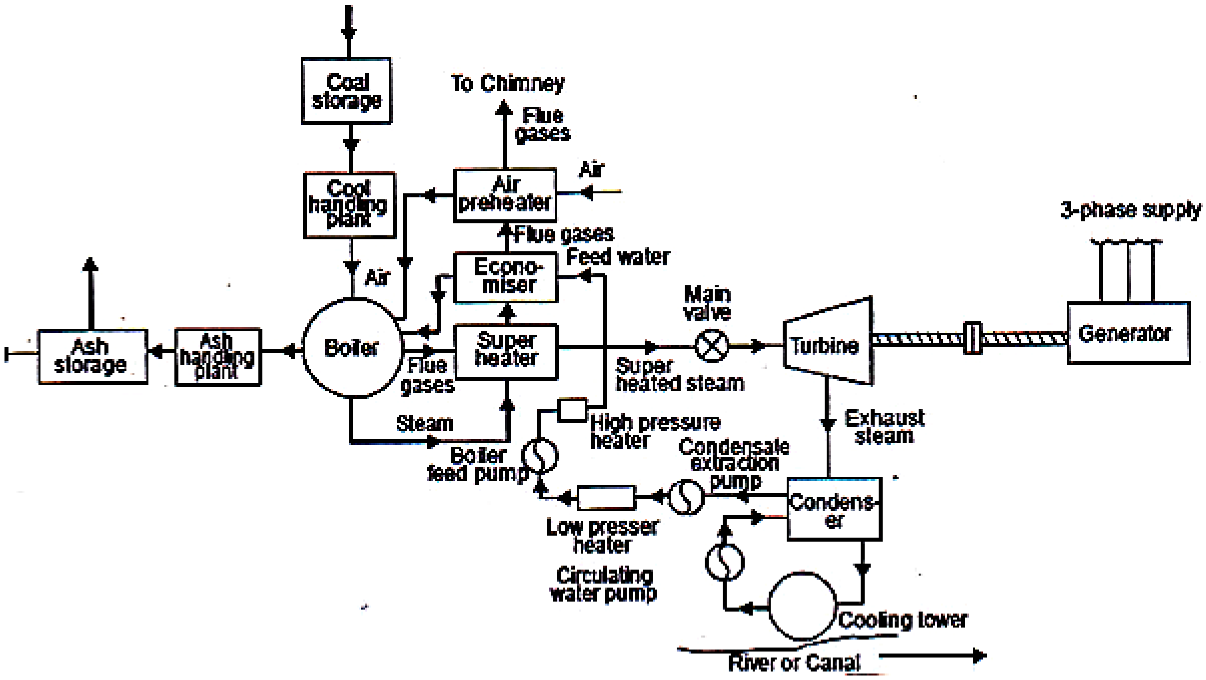
Unit-II
CONVENTIONAL ENERGY SOURCES

COAL FIRED STEAM THERMAL POWER PLANT: (April/May 2012) (Nov 2013) (May 2016) (Nov 2011) (Nov 2012)

Steam is the most common working fluid used in steam/thermal power plant because of its many desirable characteristics, such as low cost, availability and high enthalpy of vaporization. The general arrangement and layout of basic elements of thermal power plant isshown below.



A thermal power plant can be roughly divided into three segments

(1) The furnace boiler and auxiliaries

(2) The turbine which includes condenser, pump, feed water heaters and rejection system.

(3) The electric generator.

Working:

Feed water flowing into the boiler is first preheated in the economiser, which recover the part or heat from the flue gases flowing to the chimney and then going to the atmosphere. This increases the efficiency as less heat must be supplied to the boiler.

The steam generated in the boiler may be wet or dry. It is superheated in the super heater which again takes the heat from the flue gases moving towards the chimney.

The superheated steam is supplied to the turbine which generated power.

In condenser the latent heat of vaporization of steam is transferred to the circulating waste water supplied from cooling tower.

The boiler feed pump raises the feed water pressure and sends water to boiler through high pressure feed water heaters

Layout of thermal plant can be easily understood by dividing the plant components into four circuits.

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

Coal and ash circuit:

Coal arrives at storage yard and after necessary handling it passes on to the furnace through fuel feeding system. In case of pulversing system, coal is pulverised and then goes to the fuel burners. Ash resulting from combustion of coal gets collected at the ash pit and is removed to ash storage yard by ash handling equipment.

Air and gas circuit:

Air is taken in from atmosphere through forced draught or induced draught fans and passes to the furnace through air preheater, where it has been heated of the flue gases which pass to chimney via preheater. The hot gases of combustion first flow through boiler tubes, and super heater tubes in furnace then through economiser and then finally through air preheater and then discharges through chimney to the atmosphere.

Feed water and steam circuit:

The condensate leaving the condenser is first heated in a closed water heaters, The steam from the turbine is used to heat the feed water in the heaters. In boiler drum and tubes, water circulates due to natural circulation. Wet steam from drum further is heated up in pre heater. Steam then expands in turbine and produces power. From there it is exhausted in to condenser. The condensate is collected in hot well. Then it goes to feed water heaters, economiser and to the boiler. Make up water is added in the condenser after purification.

Cooling water circuit:

The condenser requires cooling water to condense the exhaust steam. The water is cooled in cooling tower or in cooling ponds and reused again and again. Some make up cooling water is added in the circuit.

Advantages and disadvantages of Thermal power plants

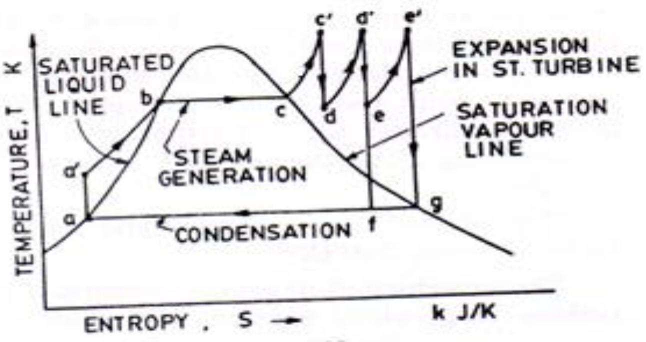
Advantages:

1. They can be located very conveniently near the load centres.
2. Does not require shielding like required in nuclear power plants. Unlike nuclear power plants whose power production method is difficult, for thermal power plants it is easy if compared.
3. Transmission costs are reduced as they can be set up near the industry.
4. The portion of steam generated can be used as process steam in different industries.
5. Steam engines and turbines can work under 25% of overload capacity.
6. Able to respond changing loads without difficulty.

Disadvantages:

1. Large amounts of water are required.
2. Great difficulties experienced in coal handling and disposal of ash.
3. Takes long time to be erected and put into action.
4. Maintenance and operating costs are high.
5. With increase in pressure and temperature, the cost of plant increases.
6. Troubles from smoke and heat from the plant.

Rankine Cycle (for Steam Turbine)

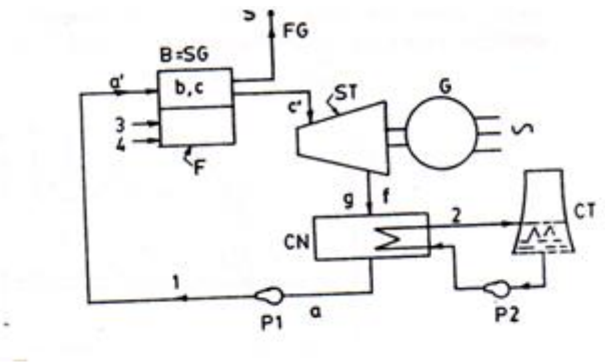


a—a' Pumping of feed-water into boiler
a—b Heating of water in boiler to raise temperature to boiling point.
b-c Evaporation in boiler, conversion to saturated steam.
c—c' Superheating of steam
c'—d Expansion in turbine stage
d-d' Reheating of steam to increase temperature and superheat
d'-e Expansion in steam turbine buckets
e—e' Reheating of steam to increase temperature and superheat
e'—g Expansion in turbine stage

The four processes in the Rankine cycle

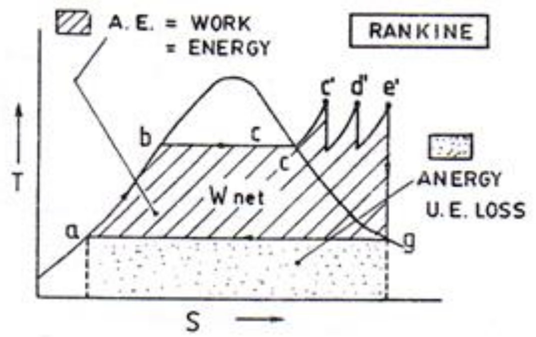
There are four processes in the Rankine cycle. These states are identified by numbers (in brown) in the diagram to the left.

- **Process a-a'**: The working fluid is pumped from low to high pressure, as the fluid is a liquid at this stage the pump requires little input energy.
- **Process a'-c**: The high pressure liquid enters a boiler where it is heated at constant pressure by an external heat source to become a dry saturated vapour. The input energy required can be easily calculated using mollier diagram or h-s chart or enthalpy-entropy chart also known as steam tables.
- **Process c-d**: The dry saturated vapour expands through a turbine, generating power. This decreases the temperature and pressure of the vapour, and some condensation may occur. The output in this process can be easily calculated using the Enthalpy-entropy chart or the steam tables.
- **Process d-a**: The wet vapour then enters a condenser where it is condensed at a constant temperature to become a saturated liquid.



Efficiency of Rankine Cycle

The total area within the closed cycle on TS diagram is equal energy and net work. Also the area under the low temperature exhaust line is the energy. (Heat is not converted to work but lost)



Applying these principles to the Rankine cycle,

$$\eta = \frac{W_{net}}{Heatinput}$$

$$\frac{Areaenclosed(Hatched)}{TotalArea(nHatched + Dotted)}$$

- **Typical efficiency of the system is 25% to 30 %**

$$\eta = \frac{Q_1 - Q_2}{Q_1}$$

Q1 = Heat supplied(hatched plus dotted)

Q2 = Heat rejected(dotted)

Energy Conversions in Coal fired steam turbine power plant

Coal	→	Furnace Steam Generator	→	Steam Turbine	→	Synchronous Generator AC, 3 PH, 50 Hz	→	Supply of Energy
Chemical Energy (Fuel Plus Auxiliary Power	→	Thermal Energy (Steam)	→	Mechanical Energy (Shaft)	→	Electrical Energy (Generator)	→	Supply of Energy (to Load)

Note :

Input Energy	=	Fuel + Auxiliary Energy to Station and Units
Output Energy	=	Electrical Energy Supplied by Generator Units
Losses	=	Chemical, Thermal, Mechanical, Electrical, Energy Losses in Station Auxiliaries, Generator, Turbine, Boiler etc.

The steam thermal plant has following energy-losses:

- Furnace and Boiler Losses, losses in exhaust flue gases
- Heat losses from steam pipelines and devices
- Losses in Condenser and Cooling tower
- Losses in Auxiliary Devices like Boiler feed pump,
- Electrical Losses in Generator, Transformers, Auxiliary Motors, coal handling, fuel preparation, draft fans etc. Condensate pump, air supply system etc.
- Electrical Losses in Generator, Transformers, Auxiliary Motors, drives etc.

The efficiency is improved by

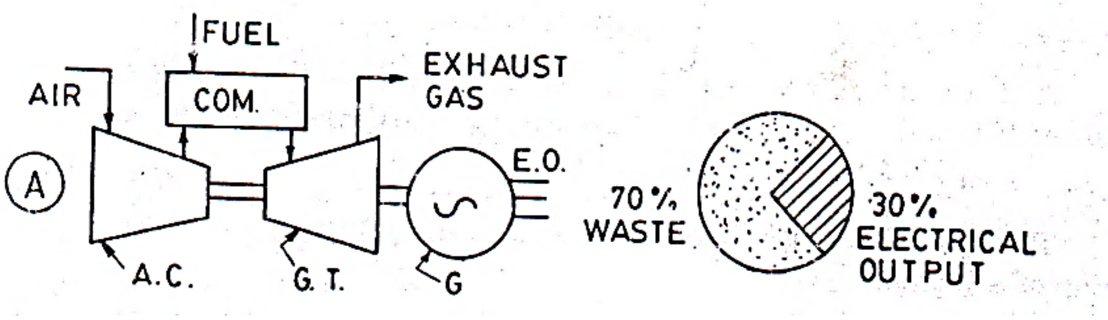
- Improving combustion and obtaining maximum heat from fuel;
- Recovery of heat instead of wasting it;
- Better operations and maintenance of Boiler, Turbine, Generator, Condenser etc.
- Improvement in basic thermodynamic cycle.
- Steam cycle has inherent disadvantage of low temperature operation and lesser efficiency due to carnot limitation. By using Combined Cycle, this limitation is overcome.

GAS TURBINE POWER PLANT (Nov/Dec 2014) (April/May 2014) (Nov 2012) (May 2012)

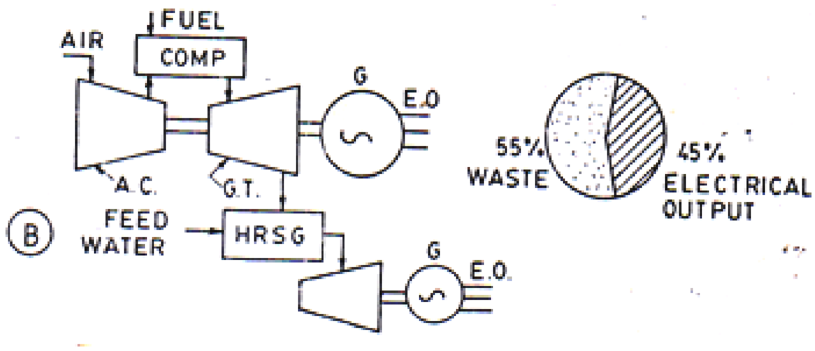
A gas turbine is similar to the steam turbine but hot gas is used to run the turbine.

