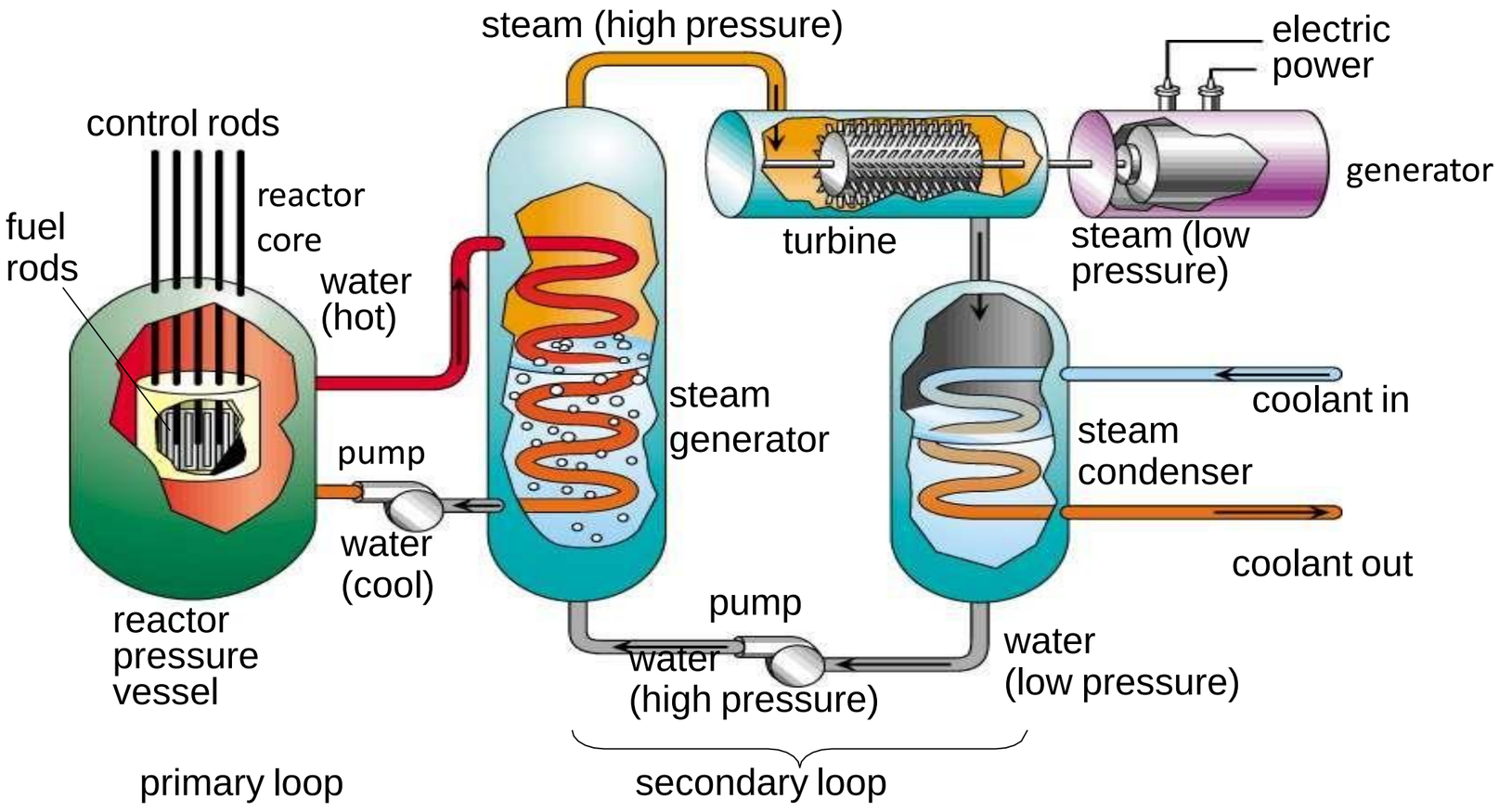
Fission Process



Fission Process

- U**235** + n → fission + 2 or 3 n + 200 MeV
- MeV s Mega Electron Volt.
- If each neutron releases two more neutrons, then the number of fissions doubles each generation. In that case, in 10 generations there are 1,024 fissions and in 80 generations about 6 x 10 **23** (a mole) fissions.

Schematic diagram of a nuclear plant



Nuclear Reactor

- A Nuclear reactor is an apparatus in which nuclear fission is produced in the form of a controlled self sustaining chain reaction.

Classification of nuclear reactor

1. According to chain reacting system, neutron energies at which the fission occurs:

a. Fast reactors

b. Intermediate reactor

c. Slow reactors

2**. Fuel moderator assembly**

a. Homogenous reactors: fuel and moderator are mixed to form a homogenous material,

b. Heterogeneous reactors: the fuel is used in the form of rods, plates, lamps or wires and the moderator surrounds the each fuel element in the reactor core.

Nuclear Reactor

3. Fuel State

a. Solid

b. Liquid

c. Gas

4. Fuel material

a. Natural uranium with 235U(occurs in nature)

b. Enriched uranium with more than 0.71% of 235U

c. 239Pu, 241Pu or 239Pu(man made)

Natural uranium (0.7%) and its contents increase upto 90% in enriched uranium.