VARIOUS OPTIONS

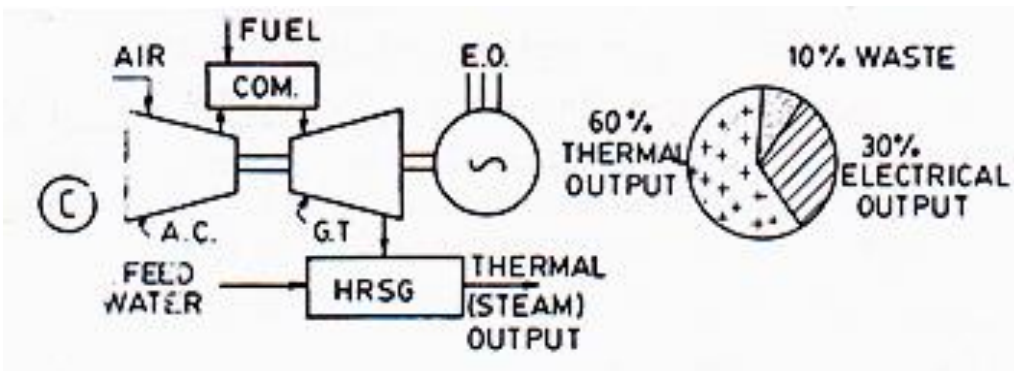
Simple Cycle



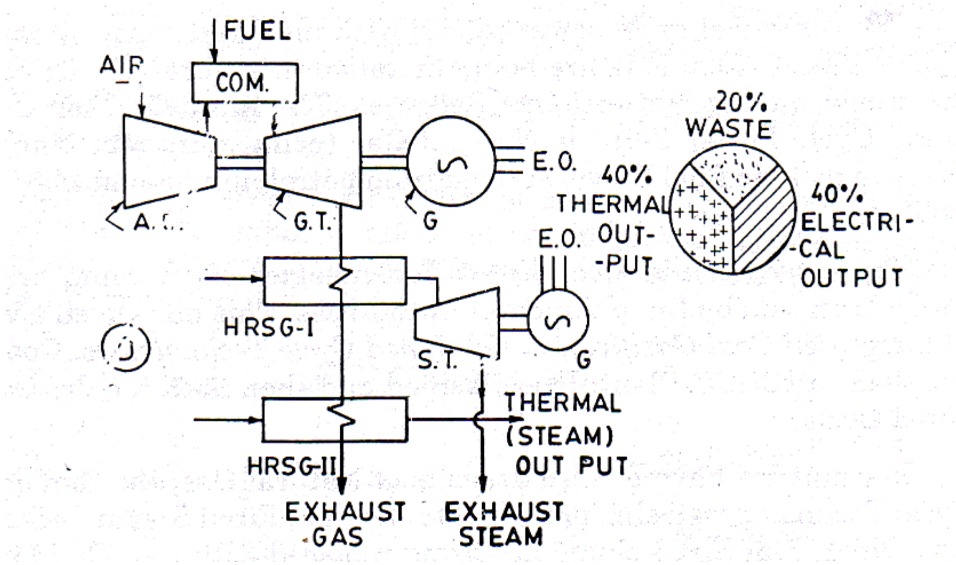
Combined cycle



Combined heat and power gas turbine cycle



Combined heat and power combined cycle



Classification of Gas Turbines

1. According to the cycle of operation
    a. Open cycle gas turbines
    b. Closed cycle gas turbines, and
    c. Semi closed cycle gas turbines
2. According to the type of fuel
    a. Liquid
    b. Gas
    c. Solid

Advantages of gas turbine engines

- Very high power-to-weight ratio, compared to reciprocating engines;
- Smaller than most reciprocating engines of the same power rating.
- Fewer moving parts than reciprocating engines.
- Low operating pressures.
- High operation speeds.

Disadvantages of gas turbine engines

- Cost is very high
- Less efficient than reciprocating engines at idle speed
- Longer start up than reciprocating engines
- Less responsive to changes in power demand compared to reciprocating engines

Application of Gas Turbine Power Plant

The gas turbine can be used as base load plant where the gas turbine fuel is relatively cheap. It is mainly used in the aircraft engines, electric power generation, marine propulsion etc.

LAYOUT OF GAS TURBINE POWER PLANT

Main Components of Gas Turbine

A gas turbine unit consists of the following essential parts:

1. **Compressor:**

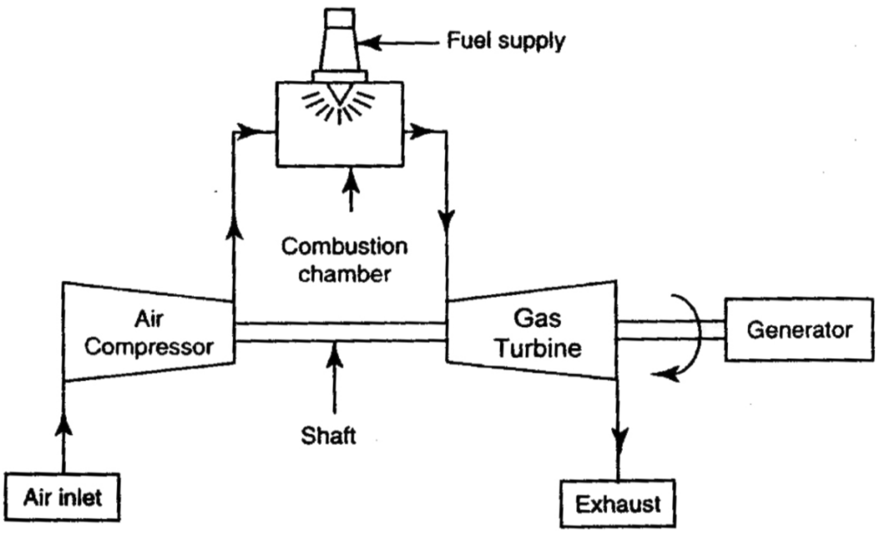
    The air compressor used in gas turbines is of rotary type mainly axial flow turbines. It draws air from the atmosphere and compressed to the required pressure. This compressed air is then transferred to the combustion chamber.

2. **Combustion chamber:**
   The compressed air from the air compressor is drawn to combustion chamber. The fuel is injected to the air and then ignited in the combustion chamber. It increases the pressure and temperature of the air instantaneously.
3. **Turbine:**
   The high pressure and temperature air is expanded in the turbine. Turbine is also of rotary type. During the expansion, the heat energy in the gas is converted into mechanical energy. This mechanical energy is gain converted into electrical energy by using generator.

Working of Open Cycle Gas Turbine

The most basic gas turbine unit is one operating on the open cycle in which a rotary compressor and a turbine are mounted on a common shaft as shown in figure below.

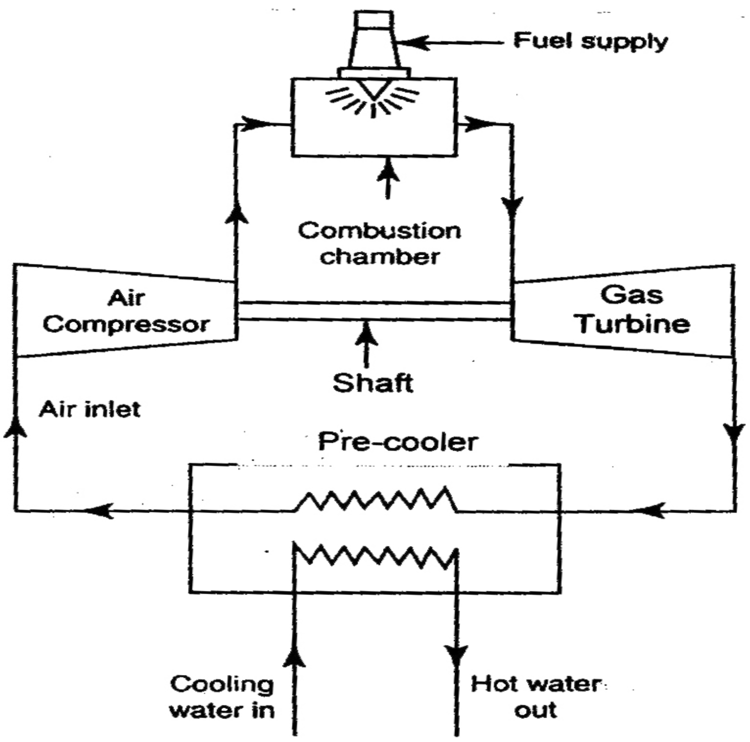
Air is drawn from the atmosphere into the compressor and compressed to pressure of 300 to 400kN/m^2. The compressed air is then entered into the combustion chamber where the energy is supplied by spraying fuel into the air and ignited by hot gases. The hot gases expand through the turbine to produce the mechanical power. Then the burned gases are exhausted to the atmosphere. Then fresh air is drawn into the compressor for the next cycle. The process is repeated again and again. Here, the compressor is driven by turbine itself. In order to achieve the network output from the unit, the turbine must develop more gross work output than the work required to drive the compressor and to overcome mechanical losses in the drive.



Working of Closed Cycle Gas Turbines

It consists of compressor, combustion chamber, gas turbine and pre cooler. The schematic diagram of a closed cycle gas turbine plant is shown in figure below.

In a closed cycle gas turbine, the air is compressed in air compressor isentropic ally to a required pressure and then passed through a combustion chamber where fuel injects to the air and ignited. The high temperature air from combustion chamber expands through a gas turbine where the heat energy is converted into mechanical energy. Then the exhaust gas from the gas turbine is passed through a pre-cooler where it is cooled at constant pressure with the help of circulating water to its original pressure. Then the same air is passed through the compressor again and again.



It is thus obvious in a closed cycle gas turbine the same air is continuously circulated repeatedly throughout the system. **Typical efficiency of the system is 27% to 38 %**

Comparison of Open and Closed Cycle Gas Turbines **(April 2013)**

s.no	Criterion	Closed Cycle Gas Turbine	Open Cycle Gas Turbine
1	Cycle of operation	It works on closed cycle. The working fluid is re circulated again and again. It is a clean cycle.	It works on open cycle. The fresh charge is supplied to each cycle and after combustion and expansion. It is discharged to atmosphere.
2	Working fluid	The gases other than the air like Helium or Helium-Carbon dioxide mixture can be used, which has more favourable properties.	Air-fuel mixture is used which leads to lower thermal efficiency.
3	Type of fuel used	Since heat is transferred externally, so any type of fuel; solid, liquid or gaseous or combination of these can be used for generation of heat.	Since combustion is an integral part of the system thus it requires high quantity liquid or gaseous fuel for burning in a combustion chamber.
4	Manner of heat input	The heat is transferred indirectly through a heat exchanger.	Direct heat supply. It is generated in the combustion chamber itself

5	Quality of heat input	The heat can be supplied from any source like waste heat from some process, nuclear heat and solar heat using a concentrator.	It requires high grade heat energy for generation of power in a gas turbine.
6	Efficiency	High thermal efficiency (45%) for given lower and upper temperature liquids.	Low thermal efficiency (30%) for same temperature limits.
7	Part load efficiency	Part load efficiency is better.	Part load efficiency is less compared to Closed cycle gas turbine.
8	Size of plant	Reduced size per MWh of power output.	Comparatively large size for same power output.
9	Blade life	Since combustion products do not come in direct contact of turbine blade, thus there is no blade fouling and longer blade life.	Direct contact with combustion products, the blades are subjected to higher thermal stresses and fouling and hence shorter blade life.
10	Control on power production	Better control on power production.	Poor control on power production.
11	Cost	Closed cycle gas turbine plant is complex and costly.	Open cycle gas turbine plant is simple and less costly.

Methods of improving the thermal efficiency of GAS turbine plant. (May 2016)

A clear understanding of the thermodynamic cycle is necessary in order to appreciate the efficient operation of the gas turbine i.e. production of largest mechanical energy with least fuel consumed. To achieve this end in a gas turbine, following steps in design and operation are necessary:

Turbine and compressor efficiencies: The turbine and compressor should be designed to give highest efficiency. Efficiencies obtained in present day designed compressors and turbines are of the order of 85 to 90% and future progress in this direction will be slow. Axial flow compressors are efficient than centrifugal compressors. Figure 4-4 illustrates the critical effect of compressor and turbine efficiencies on the thermal efficiency of the simple open gas turbine plant.

Effect of compressor intake temperature: The intake temperature of air, affects the temperature at the end of compression. The compressor work for a fixed pressure ratio is proportional to the absolute temperature at the inlet to compression, that is, T 1. Consequently, if the intake temperature is reduced and all other variables remain unchanged, the net power output is increased and the efficiency of the cycle is raised.

Effect of Turbine Inlet Temperature: The turbine efficiency is greatly increased by increasing turbine inlet temperature (fig. 4-5). A practical limitation to increasing the turbine inlet temperature, however, is the ability of materials available for the turbine blading to withstand the high rotative and thermal stresses. For a turbine inlet temperature range of 650° to 750°C, a simple gas turbine may realize an efficiency between 18 to 26 % , depending upon design. Considerable effort is being made to find new materials, coatings and techniques, to increase the permissible turbine inlet temperature.