5. Moderator

a. Water

b. Heavy water (D2O)

c. Graphite

d. Berylium or berylium oxide

e. Hydrocarbons or Hydrides.

Nuclear Reactor

6. Principal product:

a. Research reactor: To produce high neutron flux for research work.

b. Power reactor: To produce heat

c. Breeder reactor: produce fissionable material, convert fertile material to fissionable materials.

d. Production reactor: To produce isotopes, output is radioactive material used as source of radiation and tracers.

7. Coolant:

a. Air, carbon and helium cooled

b. Water or other liquid cooled

c. Liquid metal cooled

8. Construction of Core

a. Cubical
b. Spherical
c. Cylindrical
d. Slab
e. Octagonal

Nuclear Reactor

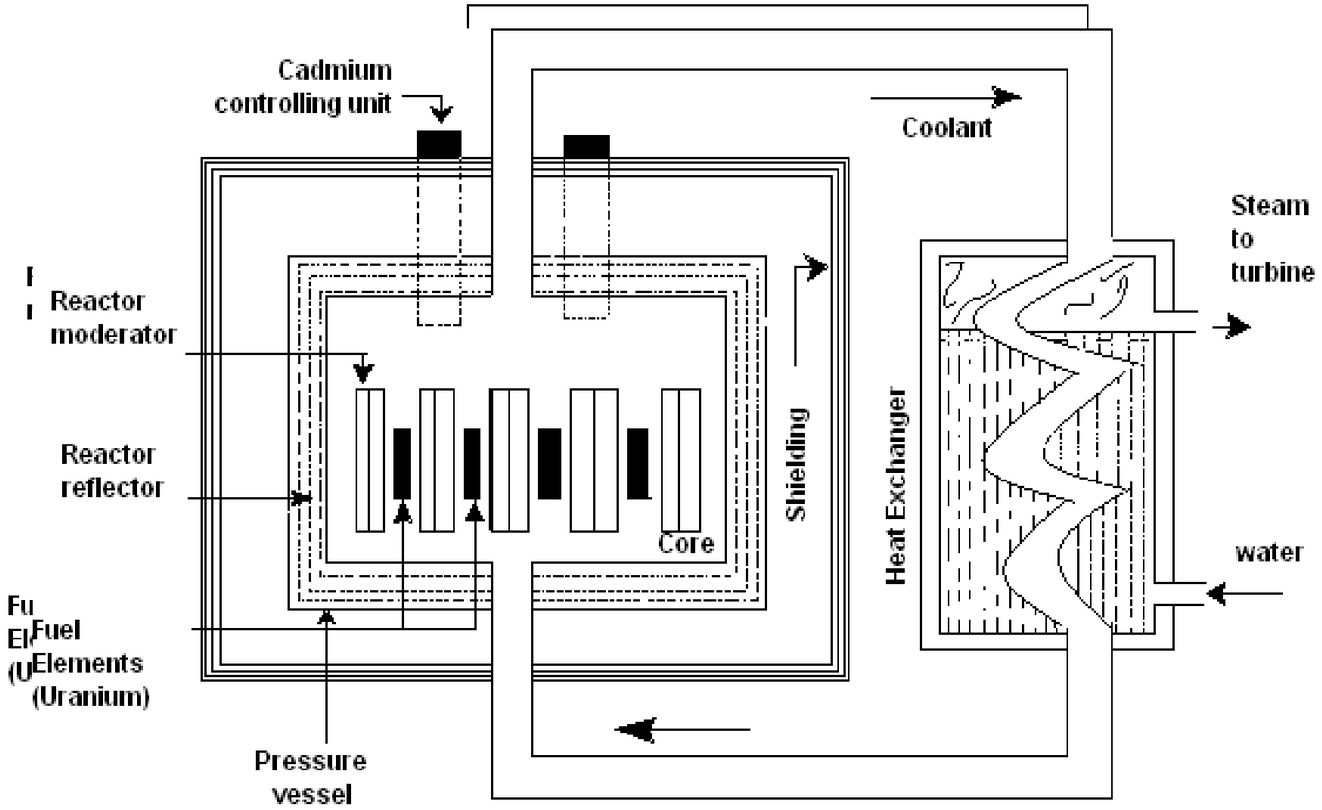


Fig.1.4. Nuclear Reactor

Nuclear Reactor

- **Reactor Core :**This is the main part of reactor which contain the fissionable material called **reactor fuel.** *Fission energy is liberated in the form of heat for operating power conversion equipment.* The fuel element are made of plate of rods of uranium.
- **Reactor reflector :**The region surrounding the reactor core is known as **reflector.** Its function is to reflect back some of the neutron that leak out from the surface of core.
- **Control rods :**The rate of reaction in a nuclear reactor is controlled by control rods. Since the neutron are responsible for the progress of chain reaction, suitable neutron absorber are required to control the rate of reaction.

a. For starting the reactor
b. For maintaining at that level. To keep the production at a steady state
c. For shutting down the reactor under normal or emergency conditions

- **Cadmium** and **Boron** are used as control rods.

Nuclear Reactor

- **Moderator :**The function of a reactor is to slow down the fast neutron.The moderator should have

- High slowing down power
- Non corrosiveness
- High melting point for solids and low melting point for liquids.
- Chemical and radiation stability.
- High thermal conductivity
- Abundance in pure form.
- The commonly used moderator are :

  (I) Ordinary water

  (II) Heavy water

  (III) Graphite.

Nuclear Reactor

- **Coolant :**The material used to remove heat produce by fission as fast as liberated is known as **reactor coolant.** The coolant generally pumped through the reactor in the form of liquid or gas. It is circulated throughout the reactor so as to maintain a uniform temperature.

.

- **Measuring Instruments:** Main instrument required is for the purpose of measuring **thermal neutron flux** which determines the power developed by the reactor.

- **Shielding:** The large steel recipient containing the core, the control rods and the heat-transfer fluid.
- All the components of the reactor are container in a solid concrete structure that guarantees further isolation from external environment. This structure is made of concrete that is one-metre thick, covered by steel.

Pressurized water reactor(PWR)

In a typical commercial pressurized light-water reactor, can use both natural and highly enriched fuels.

Primary Circuit Secondary Circuit

(1) the core inside the reactor vessel creates heat,

(2) pressurized water in the primary coolant loop carries the heat to the steam generator. Pressurizer keep the pressure at 100kg/cm2 so that it doesn't boil.

(3) inside the steam generator, heat from the steam, and

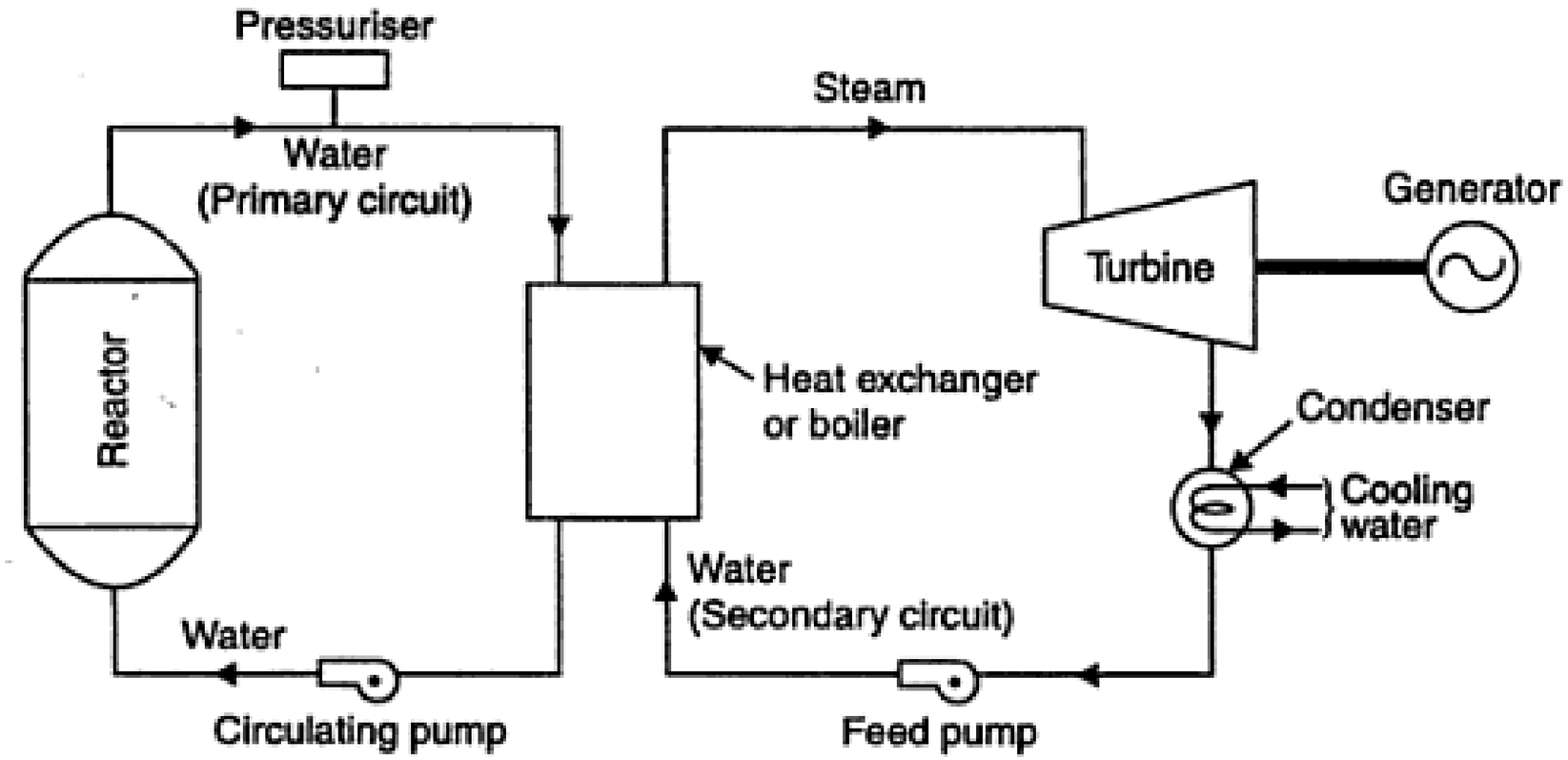
(4) the steam line directs the steam to the main turbine, causing it to turn the turbine generator, which produces electricity.

The unused steam is exhausted in to the condenser where it condensed into water. The resulting water is pumped out of the condenser with a series of pumps, reheated and pumped back to the steam generators.