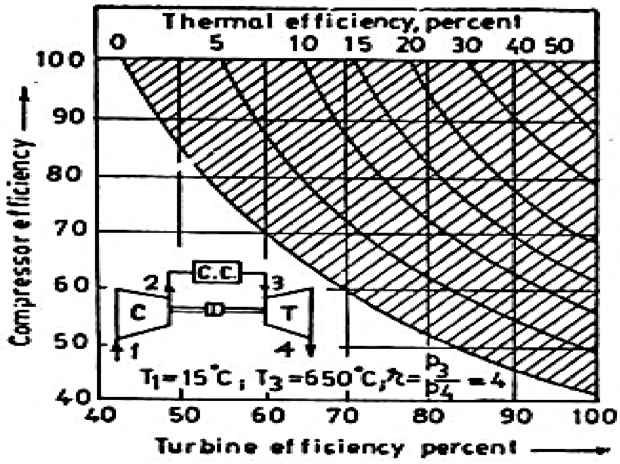


Fig. 4–4 Effect of compressor and turbine efficiencies on the overall thermal efficiency.

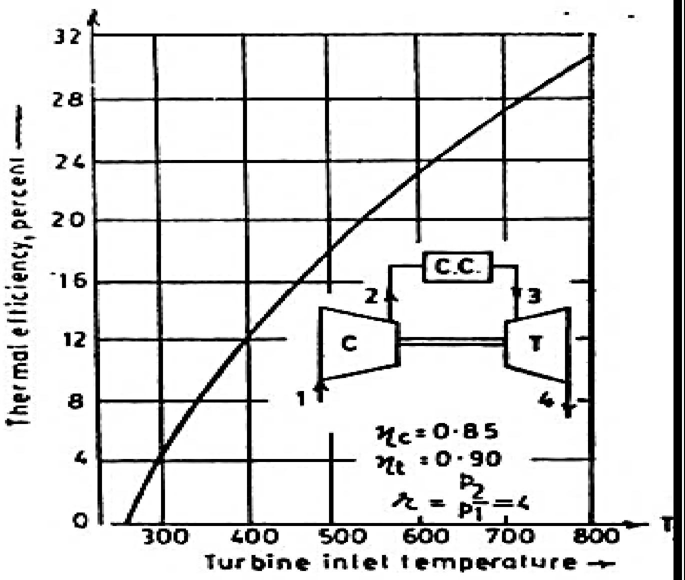


Fig. 4–5 Effect of turbine inlet temperature on thermal efficiency

Regeneration: In this method, a regenerator (heat exchanger) is used for utilising heat of exhaust gases from turbine, in pre-heating the compressed air before it enters the combustion chamber. The preheating of the compressed air reduces the fuel consumption and consequently improves the thermal efficiency. Regeneration is shown in fig. 4—6. As a result of regeneration, compressed air is preheated from 2 to 5 and exhaust gases are cooled from 4 to 6.

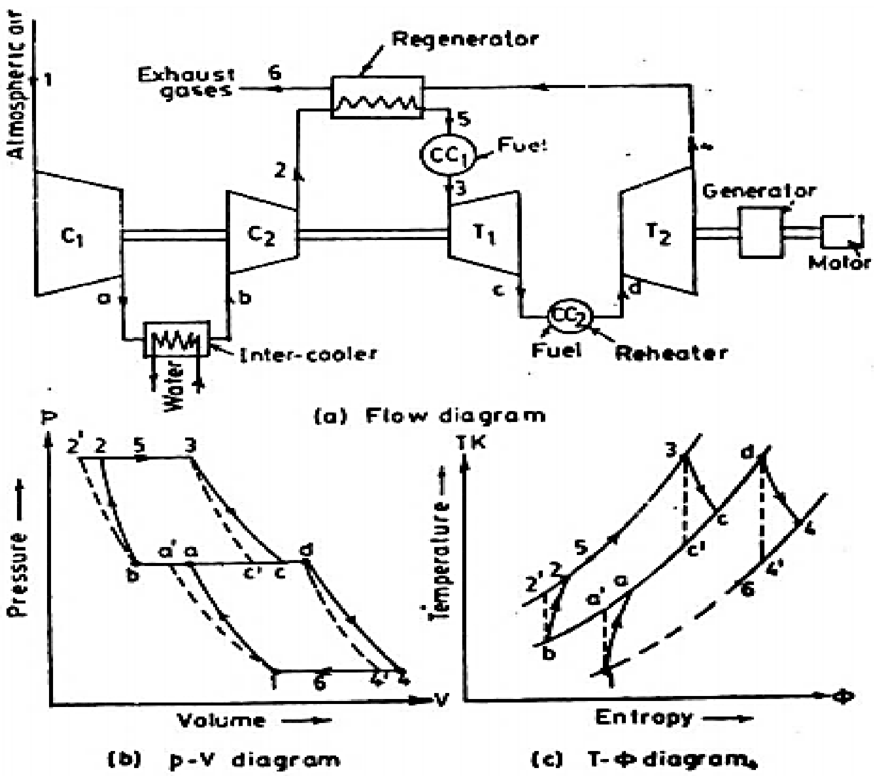


Fig. 4 – 6 Constant pressure open cycle with regeneration, intercooling and reheating.

Inter-cooling: The work required to compress air depends upon its temperature during compression. The efficiency of gas turbine is improved by adopting multi-stage compression with intercooling in between two stages as it reduces the work required to compress the air. The process a — b in fig. 4-6 shows intercooling of air.

Reheating: The expressions for thermal efficiency, for Brayton and Ericsson cycles, suggest that higher inlet temperature to the turbine result in improved efficiencies. Thus, to improve the efficiency, the temperature of the gases after partial expansion in the turbine is increased by reheating the gases, before gases start further stage of expansion. The process c - d in fig. 4-6 shows reheating. It becomes apparent therefore, that there are a number of ways to increase the efficiency of the gas turbine plant. It may be noted that gain in efficiency due to the provision of heat exchangers, intercoolers, and reheaters is achieved at the cost of increased pressure loss, increased weight and increased cost. In addition, modifications of the basic gas turbine plant have been developed, namely, closed, semi-closed system and free piston gas generators, which further increase the overall plant efficiency

Nuclear power plant and its properties.

FUELS FOR NUCLEAR FISSION REACTOR

Natural Uranium (U) and Thorium (Th) are radioactive materials found in minute quantities in nature mixed with earth's crust (and in ocean water yet to be commercially extracted/used). The natural ores containing Uranium or thorium are the primary resources of nuclear energy, which are subjected to complex, advanced processes to get desired "fuel" for Nuclear Reactors. The "fuel" fed to a reactor is an enriched fissile material (with U^{235} enrichment up to 2.5 to 3%).

Natural Uranium contains only a small amount of fissile U^{235}, and large amount of fertile U^{238}.

Natural Uranium 100% = (U^{235}: 0.71% + U^{238} : 99.29%).

The absorption of neutron by U^{238} produces Plutonium (Pu^{239}) a fissile material. If only Uranium were to be used as a fuel, the resources would be exhaust very quickly. Fortunately, Thorium, a fertile material is available in plenty. When a neutrons are absorbed by thorium a new isotope of Uranium U^{233} is produced, which is fissile. Plutonium and U^{233} can be used as fuel in nuclear reactors.

Natural ore contains a mixture of three isotopes:

- U^{235}– a fissile material
- U^{238} –a non-fissile, but fertile material.
- Th^{232}– a non-fissile but fertile material.

In Fast Breeder Reactor U^{238} or Th^{232} are converted rapidly to fissile materials within the core of the reactor, thus generating the surplus fissile fuel. Nuclear chain reaction can be obtained only from fissile material U^{235}, Pu^{239}, U^{233}. The fertile materials like U^{238} can be converted to fissile materials U^{235} by the neutron bombardment.

During chain reaction the energy release high neutron flux appears and which acts on U^{238} and a small part of U^{238} is converted to Plutonium Pu^{239} which is a fissile material.

Fertile Material can be converted into fissile material by neutron flux action. e.g. U^{238} (fertile) — U^{235} (fissile) Fertile material itself is not fissionable, but it can be converted to a fissionable material by irradiation of neutrons in a nuclear reactor.

Three basic fertile materials and their conversion product are

Fertile		Fissile
U^{238}	---	Pu^{239}

U^{238} — U^{235}

Th^{232} — U^{233}

Thorium (Th) is also of fertile material available in nature. Some very large deposits of thorium have been discovered in several places in the world. In India Uranium and Thorium deposits have been located in West Bengal. The process of converting the non-fertile U^{238} to fissile Pu^{239} is called "**Conversion**". The natural Uranium Ore is processed through several steps to obtain fissile fuel for Nuclear Reactor. The spent fuel is disposed of as nuclear waste.

Some of the properties required by the Uranium fuel are as follows:

1. Undergo fission process.
2. High radiation stability to resist nuclear radiation against buckling.
3. High conductivity to transfer the large amount of heat released and to reduce high thermal stresses.
4. Better corrosion resistance.

There are two kinds of nuclear fuels available depending on the method of releasing energy.

i. Fissile fuels
ii. Fertile fuels

i. Fissile fuels:

These fuels undergo fission process. When unstable heavy nuclear is bombarded with neutrons, it splits into two fragments of approximately equal mass. A large amount of heat is released during this fission process. The fissile materials are used as fuel in nuclear power plant. There are three basic fissionable materials available. They are U^{235}, PU^{239} and U^{233}

ii. Fertile fuels:

Some materials are not fissionable by themselves. Yet, they can be converted into fissionable materials. They are called as *fertile fuels*. These materials absorb neutron and undergo spontaneous change to produce fissionable materials. Only U^{235} is available in nature. U^{235} and PU^{239} are produced artificially. U^{233} is produced by nuclear reaction of thorium element. PU^{239} is produced by neutron irradiation of U^{238}. These PU^{239} and U^{233} can be fissioned by neutrons. U^{238} and Th^{232} are known as *fertile fuels*.

Nuclear Fission

Nuclear fission is the process of splitting of nucleus into two almost equal fragments accompanied by release of heat.

To sustain the fission process, the following requirements must be fulfilled.

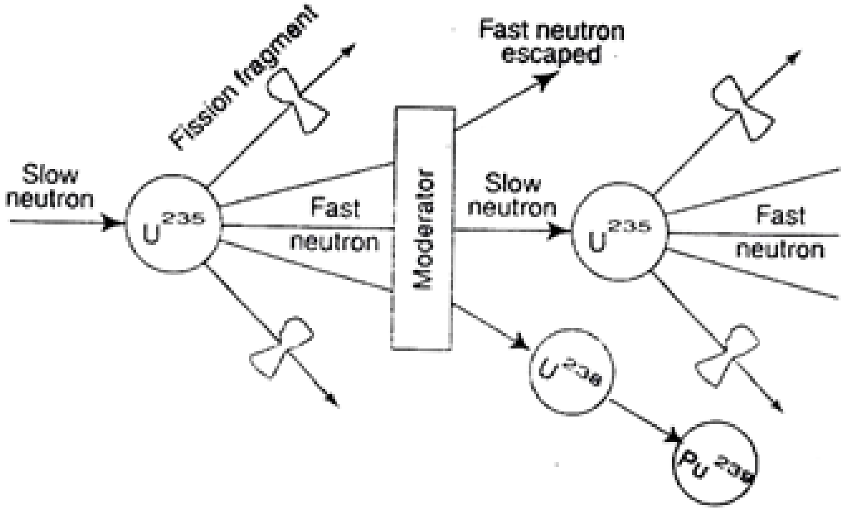
(i) The neutrons emitted in fission must have adequate energy to cause fission of other nuclei.
(ii) The number of neutrons produced must be able not only to sustain the fission process but also to increase the rate of fission.
(iii) The fission process must liberate the energy.
(iv) It must be possible to control the rate of energy liberation.

Chain Reaction

During fission process, neutron is absorbed by the nucleus of atom of U^{235} and splits up into two fragments of approximately equal size. Also about 2.5 neutrons are released and a large amount of energy is produced. The neutrons produced move with very high velocity ($1.5 \times 10^7 m/s$) and fission other nuclei of U^{235}. Thus, fission process and release of neutrons take place continuously throughout the remaining material. This self-sustaining reaction is known as chain reaction.

Definition:

This chain reaction is the process in which the number of neutrons keeps on multiplying rapidly during the fission till whole of the fissionable material is disintegrated.



The chain reaction will become self-sustaining or self-propagating only. At least one fission neutron becomes available for causing fission of another nucleus.

This condition can be conveniently expressed in the form of *multiplication factor or reproduction factor* of the system.

$$k = \frac{\text{Number neutrons in any particular generation}}{\text{number neutrons in the preceding generation}}$$

For sustaining chain reaction, K should be greater than 1 and if K is less than 1, chain reaction cannot be maintained.

There are two reasons why not all the fission neutrons cause further fission.

1. Absorption of some neutrons cause further fission products, non-fissionable nuclei in the fuel, structural material, moderator and so on.
2. Leakage of neutrons escaping from the core.

For example, about 2.5 neutrons are released in fission of each nuclei of U^{235}. Out of these, one neutron is used to sustain the chain reaction. 0.9 neutrons are absorbed by U^{238} and become fissionable material Pu^{239}. The remaining 0.6 neutrons are partly absorbed by control rod material, coolant, moderator, and partly escape from the reactor.

Nuclear Fusion

Nuclear fusion is the process of combining of fusing two higher nuclei into a stable and heavier nuclide. In this process also, large amount of energy is release because mass of the product nucleus is very less when compared to mass of the two nuclei which are fussed.

Difference between nuclear fission and nuclear fusion

S. No	Nuclear fission	Nuclear fusion
1.	It is the process of breaking a heavy nucleus with some projectiles into two or more light fragments with liberation of a large amount of energy.	It is a process of fusing two light nuclei into single nucleus with the liberation of a large amount of heat.
2.	This process results in the emission of radioactive rays.	This process does not emit any king of radioactive rays.

3.	This process takes place spontaneously at ordinary temperature.	This process takes place at very high temperature (nearly at about > 10^5K).
4.	The mass number and atomic number of the daughter elements (new elements) are considerably lower than that of the parent nucleus.	The mass number and atomic number of the product are higher than that of the starting elements.
5.	This process gives rise to chain reaction.	This process does not give rise to chain reaction.
6.	During nuclear fission, neutrons are emitted.	During nuclear fusion, protons are emitted.
7.	Nuclear fission can be performed under controlled conditions.	Nuclear fusion cannot be performed under controlled conditions.

Advantages of Nuclear power plants:

- No atmospheric pollution by combustion products.
- Space requirement is less when compared to other conventional power plants are of equal size.
- Environmental pollution is less as compared to fossil fuel power plants.
- Increased reliability of operation.
- Fuel transportation cost is less and large storage facilities are not needed since nuclear fuel has very high energy density.
- Water requirement is very less.

Disadvantages of nuclear power plants:

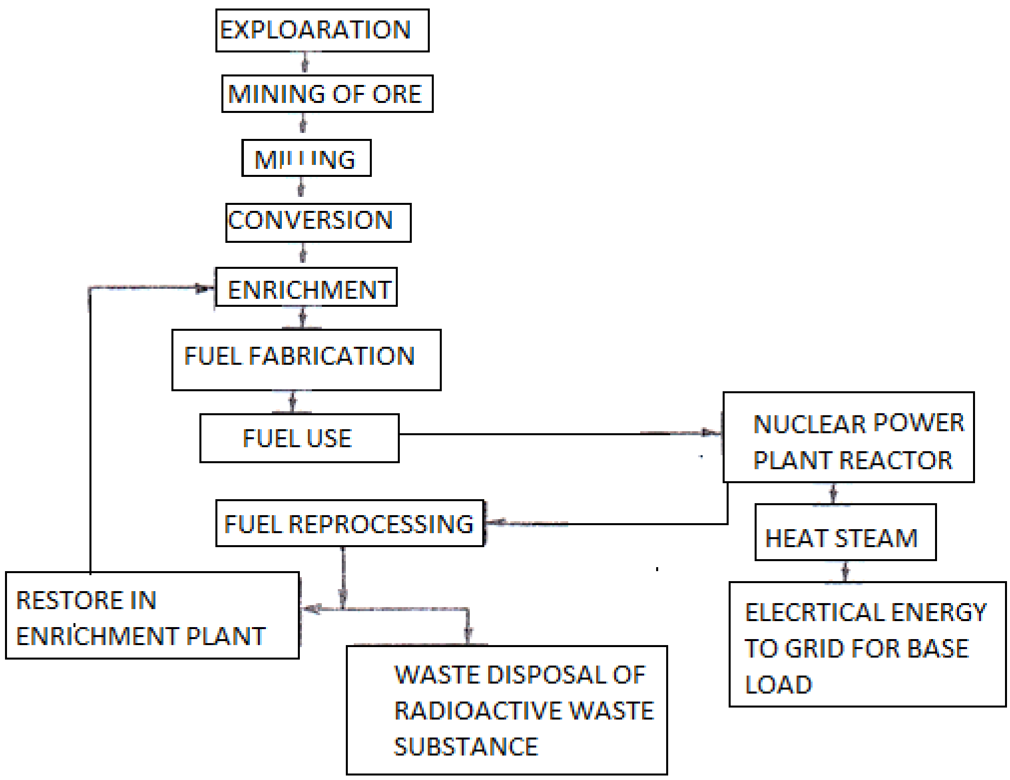
- Nuclear power plants are not well suited for varying load conditions.
- Danger of nuclear explosion in the reactor due to failure of controls.
- Maintenance cost is very high.
- Disposal nuclear radioactive waste is major problem in nuclear power plants. If they are not disposed carefully, it may have bad effect on the health of workers.
- These power plants require highly trained personnel to operate nuclear reactors.

NUCLEAR FUEL CYCLE AND ENERGY ROUTES. (Nov/Dec 2014)

Fuel cycle is a series of a sequential steps involved in supplying fuel to a nuclear power reactor and subsequent processing up to final disposal of nuclear wastes.

There are several steps in the nuclear fuel cycle - mining and milling, conversion, enrichment, and fuel fabrication. These steps are known as the 'front end' of the cycle.

Once uranium becomes 'spent fuel' (after being used to produce electricity), the 'back end' of the cycle follows. This may include: temporary storage, reprocessing, recycling, and waste disposal.



Mining

There are several different ways in which uranium can be mined; on the surface (called open cut mining), underground.(when the ore body is too deep for open cut methods, underground methods are necessary.)

Uranium concentration in the raw ore is very low and ranges between 1Kg of U_3O_8 to 2.8 Kg per 1 ton of ore. 10000 ton ore gives only about 36 ton enriched uranium fuel.

Milling

After the uranium ore is mined, using underground or open-cut methods, it is then sent to the closest mill where it is crushed and ground finely into a paste.

Concentration

The uranium is dissolved from the other materials by sulphuric acid. The uranium-rich solution is filtered, and the uranium separated and dried to produce a solid uranium concentrate called yellow cake. It contains 70 to 90% of U_3O_8. 10000 ton ore gives about 190 ton of U_3O_8.

Refining, Concentration and conversion

The Uranium is refined for removal of impurities. Refined uranium gives more efficient chain reaction.

The crude concentrate(yellow cake) is purified by solvent Extraction and the product is Calcined to produce Uranium Trioxide (UO_3) which is a fine bright orange coloured powder (orange oxide). Orange oxide is subjected to hydrogenation to get Uranium di oxide (UO_2).

UO_2 is then passed through Hydrogen Fluoride gas (HF) to get Uranium tetra fluoride (UF_4).

It is converted into uranium hexafluoride (UF_6) which is a gas at relatively low temperatures. The conversion is obtained within the nuclear reactor during the chain reaction.

The material like U238 which can be converted to a fissile by the neutron flux is called "fertile material".

Enrichment

Uranium primarily occurs naturally as two isotopes: 99.3% is Uranium-238 and 0.7% is Uranium-235. Their atoms are identical except for the number of neutrons in the nucleus: Uranium-238 has three more and this makes it less able to fission. Uranium enrichment is used to increase the percentage of the fissile U-235.

Enrichment is the process of concentrating or increasing the amount of the U-235 isotope, compared with the U-238 isotope. The process is complex and expensive.

The concentration of U-235 in the uranium hexafluoride (UF_6) must be increase from the 0.07% in natural uranium to 2 to 4%. This is called enrichment and is accomplished in an Enrichment plant.

The enrichment of uranium is carried out in two ways.

- By adding fissile material U-235 or U-233.
- By removal of non-fissile material.

270 ton of enriched UF6 gives only about 52 ton of enriched fuel.

Fuel Fabrication

The enriched uranium, which has been milled to separate it from the ore, converted and enriched, is now sent to a fuel fabrication plant where it is changed into uranium dioxide powder. The powder is pressed into small pellets, which are then put into metal tubes, forming fuel rods. These fuel rods are put together to form a fuel assembly.

Fuel pellet : a cylindrical piece of fissile uranium fuel.
Fuel Rod :a series of pellets encased in a thin cylindrical metal tube and sealed.
Fuel Element : a cluster of fuel rods fed into a reactor.

53 ton of enriched fuel gives only about 36 ton of fabricated fuel for the reactor.

Reprocessing

Used fuel still contains approximately 96% of its original uranium, of which the fissionable U-235 content has been reduced to less than 1%. About 3% of used fuel comprises waste products and the remaining 1% is plutonium (Pu) produced while the fuel was in the reactor and not "burned" then.

Reprocessing separates uranium and plutonium from waste products (and from the fuel assembly cladding) by chopping up the fuel rods and dissolving them in acid to separate the various materials. Recovered uranium can be returned to the conversion plant for conversion to uranium hexafluoride and subsequent re-enrichment. The reactor-grade plutonium can be blended with enriched uranium to produce a mixed oxide (MOX) fuel, in a fuel fabrication plant.

Waste Disposal

It is when uranium is used in the reactor that significant quantities of highly radioactive wastes are created. When the uranium-235 atom is split it forms fission products, which are very radioactive and make up the main portion of nuclear wastes retained in the fuel rods. There is also a relatively small amount of radioactivity induced in the reactor components by neutron irradiation.

Three categories of waste materials:

- **Low-level** radioactive material: It is dispersed or stored without elaborate shielding.
- **Intermediate-level** radioactive material: It is stored for short duration of about 5 years to allow decay of radioactivity.
- **High-level** radioactive material: They are stored in water for several months to permit radioactive decay to an acceptable low level.

Working principle of Nuclear power station. **(Nov 2013) (April 2013) (Nov/Dec 2014)**

Main Components of a Nuclear Power Plant

The main components of nuclear power plant are

- Nuclear reactor.
- Heat exchange or steam generator.
- Steam turbine.
- Condenser.
- Electric generator.

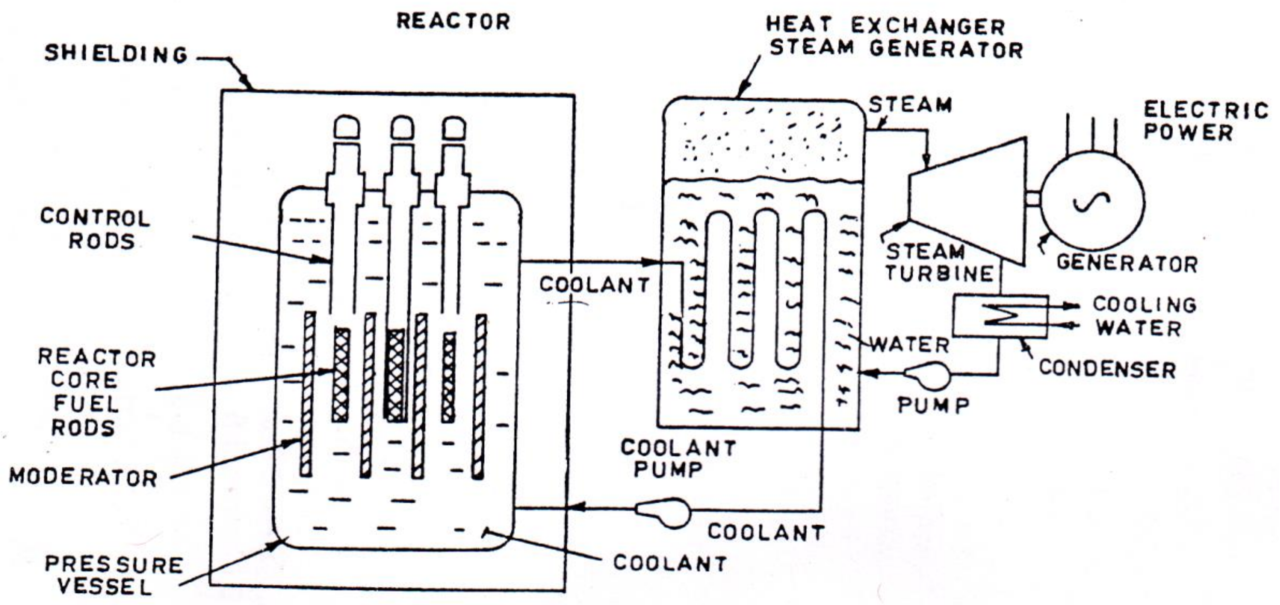


Fig shows a schematic diagram of nuclear power plant. In nuclear power plants, the reactor function is similar to the furnace of steam power plant. It contains pressure vessel, fuel rods, moderator, shielding as shown in fig. There are various types of reactor used in practice which will be discussed later. The fuel elements are inserted in the reactor core. The control rods are introduced and positioned in the core to control the chain reaction. Heavy water reactor acts as a moderator as well as the coolant.

The heat liberated in the reactor as a result of nuclear fission of the fuel is taken up by the coolant circulating through the reactor core. Hot coolant coming out of the reactor core is then circulated through the tubes of steam generator to generate the steam. The water coming out of the heat exchanger is circulated by the pump to maintain the pressure in the circuit in the range of 100 to 130*bar*.

The steam so produced expands in the steam turbine for producing work. Steam is coming out of the turbine flows to the condenser for condensation. The steam turbine in turn runs an electric generator thereby producing electrical energy.