Water acts both as **coolant** and **moderator**

It produces on **saturated steam**

Pressurized water reactor(PWR)



Pressurized water reactor(PWR)

Advantages of PWR :

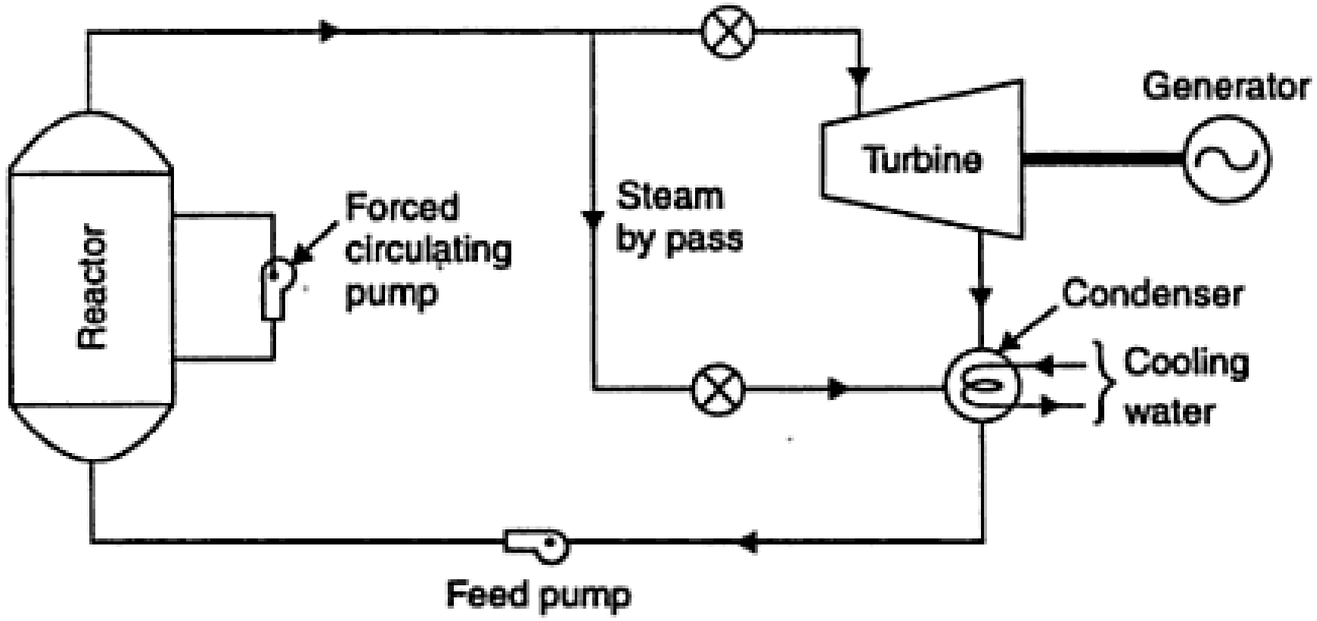
1. Water used in reactor (as coolant, moderator and reflector) is cheap and easily available.
2. The reactor is compact and power density is high.
3. Fission products remain contained in the reactor and are not circulated.
4. A small number of control rods is required.
5. There is a complete freedom to inspect and maintain the turbine, feed heaters and condenser during operation.
6. This reactor allows to reduce the fuel cost extracting more energy per unit weight of fuel as it is ideally suited to the utilisation of fuel designed for higher burn-ups.

Disadvantages :

1. Capital cost is high as high primary circuit requires strong pressure vessel.
2. In the secondary circuit the thermodynamic efficiency of this plant is quite low.
3. Fuel suffers radiation damage and, therefore its reprocessing is difficult.
4. Severe corrosion problems.
5. It is imperative to shut down the reactor for fuel charging which requires a couple of month's time.
6. Low volume ratio of moderator to fuel makes fuel element design and insertion of control rods difficult.
7. Fuel element fabrication is expensive.

Boiling Water Reactor(BWR)

- Uses Enriched fuel.
- The plant can safely operate using natural convection within the core or forced circulation.



Boiling water reactor.

Boiling Water Reactor(BWR)