Main parts of a nuclear reactor with their function. **(April/May 2014)**

MAIN COMPONENTS OF A NUCLEAR REACTOR

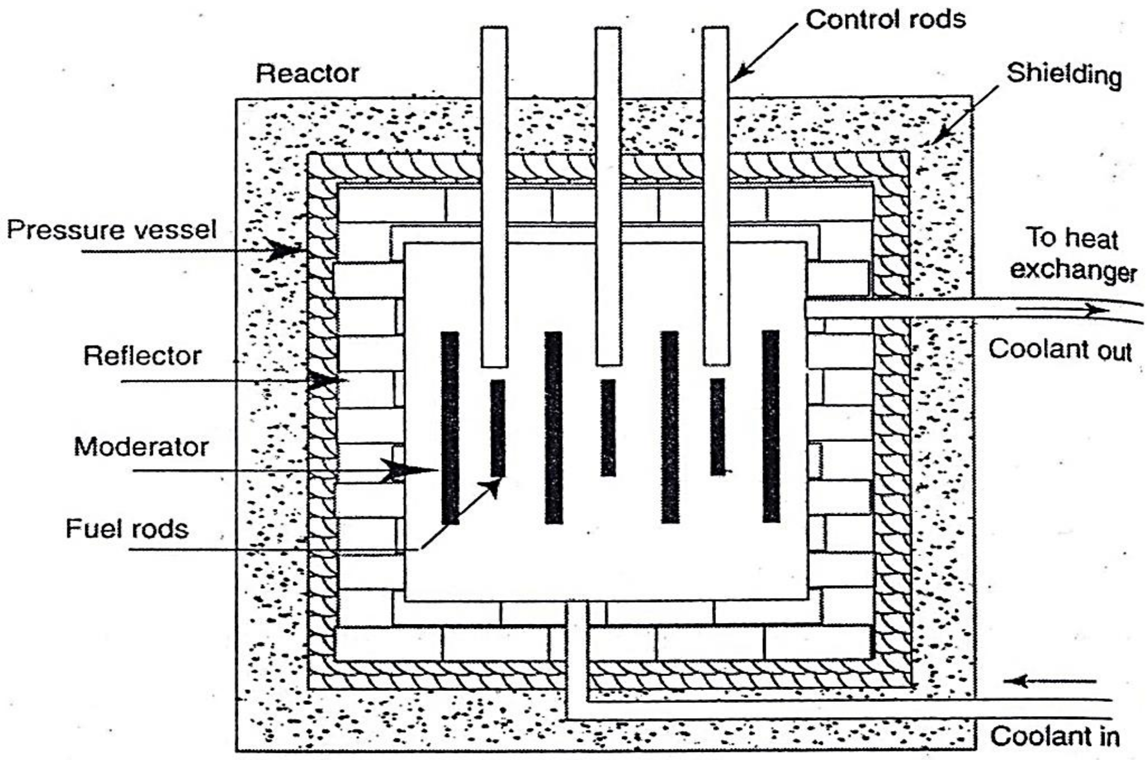
A nuclear reactor is similar to the furnace of a steam power plant or combustion chamber of a gas turbine plant. In this nuclear reactor, heat is produced due to nuclear fission chain reaction. Fig.shows the various components of a nuclear reactor.

The nuclear reactor consists of the following principle parts:

(i) Reactor core
(ii) Moderator
(iii) Control rods
(iv) Reflector
(v) Cooling system
(vi) Reactor Vessel
(vii) Biological shielding

1. Reactor core:

It consists of nuclear fuel, the neutron moderator and space for the coolant. The nuclear fuel is an element or isotope whose nuclear undergo nuclear fission by nuclear bombardment and produces a fission chain reaction. Nuclear fuel may be one or all of the following U^{235}, U^{235} and $P\ U^{239}$. Reactor core generally has a shape approximately a right circular cylinder with diameters ranging from 0.5m to 15m.



The fuel elements are made of plates or rods of Uranium metal. These plates are usually clad in a thin sheet of stainless steel, Zirconium or Aluminum to provide corrosion resistance. The fuel is shaped and located in such a way that heat produced within the reactor is uniform. Adequate arrangements should be made for fuel supply, charging or discharging and storing of the fuel.

2. Moderator:

The process of slow down the neutrons from high velocity without capturing them is known as *moderation.* Moderator is a material which is used to slow down the neutrons from high velocities without capturing them. The fast moving neutrons are far less effective in causing the fission and try to escape from the reactor. Thus, the speed of the fast moving neutron is reduced by introducing moderator. Heavy water (D_2O), Water (H_2O), Beryllium (Be), Graphite (C) and Helium (He) gas are commonly used moderators.

A good moderator should possess the following properties:

- High thermal conductivity
- High slowing down power

- ❖ Low parasite captures
- ❖ Lighter
- ❖ High resistance to corrosion
- ❖ Stability under heat and radiation
- ❖ Abundance in pure form
- ❖ High meeting point for solids and low melting point for liquids.

The moderator is characterized by *moderating* ratio which is the ratio of moderating power to the macroscopic neutron capture coefficient. If the moderating ratio is high, the given substance is more suitable for slowing down the neutrons.

3. Control rods:

The function of control rod is:

- ❖ To control the rate of fission.
- ❖ To start the nuclear chain reaction when reactor is started from cold.
- ❖ To shut down the reactor under emergency condition.
- ❖ To maintain the chain reactor at a steady state.
- ❖ To prevent the melting of fuel rods.

Boron, Cadmium and Hafnium are mostly used as control rods. These control rods are used to absorb the neutrons thereby reducing the chain reaction. The control rods must be able to absorb excess neutrons. The position of these rods is regulated by electronic or electro-mechanical device. Control rods should possess the following properties:

- ❖ Good stability under heat and radiation
- ❖ Adequate heat transfer properties
- ❖ Better corrosion resistance
- ❖ Sufficient cross-sectional are for the absorption of neutrons.

4. Reflector:

Reflector material is placed round the core to reflect back some of the neutrons that leak out from the surface of the core. The reflected neutrons cause more fission and improve the neutrons economy of the reactor. Reflector is generally made of the same material as the moderators. Water, carbon, graphite, beryllium are generally used as reflectors.

5. Cooling system:

The coolants are used to carry away heat produced inside the reactor to the heat exchanger. From the heat exchanger, heat is transferred to another working medium for further utilization of power generation.

The desirable properties for a reactor coolant are:

- ❖ Low melting point
- ❖ High boiling point
- ❖ Low viscosity
- ❖ Non-corrosiveness
- ❖ Non-toxicity
- ❖ Low parasite capture
- ❖ High chemical and radiation stability
- ❖ High specific heat
- ❖ High density

The various fluids are used as coolant like water (light water or heavy water), gases (helium, CO_2, hydrogen or air), liquid metals such as sodium and organic liquids.

6. Reactor vessel:

The reactor vessel encloses the reactor core, moderator, reflector, shield and control rods. It is a string walled container to withstand high pressure. At the top of the vessel, holes are provided to insert control rods. At the bottom of the vessel, the reactor core is placed.

7. Biological shielding:

Shielding is necessary to protect the walls of the reactor vessel from radiation damage and also protect the operating personnel from exposure to radiation. Thick layers of lead concrete or steel are provided all around the reactor. These layers absorb the gamma rays, neutrons etc. A good shielding material should have the following properties.

- It should absorb α, β and γ radiations efficiently.
- It should have uniform density.
- It should not be decomposed by radiation.
- It should be fire resistant.

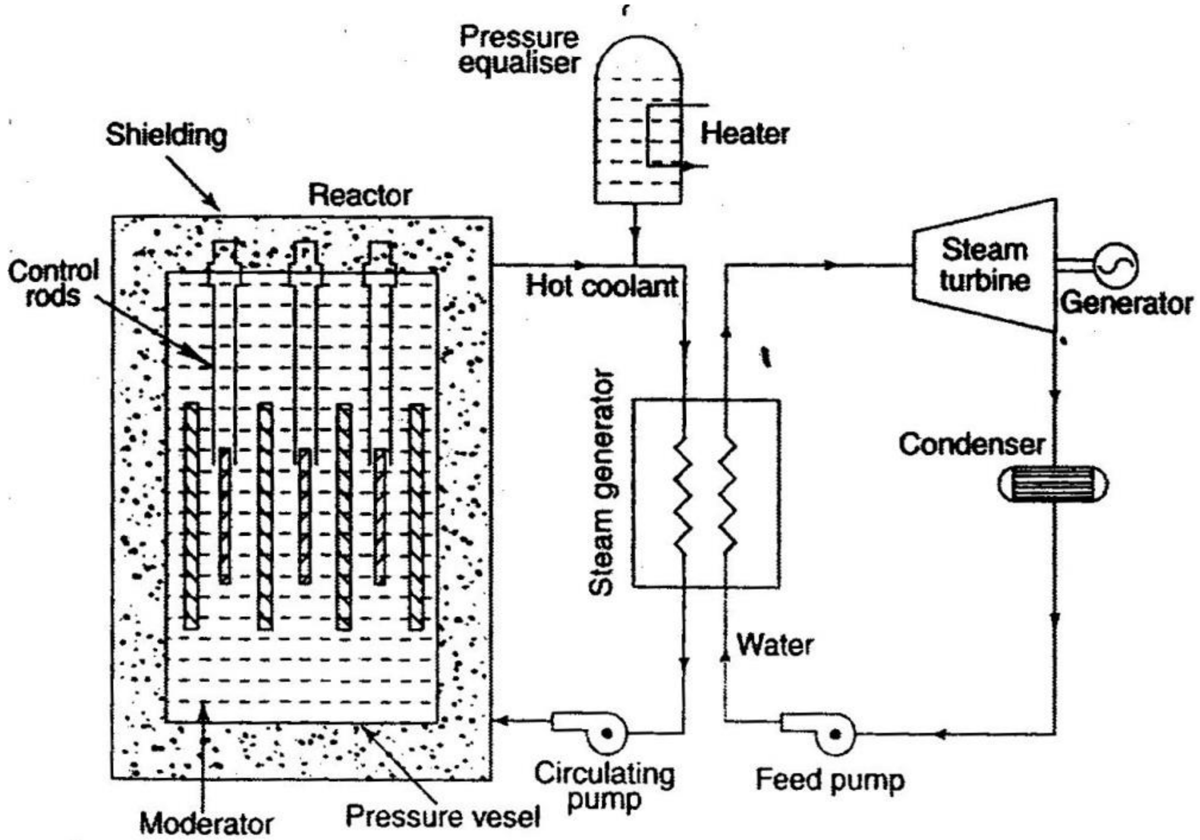
TYPES OF REACTORS **(April 2015)**

Factors control the selection of a particular type of a reactor:

1. Neutrons energy
2. Type of fuel
3. Type of coolant
4. Type of moderators
5. Construction of core

1. Pressurized Water Reactor (PWR):

A pressurized water reactor is a light water cooled and moderated reactor having an unusual core design using both natural and highly enriched fuel. The nuclear power plant using a prescribed water reactor is shown in figure below.



Typical efficiency of the system is 20 %.

The main components of the reactor are

(i) Reactor
(ii) Pressurizer
(iii) Heat exchanger
(iv) Coolant pump

The components of the secondary circuit of pressurized water plant are similar to those in a normal steam station (ie. Steam turbine, condenser, feed pump, and heat exchanger)

The coolant in the primary circuit is pumped to the reactor core. The coolant absorbs heat energy which is liberated during nuclear fission in the reactor core. The hot coolant passes through the heat exchanger where the coolant transfers heat energy to the feed water and steam is generated. The water from the heat exchanger is again circulated by the coolant pump. The water becomes radioactive in passing through the reactors. Therefore, the entire primary circuit including heat exchanger must be shielded to protect the operating personnel. The steam in the turbine is not radioactive and need not be shielded.

The pressure in the primary circuit should be high so that the boiling of water will takes place at high pressure. This enables water to carry more heat from the reactor. The pressurizing tank keeps the water at about 14MN/$m^{2.}$ So that it will not boil. Electric heating- coil in the pressurizer boils the water to form the steam which is collected in the dome as shown if fig. as more steam is forced into the dome by boiling, its pressure rises and pressurizes the entire circuit. To reduce the pressure, water spray is used to condense the steam.

A pressurized water reactor can produce only saturated steam. If there is a need of superheated steam, separate furnace should be provided.

Advantages:

1. Water which is cheaply available in plenty is used for coolant, moderator and reflector.
2. The reactor is compact and high power density (65kN/litre).
3. Number of control required is less.
4. Easily available natural uranium is used as fuel.

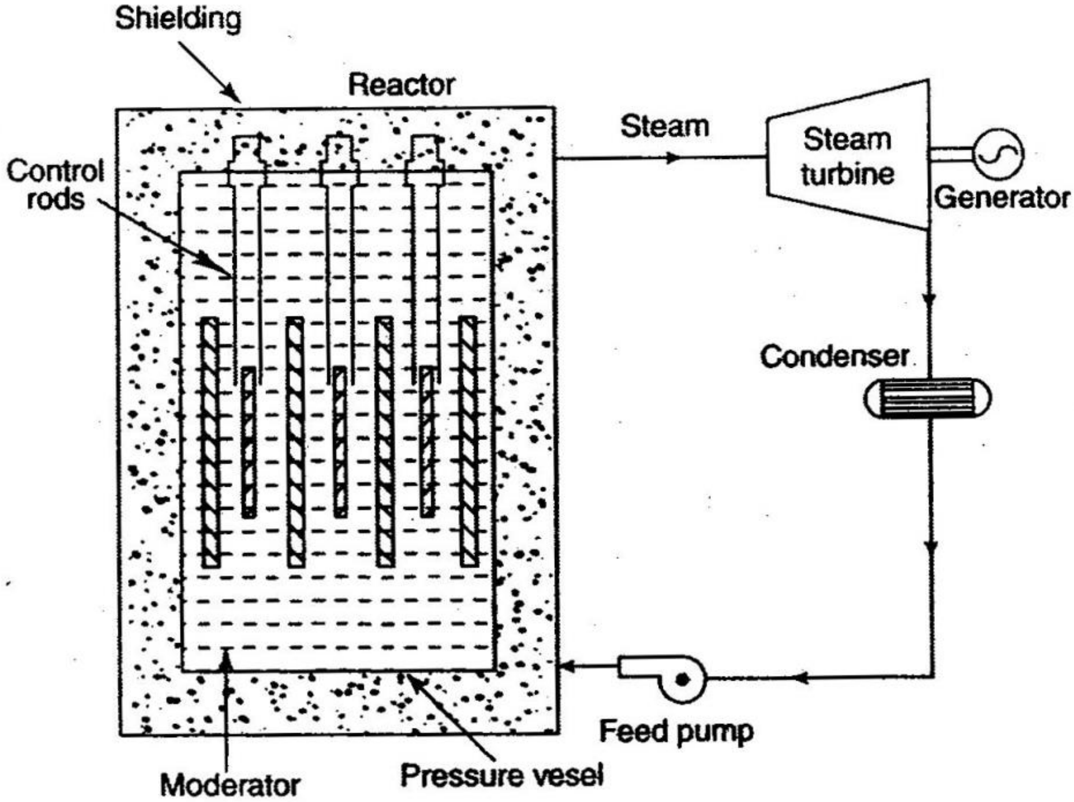
Disadvantages:

1. High pressure requires stronger reactor vessel and hence capital cost is high.
2. Thermal efficiency of the plant is low since low pressure is maintained in secondary circuit.
3. Fuel element fabrication is expensive.
4. Reprocessing of fuel is difficult since, it is affected by radiation.