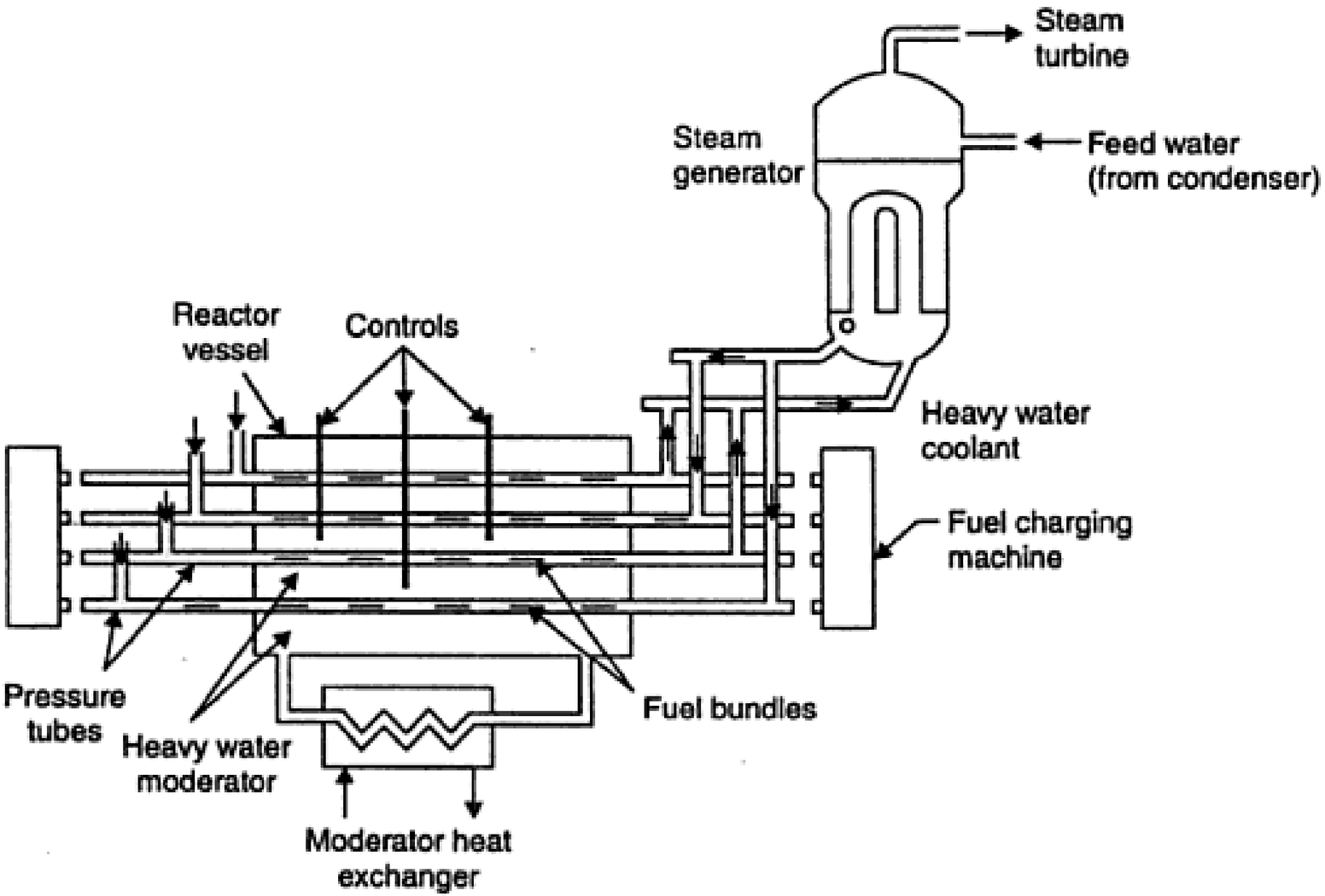
Advantages of BWR :

1. Heat exchanger circuit is eliminated and consequently there is gain in thermal efficiency and gain in cost.
2. There is use of a lower pressure vessel for the reactor which further reduces cost and simplifies containment problems.
3. The metal temperature remains low for given output conditions.
4. The cycle for BWR is more efficient than PWR for given containment pressure, the outlet temperature of steam is appreciably higher in BWR.
5. The pressure inside the pressure vessel is not high so a thicker vessel is not required.

Disadvantages :

1. Possibility of radioactive contamination in the turbine mechanism, should there be any failure of fuel elements.
2. More elaborate safety precautions needed which are costly.
3. Wastage of steam resulting in lowering of thermal efficiency on part load operation.
4. Boiling limits power density ; only 3 to 5% by mass can be converted to steam per pass through the boiler.
5. The possibility of "burn out" of fuel is more in this reactor than PWR as boiling of water on the surface of the fuel is allowed.

CANDU(Canadian-Deuterium-Uranium) REACTOR



CANDU(Canadian-Deuterium-Uranium) REACTOR

- Heavy water is used as moderator and coolant as well as neutron reflector.
- Natural Uranium(0.7% 235U) is used as fuel.
- In CANDU reactor the moderator and coolant are kept separate.

Reactor Vessel and Core: Steel cylinder with horizontal axis, length and diameter are 6m and 8m. Vessel is penetrated by 380 horizontal channels called pressure tubes. The channels contain the fuel elements, and pressurized coolant flows along the channel and around fuel elements to remove heat generated by fission.

- The temperature 370deg C and high pressure 10Mpa coolant leaving the reactor core enters the steam generator.

Fuel: Uranium Oxide as small cylinder pellets, packed in corrosion resistance zirconium alloy tube to form fuel rod.

CANDU(Canadian-Deuterium-Uranium) REACTOR

Control and Protection system:

Vertical control system:

Control and protection system :

There are the various types of vertical control system incorporated in the CANDU reactor :

— A number of strong neutron absorber *rods of cadmium* which are used mainly for *reactor shut-down* and *start-up*.

— In addition to above there are other *less strongly*, absorbing rods to *control power varia tions* during reactor operation and *to produce an approximately uniform heat* (power) distribution throughout the core.

In an emergency situation, the shut-down rods would immediately drop into the core, followed, if necessary by the injection of a gadolinium nitrate solution into the moderator.

Steam system. Steam system is discussed below :

— The respective ends of the pressure tubes are all connected into inlet and outlet headers.

— The high temperature coolant leaving the reactor passes out the outlet header to a steam generator of the conventional inverted U-tube and is then pumped back into the reactor by way of the inlet header.

— Steam is generated at a temperature of about 265°C.

CANDU(Canadian-Deuterium-Uranium) REACTOR

Advantages of CANDU reactor :

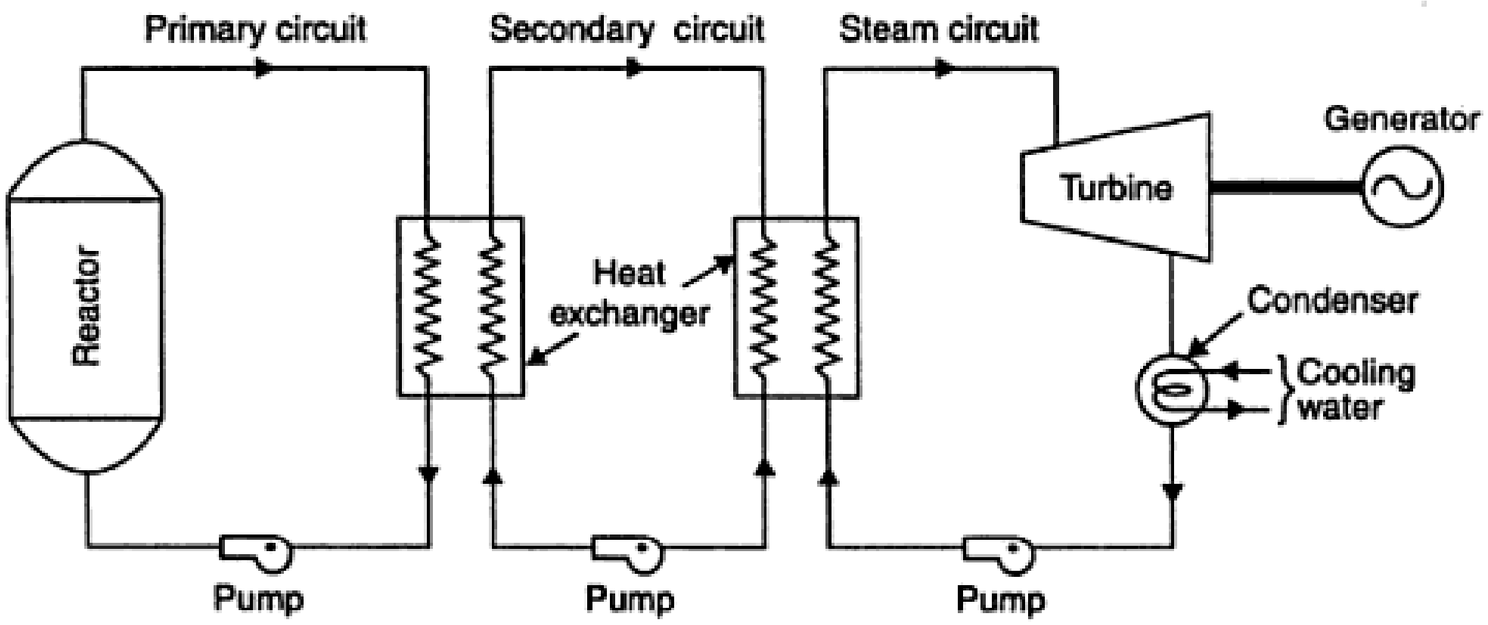
1. Heavy water is used as moderator, which has higher multiplication factor and low fuel consumption.
2. Enriched fuel is not required.
3. The cost of the vessel is less as it has not to withstand a high pressure.
4. Less time is needed (as compared to PWR and BWR) to construct the reactor.
5. The moderator can be kept at low temperature which increases its effectiveness in slowing down neutrons.

Disadvantages :

1. It requires a very high standard of design, manufacture and maintenance.
2. The cost of heavy water is very high.
3. There are leakage problems.
4. The size of the reactor is extremely large as power density is low as compared with PWR and BWR.

Liquid Metal Cooled Reactor

- Sodium graphite reactor is liquid metal reactor.
- Sodium works as a coolant and graphite works as moderator.
- Sodium boils at 880deg C, sodium is first melted by electric heating system and be pressurized to 7bars. The liquid sodium is then circulated by the pump.



Liquid metal-cooled reactor.

Working - Liquid Metal Cooled Reactor

(*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. The steam generated from this boiler will be superheated. Feed water from the condenser enters the boiler, the heated sodium-potassium passing through the tubes gives it heat to the water thus converting it into steam. The sodium-potassium liquid in the second circuit is then pumped back to the intermediate heat exchanger thus making it a closed circuit.

- **Breeder Reactor : Almost same as Liquid Metal Cooled Reactor**

Advantages of SGR :

1. The sodium as a coolant need not be pressurised.
2. High thermal efficiency at low cost.
3. The low cost graphite moderator can be used as it can retain its mechanical strength and purity at high temperatures.
4. Excellent heat removal.
5. High conversion ratio.
6. Superheating of steam is possible.
7. The size of the reactor is comparatively small.
8. The neutron absorption cross-section of sodium is low and, therefore, it is best suited to thermal reactor with slightly enriched fuel.

Disadvantages :

1. Sodium reacts violently with water and actively with air.
2. Thermal stresses are a problem.
3. Intermediate system is necessary to separate active sodium from water.
4. Heat exchanger must be leak proof.
5. It is necessary to shield the primary and secondary cooling systems with concrete blocks as sodium becomes highly radioactive.
6. The leak of sodium is very dangerous as compared with other coolants.