2. Boiling Water Reactor (BWR):

The arrangement of boiling water reactor is simple when compared to the pressurized water reactor. The nuclear power plant using boiling water reactor as shown in fig. below. In this type of reactor also, enriched uranium is used as a fuel and water is used as moderator, coolant and reflector in PWR. Only difference between PWR and BWR is that in a B.W.R, the steam is generated in the reactor itself of a separate steam generator.

Water enters the reactor at the bottom. This water is heated by the heat released due to this fission of fuel and gets converted into steam. The steam which leaves from the top of the reactor is passed through the turbine and expanded.



Typical efficiency of the system is 39%. Exhaust steam from the turbine passes through the condenser and condensed. The condensed water is again re circulated again by using feed pump. India's first nuclear power plant at Tarapur has two B.W.R.S of 200*MW* capacity each.

Advantages:

1. The reactor vessel is much lighter than PWR since the pressure inside the reactor is small.
2. There is no heat exchanger, pressuiser and circulation pump. This reduces cost of the plant.
3. Thermal efficiency of BWR plant is more (30%) than PWR plant (20%).
4. The metal temperature remains low for given output condition.
5. BWR is a self-controlled reactor as the reactivity is automatically reduced, if the vapour is not dense to moderate the neutrons effectively.
6. A BWR is more stable than PWR and much stable than any other type of reactor.

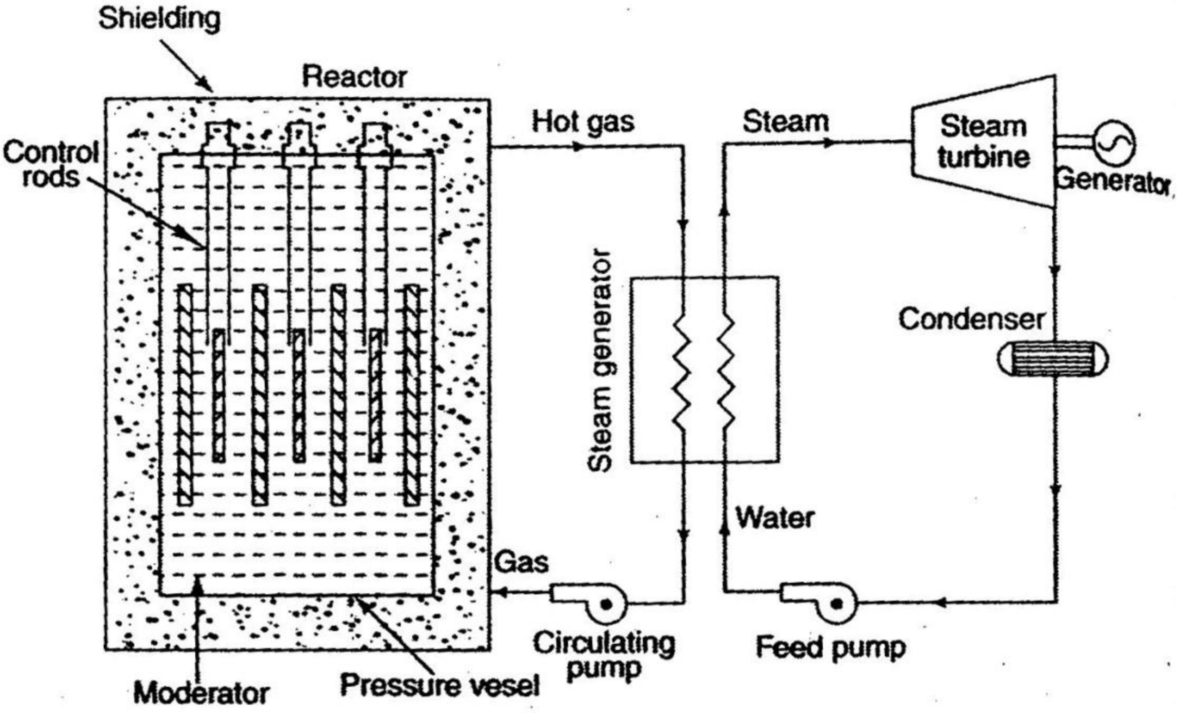
Disadvantages:

1. The steam entering the turbine is slightly radioactive. Hence, shielding of turbine and piping are needed.
2. Wastage of steam resulting in lowering of thermal efficiency on part load operation.
3. Lower power density (33.6kW/*litre)* and large in size.
4. Power demand fluctuation cannot be met.

3. Gas Cooled Reactor (GCR):

In this reactor, carbon dioxide gas is used to carry away the hear produced due to nuclear fission in the reactor. The first gas cooled rectors with CO2 gas as coolant moderator were developed in Britain during 1956-69. The fuel was natural Uranium, clad with an alloy of magnesium called Magnox. The gas is maintained at a pressure of about 16*bar*.

Various types of GCR have been developed. England developing an advanced gas cooled reactor (AGR system) and Germany and the USA developing helium cooled, graphite moderated systems. Gas enters the reactor at the bottom. This gas is heated by the heat released due to the fission of fuel and leaves the reactor at the top and flows to heat exchanger. In the heat exchanger, hot gas transfers its heat to water which gets converted into steam. The gas is recirculated with the help of gas blowers.



This steam passes through the turbine and expanded to get mechanical work. Exhaust steam from the turbine is condensed with the help of condenser.

Advantages:

1. Fuel processing is simpler than any other reactors.
2. No corrosion problem.
3. The Uranium carbide and graphite are able to resist high temperatures and hence, the problem of limiting the fuel element temperature is not as series as in other reactors.
4. It gives better neutrons economy due to low parasite absorption.

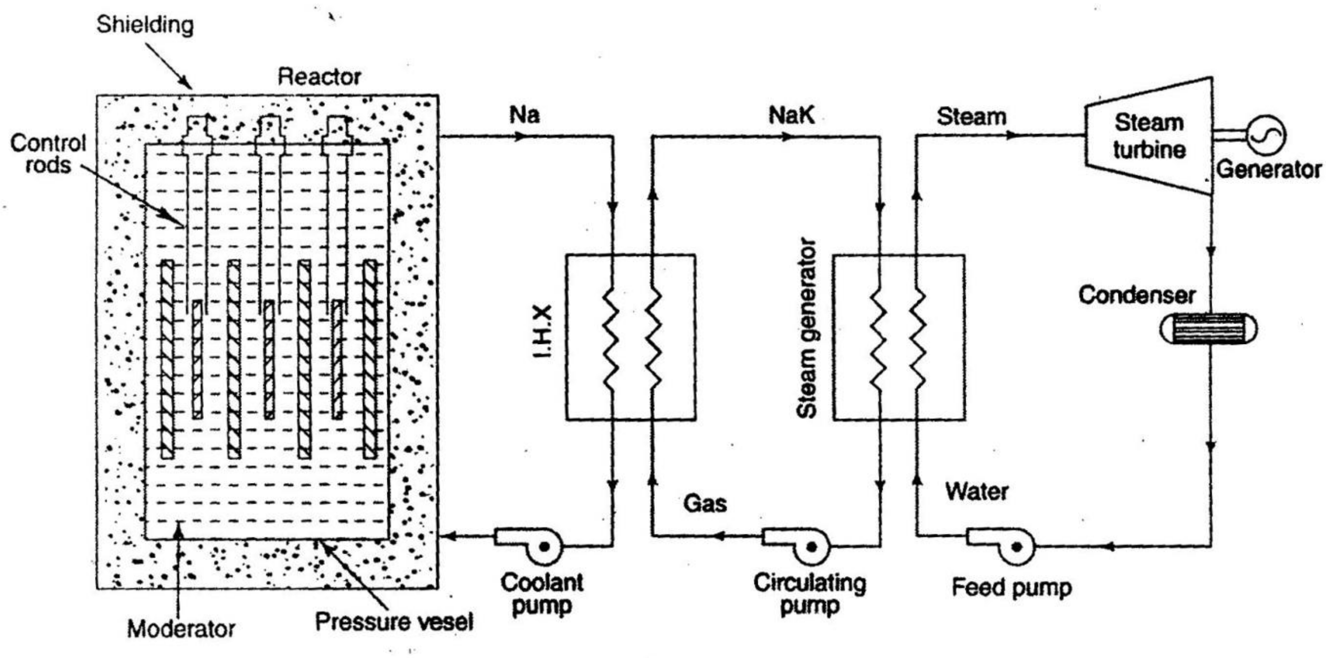
Disadvantages:

1. Fuel loading is more elaborated and costly.
2. The cost of heavy water (D_2O) is high (Rs. 500 per kg).
3. Power density is very low (9.7kW/litre) and hence, large vessel is required.
4. Large amount of fuel loading is initially required since, the critical mass is high.

4. Fast Breeder Reactor (FBR):

In fast breeder reactors, enriched Uranium (U^{235}) or Plutonium is kept in the casing without using moderator; the casing is surrounded by a thick blanket of fertile Uranium (U^{238}). This is known as *breeding material*. Fig. shows a schematic diagram of a fast breeder reactor. Fast moving neutrons are liberated due to fission of enriched uranium (U^{235}). The ejected excess neutrons are absorbed by the fertile Uranium (U^{238}) which is converted into fissionable material (PU^{239}). The fissionable material ($P\ U^{239}$) is capable of sustaining chain reaction.

The reactor employs two liquid metal coolant circuits as shown in fig. 3.10. Liquid sodium (Na) is used as primary coolant. Sodium potassium (NaK) alloy is used as secondary coolant.



There are two heat exchangers used in this power plant. One is intermediate heat exchanger (IHE) and other is steam generator. The intermediate heat exchanger is used to transfer heat from primary coolant (Na) to secondary coolant (Na K). The feed water is heated in the steam generator by the hot secondary coolant. The steam produced in the steam generator is then utilized for power generation.

Advantages:

1. No moderator is required.
2. High efficiency in the order of 40% can be obtained.
3. Better fuel utilization.
4. Absorption of neutrons is low.

Disadvantages:

1. Special coolants are required to carry out the large quantity of heat from the reactor core.
2. Handling of sodium is a major problem because it becomes hot and radioactive.
3. Safety must be provided against melt-down.
4. Neutron flux is high at the centre of the core.

Nuclear waste management

The Radioactive waste, like any waste, is need to be managed to protect people and the environment.

TYPES OF NUCLEAR WASTES:

The nuclear wastes are classified as follows:

(i) On the basis of half life
  (a) Fission products
  (b) Actirides
  (c) The neutron activation products

(ii) On the basis of the intensity of radiation
  (a) Low level waste
  (b) Medium level waste
  (c) High level waste

1. Fission products:

The wastes produced from reactor operations include fission products and Plutonium. The half-lives of most of the fission products are 30 years or less. But their toxic lifetime is of the order of 500 to 1000 years. Most of the fission products are initially radioactive and decay with the emission of β and γ-rays.

2. Actirides:

Actirides are produced in nuclear reactors as a result of neutron capture by Uranium. The most important is Plutonium. The other Actirides are Neptunium, Americium and Curium. The Actirides decay mainly by emission of α-particles until a stable isotope of load is formed. α-particles can be easily stopped and hence, Actirides do not require thick shielding. However, α-particles are very energetic and toxic if inhaled as dusts.

3. Neutron activation products:

These are produced when fast neutrons are absorbed by structural materials in the reactors as coolant, fuel cladding, etc. These products decay with the emission of β and γ radiations.

4. Low level wastes:

Low level wastes contain less than 10 nanocuries per gram of transuranium contaminants and that have low but potentially hazardous concentration of radioactive materials. Low level wastes are produced in almost all activities (such as power generation, medical, industrial, etc.) that involve radioactive materials. They require little or no shielding, and are usually disposed off in liquid form shallow land burial.

5. Medium level wastes:

Medium level wastes contain more than 10 nanocuries but less than 100 nanocuries per *gram* of transuranium contaminants. These wastes are mainly contaminated with neutron activation product isotopes.

6. High level wastes:

The high level wastes contain more than 100 nanocuries per *gram* of transuranium contaminants. These are generated in the reprocessing of spent fuel. The spent fuel is withdrawn from the reactor and placed in a water pond. The heat is removed in the water pond and shorter lived radianuclides decay. The pond wastes are continually treated to remove activity due to release of fuel from defective cladding. The spent fuel is then transferred to the reprocessing plant where cladding that contains the fuel is removed and the fuel is dissolved in nitric acid. The U^{235} and Pu^{239} are then removed laving 99% non-volatile fission products behind in solutions known as *"highly active liquid waste"*.