Advantages and disadvantages of Nuclear Power plants

Some of the *major advantages* of nuclear power plants are :

1. A nuclear power plant *needs less space* as compared to other conventional power plant of equal size.
2. Nuclear power plants are well suited to meet large power demands. They give better performance at high load factors (80 to 90%).
3. Since the fuel consumption is very small as compared to conventional type of power plants, therefore, there is *saving in cost of the fuel transportation.*
4. The nuclear power plants, besides producing large amount of power, *produce valuable fissible material* which is produced when the fuel is renewed.
5. The operation of a nuclear power plant is *more reliable.*
6. Nuclear power plants are not affected by adverse weather conditions.
7. Bigger capacity of a nuclear power plant is an additional advantage.
8. The expenditure on metal structures piping, storage mechanisms is much lower for a nuclear power plant than a coal burning power plant.

Disadvantages/Limitations

1. The *capital cost* of a nuclear power station is always *high.*
2. The *danger of radioactivity* always persists in the nuclear stations (inspite of utmost precautions and care).
3. These plants *cannot be operated at varying load efficiently.*
4. The *maintenance cost is always high* (due to lack of standardisation and high salaries of the trained personnel in this field of specialisation).
5. The disposal of fission products is a big problem.
6. Working conditions in nuclear power station are always detrimental to the health of the workers.

Nuclear Waste Disposal

- **Geological Disposal**
- The process of geological disposal centers on burrowing nuclear waste into the ground to the point where it is out of human reach.
- The waste needs to be properly protected to stop any material from leaking out. Seepage from the waste could contaminate the water table if the burial location is above or below the water level. Furthermore, the waste needs to be properly fastened to the burial site and also structurally supported in the event of a major seismic event, which could result in immediate contamination.

- **Reprocessing**
- Reprocessing has also emerged as a viable long term method for dealing with waste. As the name implies, the process involves taking waste and separating the useful components from those that aren't as useful. Specifically, it involves taking the **fissionable material** out from the irradiated nuclear fuel..

Nuclear Waste Disposal

- **Transmutation**
- Transmutation also poses a solution for long term disposal. It specifically involves converting a chemical element into another less harmful one.
- Common conversions include going from Chlorine to Argon or from Potassium to Argon.
- The driving force behind transmutation is chemical reactions that are caused from an outside stimulus, such as a proton hitting the reaction materials.
- **Natural transmutation** can also occur over a long period of time. Natural transmutation also serves as the principle force behind geological storage on the assumption that giving the waste enough isolated time will allow it to become a non-fissionable material that poses little or no risk

Nuclear Plant Site selection

- Proximity to load center
- Population distribution
- Land Use: not agricultural
- Meteorology: wind direction
- Geology: bearing capacity of soil
- Seismology: low seismic activity
- Hydrology: Near a water source

Safety Measures for Nuclear Power Plants

Three main sources of radioactive contamination are:

- Fission of nuclei or nuclear fuels
- The effect of neutron fluxes on the heat carried in the primary cooling system and on the ambient air.
- Damage of shell of fuel elements.

All the above can cause health hazards to workers , communing and natural surroundings.

- A nuclear power plant should be constructed away from human habitation.(160km radius)
- The materials used for construction should be of required standards.
- Waste water should be purified.
- Should have a proper safety system, plant could be shut down when required.
- While disposing off the wastes it should be ensured that it doesn't contaminate the river or sea.

NUCLEAR MATERIAL

- The nuclear material most commonly used for nuclear energy and nuclear weapons are uranium and plutonium in various forms.

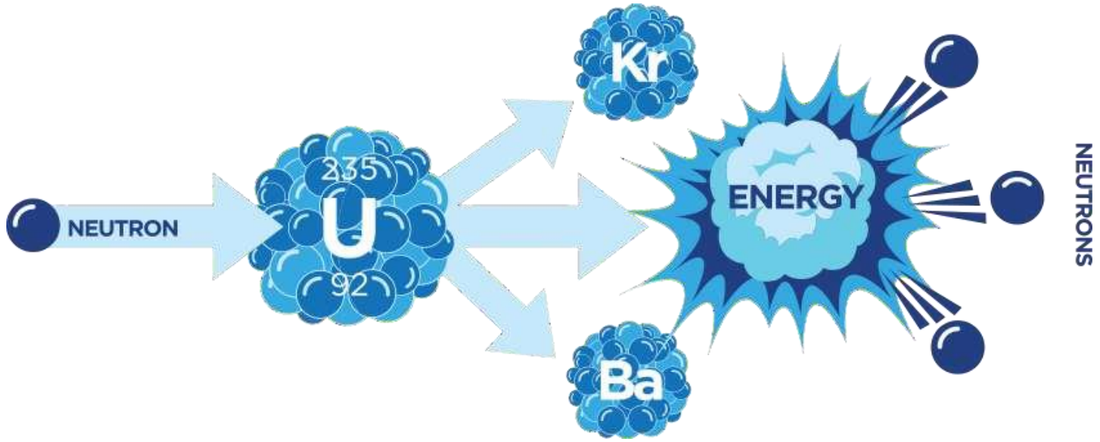
A material that possesses radioactive properties.

- Nuclear material such as Uranium 233 and 235 are used to produce nuclear energy.
- Nuclear material further differentiated into
  - Source material
  - Fissile material
  - Fissionable material
  - Fusion able material

FISSILE MATERIAL

In nuclear engineering, fissile material is material that is capable of undergoing fission reaction after absorbing thermal (slow or low energy) neutron. Theses materials are used to fuel thermal nuclear reactions.

- *For heavy nuclides with atomic number of higher than 90,most* of fissile isotopes meet the fissile rule.



ISOTOPES OF FISSILE MATERIALS

Fissile nuclides in nuclear fuel includes:

Uranium-235 which occurs in natural uranium and enriched uranium.

Plutonium-239 bred from U^{238} by neutron capture

Plutonium-241 bred from plutonium-240 by neutron

capture. The Pu^{240} comes from Pu^{239} by the same process.

Uranium-233 bred from thorium-232 by same process.

- Pu^{239}
- Pu^{241}
- U^{233}
- U^{235}

FUSION ABLE MATERIAL

First time during 1970s Hans Bethe built the first powerful fusion experiment. In fusion able material is includes burning of a mixture of Deuterium and Tritium. When heated to millions of degrees, the kinetic energy begins to overcome the natural electrostatic repulsion between nuclei, the fusion takes place. This reaction gives off an alpha particle and high energy neutron.

- Deuterium can be obtained by separation of hydrogen isotope in sea water. Tritium has short half life so only trace amounts are found in nature

OTHER MATERIALS

- **Fissionable Materials:** consist of isotopes that are capable of undergoing nuclear fission after capturing either fast neutron or thermal neutron. Typical fissionable materials:

- **Fissile material** consist of fissionable isotopes that are capable of undergoing nuclear fission only after capturing a thermal neutron. ^{238}U is not fissile isotope, because ^{238}U cannot be fissioned by thermal neutron.

- **Fertile Materials:** consist of isotopes that are not fissionable by thermal neutrons, but can be converted into fissile isotopes (after neutron absorption and subsequent nuclear decay). Typical fertile materials: ^{238}U, ^{232}Th.

EFFICIENCY OF POWER PLANTS

- In general terms, efficiency is the output of a process compared to the input.

- The electric power plant efficiency η is defined as the ratio between useful electricity output from the generating unit, in a specific time unit, and the energy value of the energy source supplied to the unit, within the same time.

- In power plant we have three types of efficiency:-

1.Heat rate (energy efficiency)
2.Operational efficiency:- it is of two types:- 1. Capacity factor
2. Load factor
3.Economic efficiency

HEAT RATE

- Heat rate is a term commonly used in power stations to indicate the power plant efficiency. The heat rate is the inverse of the efficiency: a lower heat rate is better.

- Overall thermal performance or energy efficiency for a power plant for a period can be defined as

$$\varphi_{hr} = H / E$$

where

φ_{hr} = heat rate (Btu/kWh, kJ/kWh)

H = heat supplied to the power plant for a period (Btu, kJ)

E = energy output from the power plant in the period (kWh)

EXAMPLE : To express the efficiency of a generator or power plant as a percentage, divide the equivalent Btu content of a kWh of electricity (which is 3,412 Btu) by the heat rate. For example, if the heat rate is 10,500 Btu, the efficiency is 33%. If the heat rate is 7,500 Btu, the efficiency is 45%.

OPERATIONAL EFFICIENCY

- Operational efficiency is the ratio of the total electricity produced by the plant during a period of time compared to the total potential electricity that could have been produced if the plant operated at 100 percent in the period.
- Operational efficiency can be expressed as

$$\mu_{oe} = (100)\ E / E_{100\%}$$

where

μ_{eo} = operational efficiency (%)

E = energy output from the power plant in the period (kWh) $E_{100\%}$ = potential energy output from the power plant operated at 100% in the period (kWh)

Capacity Factor

The capacity factor for a power plant is the ratio between average load and rated load for a period of time and can be expressed as

$$\mu_{cf} = (100)\, P_{al} / P_{rl}$$

where

μ_{cf} = capacity factor (%)

P_{al} = average load for the power plant for a period (kW) P_{rl} = rated capacity for the power plant (kW)

Load Factor

Load factor for a power plant is the ratio between average load and peak load and can be expressed as

$$\mu_{lf} = (100)\, P_{al} / P_{pl}$$

where

μ_{lf} = load factor (%)

P_{pl} = peak load for the power plant in the period (kW)

Economic Efficiency

- Economic efficiency is the ratio between production costs, including fuel, labor, materials and services, and energy output from the power plant for a period of time.

Economic efficiency can be expressed as

$$\varphi_{ee} = C / E$$

where

φ_{ee} = economic efficiency (cents/kW, euro/kW, ...) C = production costs for a period (cents, euro, ..)

E = energy output from the power plant in the period (kWh)

Benefits of improving efficiency

- Better power plant efficiency reduces consumption of fuel, which in turn reduces emissions, so saving are also achieved in the cost of emission allowances.
- Power plant availability have direct impact to production, unplanned failures will decrease the production and at the same time the plants' profitability.
- Energy production costs can be significantly reduced by improving energy efficiency of the power plant. This has direct impact on fuel consumption which account for half of production costs.

Economic Efficiency

JECRC Foundation

Thank you!

STAY HOME, STAY SAFE