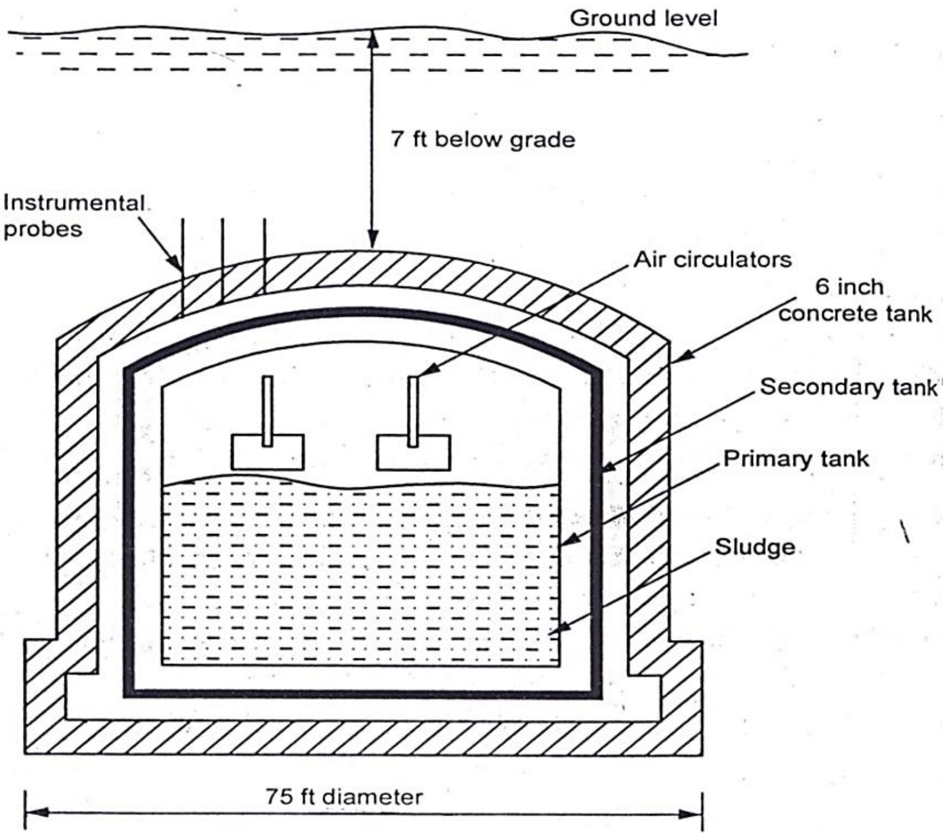
Nuclear Waste Disposal Methods:

Many ends of radioactive wastes such as gaseous, liquid and solid are formed in the various phases of nuclear fuel cycle. These wastes must be disposed off in such a manner that there is no harm to human, animal or plant life. Solids of low and medium level wastes are buried at depths of few meters at carefully selected sites. Gaseous wastes are discharged to the atmosphere through high stacks. Liquids having low or medium level of radioactivity are given preliminary treatment to remove most of the activity in the form of solid precipitate and then discharged in dry wells or deep pits.

Different methods for various nuclear wastes disposed are discussed below:

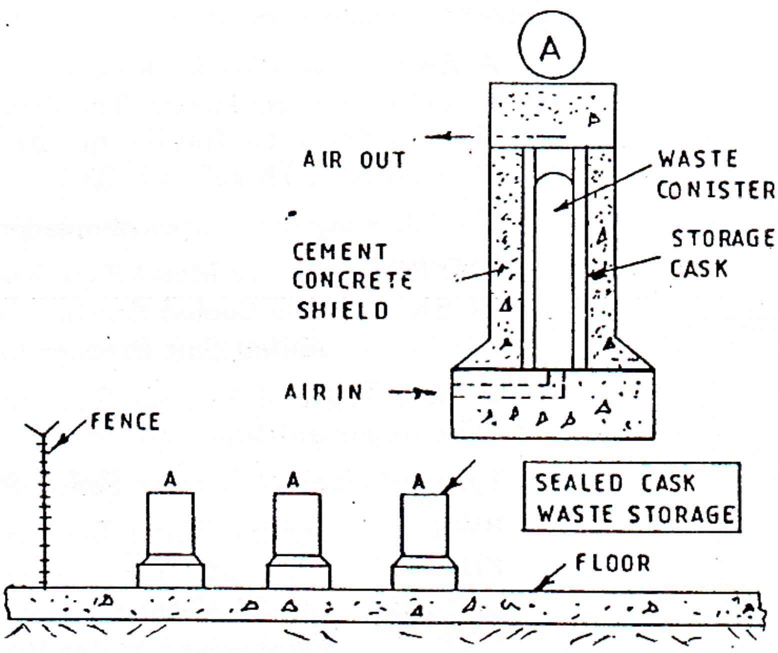
1. Disposal of level solid waste:

Low level solid waste requires little or no shielding. It is usually disposed off by keeping it in a steel or concrete tank. These tanks are buried either few meters below the soil or kept at the bed of the Ocean. This is shown is fig.3.14.



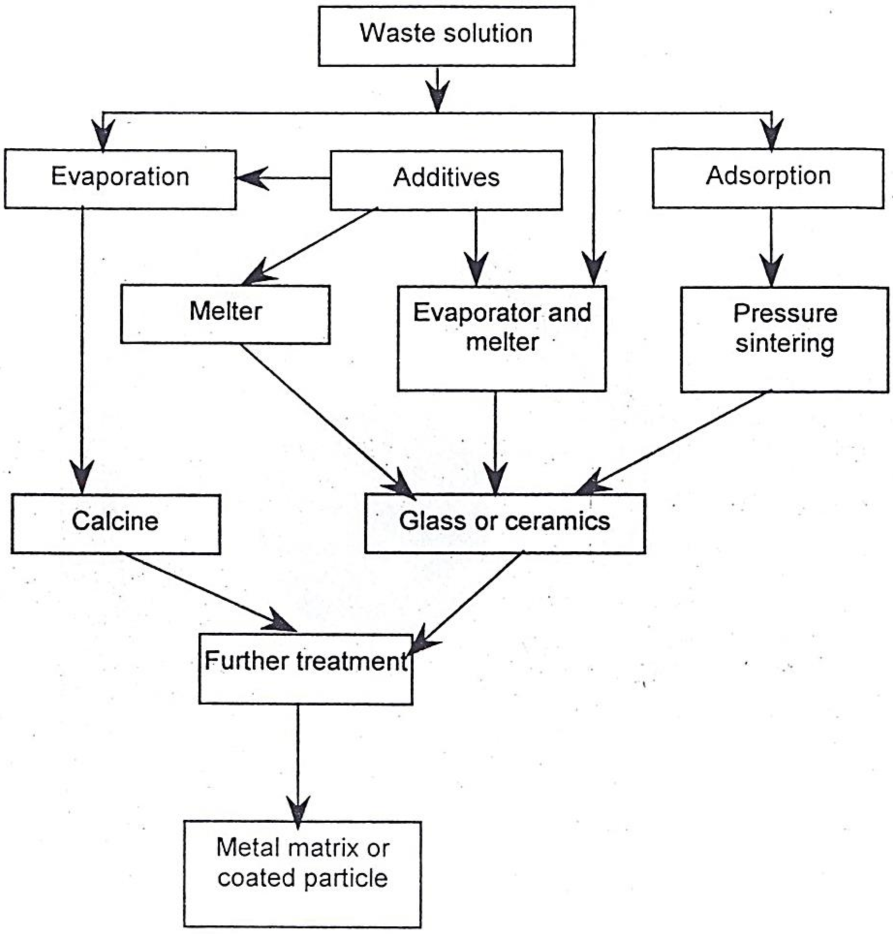
2. Disposal of medium level solid waste:

Medium level wastes are mainly contaminated with neutron activation product isotopes. They are in corporate into cement cylinders and cement in non-combustible and provide shielding against external exposure. Cement is also having the ability of resistance to reach by ground water.



3. Disposal of high level wastes:

Once uranium has been used to generate electricity, it becomes 'spent fuel'. This is the waste product of nuclear reactors and can be dealt with in several ways. As this spent fuel is highly radioactive, it cannot be, and definitely is not, simply dumped. It is often temporarily stored in special ponds that allow the fuel to 'cool down' and decrease its radioactivity. It cannot cause significant damage in these storage ponds. An important factor to address in storing different types of radioactive waste is how long they present a danger to society.



Although the spent fuel can be stored in these special ponds for fairly long periods of time, eventually the fuel will need to be either reprocessed, or disposed of. Reprocessing involves separating the remaining uranium and plutonium from the waste products in the spent fuel, by cutting up the fuel rods and dissolving them in acid. The recovered uranium is then returned to the beginning of the nuclear fuel cycle, and the plutonium is mixed with this to produce more fuel. After reprocessing, the highly radioactive waste can be heated to produce a powder, a process called **calcining**. This powder is mixed with glass to encapsulate (or lock-in) the waste, a process called **vitrification**. The liquid glass is then poured into stainless steel canisters for storage - and to this day, that is where the nuclear cycle ends.

The conversion of the liquid wastes to a solid form is very important. This avoids leakages, requires less supervision, and is more suitable for final disposal. Advanced process is currently being developed. This solid product should maintain its mechanical strength. Ideally, it should have a low leak rate.

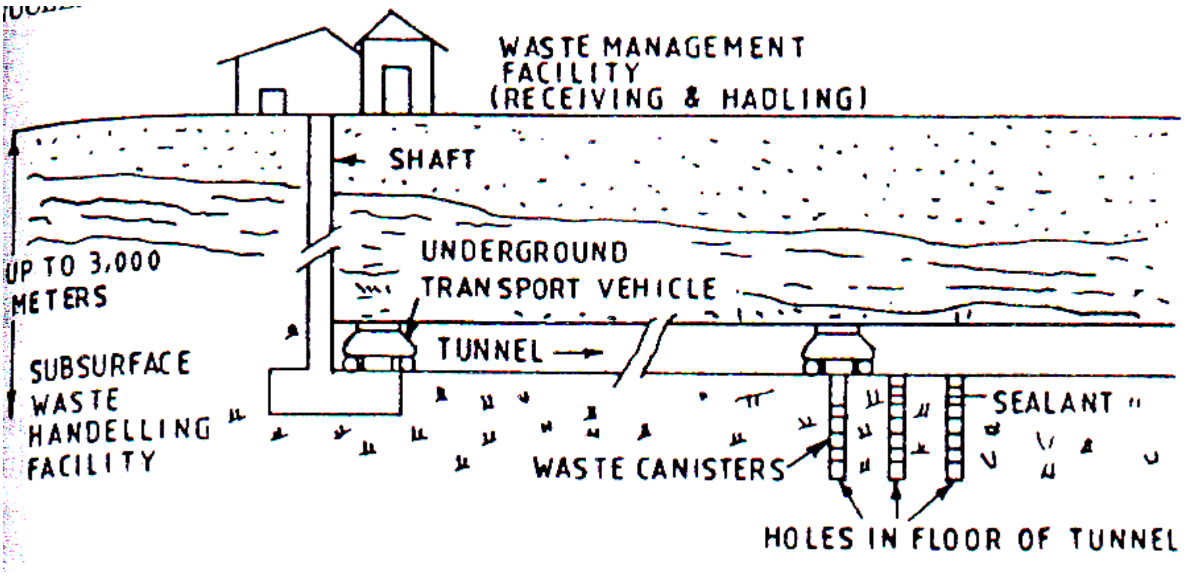
Glasses and ceramics are now considered to be most suitable forms for this final disposal. This involves evaporation and de-nitration (or calcinations) to form a granular or solid calcine. This is considered an interim product, since it does not meet all the above requirements. It is treated further by being mixed additives and is then melted to form glasses or ceramics.

A second process involves mixing the additives with the original waste solution, evaporating, de-nitrating and melting this mixture to form glasses or ceramics.

A third process uses an adsorption process and treatment at high temperature to produce the ceramics.

i. Underground disposal of high level waste:

The final disposal of the wastes with or without the above treatments is also of major concern. Many countries are undertaking activities involving underground disposal in deep geological formation.

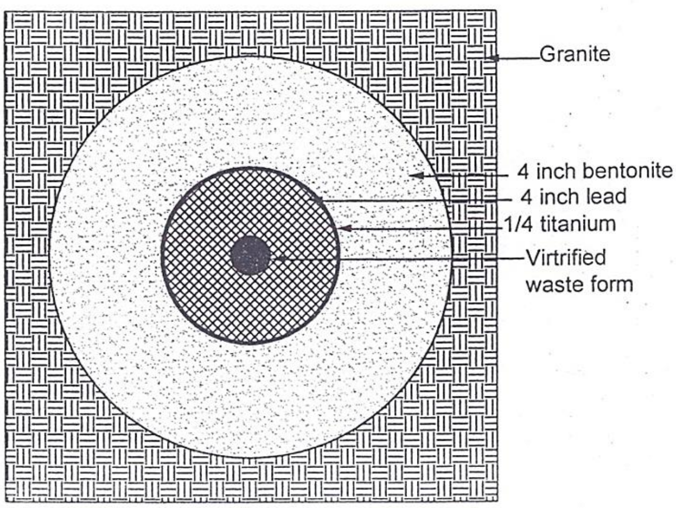


These activities include the investigation of suitable sites and suitable methods of storage in these sites.

The main objectives are the protection of present and future populations from potential hazards. The suitable sites must be free of flowing ground wastes, but the storage vessels must demonstrate reliability even in flowing condition.

A cavity is excavated 511*m* depth in salt mine and the cylinders are stored in this cavity. It has a special advantage that the salt is strong absorber of radioactive emissions and has good thermal conducting which helps to keep the temperature within acceptable limit.

The solidified waste is placed in canisters which are stored in holes in rock salt with a spacing of about 10m to allow for the efficient dissipation of energy without exceeding permissible temperature limits of either the canisters of the salt. It is estimated that each canister will require about 100m^2 of salt for cooling.



The cross-section of a canister of Swedish design for the disposal in granite. It shows vitrified waste surrounded by 4 inch of lead, 0.25 inch of titanium, 4 inch of bentonite (an absorptive and colloidal clay mineral) and finally, granite.

COMPARISON OF VARIOUS POWER PLANTS

1. Thermal power plant Vs Hydro-plant:

Sl. No.	Thermal power plant	Hydro power plant
1.	Initial cost is low.	Initial cost is high.
2.	Located near to load center.	Not like that
3.	Transmission losses are less.	Transmission losses are high
4.	Power production is not dependent on nature's mercy.	It is only dependent on nature's mercy.
5.	Construction time is less	Initial construction requires long time.
6.	Power generation cost is high	Power generation cost is less.
7.	Air pollution is more.	No air pollution.
8.	Fuel transportation is difficult.	No fuel transportation.
9.	Life of the plant is less.	Life of the plant is high.
10.	Efficiency of the plant is less.	Efficiency of the plant is high.
11.	Not suitable for peak load plant.	It is suitable.

2. Steam power plant Vs Nuclear power plant:

Sl. No.	Steam power plant	Nuclear power plant
1.	It is not suitable where water and coal resources are not available.	No such constraints.
2.	Fuel storage space is required.	No fuel storage space.
3.	Requirement of workmen is very high.	Can be managed with very less number of workmen.
4.	Capital cost is high.	Capital cost is less when size of plant is increased.
5.	No radioactive material.	Radioactive wastes.

6.	Space requirement is high.	Space requirement is less.
7.	Steam power plants are affected by weather conditions.	It will not be affected by adverse weather conditions.
8.	It requires large quantity of water.	It does not require large quantity of water.
9.	Large quantity of fuel is required.	Less quantity of fuel required.
10.	Maintenance cost is less.	Maintenance cost is high.
11.	Operating cost is high.	Operating cost is less.
12.	Steam power plant efficiency = 20 to 30%.	Nuclear power plant η = 30 to 32%.

University Exam problem:

A thermal power plant spends Rs. 30 Lakhs in one year as coal consumption. The coal has heating value of 6000 Kcal/kg and cost Rs. 600 per ton. If the thermal efficiency is 40% and electrical efficiency is 92%. Find the average load of the power plant. (May 2016)

Solution:

Overall efficiency $\eta_{overall}$ = 0.4x0.92 = 0.368

Coal used / annum = $(30 \times 10^5) / 600$ =5000 tons = 5×10^6 kg

Heat of combustion = coal use / annum x calorific value

= $5\times10^6 \times 6000 = 30 \times10^9$ kcal

Heat output = $\eta_{overall} \times$ **Heat of combustion**

= $0.368 \times (30 \times10^9) = 1104 \times 10^7$ Kcal

Heat equivalent of 1 KWh = 860 Kcal

Units generated per annum = $1104 \times 10^7 / 860$ KWh

Average load on station = (units generated/ annum) / Hours in a year

= $(1104 \times 10^7 / 860) / 8760$

= **1465.434 KW**

2- MARKS

1. Name the four major circuits in steam power plant.

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

2. What are the types of coal?

- Peat
- Lignite
- Bituminous coal
- Anthracite coal

3. What will be present in feed water and steam flow circuit in steam power?

The feed water and steam flow circuit consists of feed pump, economiser boiler drum super heater, turbine and condenser.

4. What will be present in cooling water circuit and coal & ash circuit in steam power plant?

The cooling water circuit consists of a pump, condenser and cooling tower. The coal and ash circuit consists of coal delivery, preparation of coal, handling of coal to the boiler furnace, ash handling and ash storage.

5. What are crusher and its crushing method?

A crusher is a machine designed to reduce large solid chunks of raw materials into smaller chunks. Crushers are commonly classified by the degree to which they fragment the starting material.

Crushing Methods:

1. Impact
2. Shear
3. Attrition
4. Compression

6. What is Deaerator?

A deaerator is a device that is widely used for the removal of oxygen and other dissolved gases from the feed water to steam-generating boilers.

7. What is the purpose of deaeration?

The purpose of deaeration is:

1. To remove oxygen, carbon dioxide and other non-condensable gases from feed water.
2. To heat the incoming makeup water and return condensate to an optimumtemperature.
3. Minimizing solubility of undesirable gases.
4. Providing the highest temperature water for injection to the boiler.

8. What is meant by cooling Towers?

It is a tower or building like device in which atmospheric air circulates in direct orindirect contact with warmer water and water is thereby cooled. Cooling towers mayeither use the evaporation of water to remove process heat and cool the working fluid.

9. List the factors to be considered while choosing a site for steam power station:

1. Supply of fuel
2. Availability of water
3. Transportation facilities
4. Cost and type of land
5. Nearness to load centers
6. Distance from populated area

10. List the thermal power plant in Tamil Nadu.

- Alathiur(2*18MW), Tamil Nadu, Madras cements
- Ennore(2*60MW,3*110MW) Tamil Nadu Electricity Board
- Neyveli(6*50MW,2*100MW) Tamil Nadu Neyveli lignite corp. Ltd.

11. How the thermal efficiency of a steam plant can be increased. **(Nov 2012)**

The ratio of heat equivalent of mechanical energy transmitted to the turbine shaft to the heat of combustion of coal is known as Thermal efficiency of Steam power station. To improve the thermal efficiency, the heat loss in steam from boiler to turbine should be minimized **by using adiabatictubes.**

12. List the advantage of thermal power plant.

1. The fuel used is quite cheap.
2. Less initial cost as compared to other generating plants.
3. 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.
4. It requires less space as compared to hydro power plants.
5. Cost of generation is less than that of diesel power plants.

13. List the disadvantages of thermal power plant.

1. It pollutes the atmosphere due to production of large amount of smoke and fumes.
2. The running cost is high when compared to hydroelectric plants.

14. Define super heater. (Nov 2013)

A Super heater is a device used to convert saturated steam into a dry steam usedfor power generation or processes steam which has been super-heated is known as superheated steam.

15. Define coal gasification. (Nov 2013)

Coal gasification is the process of producing syngas–a mixture consisting primarily of methane (CH_4) carbon monoxide (CO), hydrogen (H_2), carbon dioxide (CO_2) and water vapour (H_2O)–from coal and water, air and/or oxygen. Historically, coal was gasified to produce coal gas (also known as "town gas"), which is a combustible gas traditionally used for municipal lighting and heating before the advent of industrial-scale production of natural gas.

16. Write the significance of combined cycle power plant. (April/May 2012)

Combined cycle power plant is more efficient than a conventional power plant because it uses a higher proportion of the energy that the fuel produces when it burns. In a combined cycle power plant (CCPP), or combined cycle gas turbine (CCGT) plant, a gas turbine generates electricity and the waste heat is used to make steam to generate additional electricity via a steam turbine; this last step enhances the efficiency of electricity generation.

17. Define bleeding in steam power plant?

Bleed steam is steam that is taken off of certain sections of a turbine so that it can be used for heating & sealing purposes. The most typical use is in high pressure feed water heaters, which preheats the feed water prior to being introduced into the main boiler.

18. What is the use of belt conveyors?

Belt conveyors are mostly used for transporting coal over long distance with large quantity. An endless belt is made to run over a pair of end drums and pulleys and supported by series of roller at regular intervals.

19. Define draught, what is the use of draught in thermal power plants?

Draught is defined as a small pressure difference required between the fuel bed (furnace) and outside air to maintain constant flow of air and to discharge the gases through chimney to the atmosphere. Draught can be obtained by chimney, fan, steam jet (or) -air jet (or) combination of these.

The uses are

- To supply required quantity of air to the furnace for combustion of fuel.
- To draw the combustion products through the system.
- To remove burnt products from the system

20. Why ash handling system is needed?

- To remove the ashes from the furnace ash hopper
- To transport the ashes from furnace ash - hopper to a storage
- To dispose the ashes from the storage

21. What is the main purpose of chimney?

The main purpose of chimney is to emit the flue gases at a considerable height to avoid nuisance to the surrounding people.

22. What consists of air and flue gas circuit?

Air and flue gas circuit consists of forced draught fan, air-pre-heater, boiler, furnace, super heater, economiser, dust collector, induced draught fan and chimney.

23. List the disadvantages of gas turbine power plant. **(Nov 2013)**

1. No load and Partial load efficiency is low
2. High sensitive to component efficiency
3. The efficiency depends on ambient pressure and ambient temperature
4. High air rate is required to limit the maximum inlet air temperature. Hence exhaust losses are high
5. Air and gas filter is required to prevent dust into the combustion chambers.

24. List the factors which affect the performance of gas turbine power plants.

1. Part load efficiency
2. Fuel consumption
3. Air mass flow rate
4. Thermal efficiency
5. Regeneration

25. What are the working fluids in gas turbine?

1. Air
2. Helium
3. Argon
4. Carbon dioxide

26. List the advantages of gas turbine power plant. **(April 2015)**

1. Low capital cost
2. High reliability
3. Flexibility in operation
4. Capability to quick start
5. High efficiency

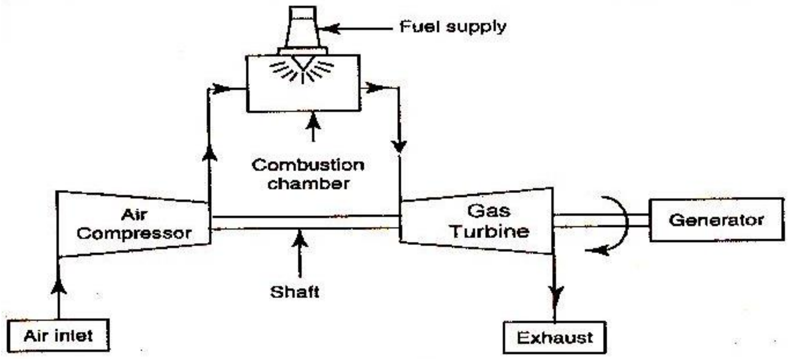
27. List the types of gas turbine power plants. **(Nov 2012)**

1. According to the cycle of operation
    a. Open cycle gas turbines
    b. Closed cycle gas turbines, and
    c. Semi closed cycle gas turbines
2. According to the type of fuel
    a. Liquid
    b. Gas
    c. Solid

28. Is it always useful to have a regenerator in a gas turbine power cycle? Why?

It is not always useful to have a regenerator in a gas turbine cycle. Regenerator causes pressure drop of 0.035 to 0.2 bars in compressed air and about 0.035 bars in exhaust gases. These pressure drops affect to contain extend the gain in efficiency due to regeneration.

29. Sketch the schematic arrangement of open cycle gas turbine plant and name the components.



30. What are the merits of nuclear power plants?

- The amount of fuel required is small.Therefore there is no problem of transportation, storage etc.
- The demand for coal, oil and gas is reduced which are tending to rise in cost as the stocks are becoming depleted.
- These plants need less area as compared to any other plant. A 2000MW nuclear plant needs 80 acres whereas thermal stations need about 250 acres of land.
- Most economical in large capacity. The operating cost is quite low and once the installation is completed, the loading of the plant is always operated as a base load plant.

31. List the disadvantages of nuclear power plant? (Nov 2013)

- Radioactive Waste
- Nuclear accidents
- Nuclear radiation
- High Cost
- Impact on human life
- Impact on aquatic life

32. List the Nuclear power plants in India.

1. Tarapur Atomic Power StationMaharastra-1400 MW
2. Rajasthan Atomic Power Station-Rajasthan-1180 MW
3. Kudankulam Nuclear Power Plant-, Tamil Nadu -1000MW
4. Kaiga Atomic Power Station, Karnataka-880 MW
5. Madras Atomic Power Station, Kalpakkam-440MW
6. Kakrapar Atomic Power Station-Gujarat-440MW

33. Name the different components of nuclear reactor? (April/May 2014)

1. Nuclear fuel
2. Moderator
3. Control rods
4. Reflectors
5. Reactor vessel
6. Biological shielding
7. Coolant

34. Define Chain reactions.

Many heavy elements, such as uranium, thorium, and plutonium, undergo both spontaneous fission, a form of radioactive decay and *induced fission*, a form of nuclear reaction. Elemental isotopes that undergo induced fission when struck by a free neutron are called fissionable; isotopes that undergo fission when struck by a thermal, slow moving neutron are also called fissile.

35. What is meant by nuclear fission? (April/May 2012)

Uranium exists in different isotopes of U^{238}, P^{234} and U^{235}. Out of these, P^{235} is most unstable. When unstable heavy nucleus is bombarded with high-energy neutrons, it splits up roughly into two equal fragments and about 2.5 neutrons are released and a large amount of energy is produced. This process is called nuclear fission.

36. Define nuclear reactor

Nuclear reactor is a device in which nuclear chain reactions are initiated, controlled, and sustained at a steady rate, as opposed to a nuclear bomb, in which the chain reaction occurs in a fraction of a second and is uncontrolled causing an explosion.

37. Define Nuclear Fusion. **(April/May 2012)**

Fusion means joining smaller nuclei to make a larger nucleus. The sun uses nuclear fusion of hydrogen atoms into helium atoms. This gives off heat and other radiation.

38. What is Uranium enrichment? What are the two ways of uranium enrichment?

In most types of reactor, a high concentration of uranium is used to make fuel rod. This produced by a process termed enrichment. The enriched uranium contains more than natural 0.7% U^{235}.The two ways of uranium enrichment are

1. Gas centrifuge process 2. Gas diffusion

39. What is the purpose of control rods?

The control rods are used to start the chain reaction, maintain the chain reaction at required level and to shut down the reactor during emergency.

40. Name few types of reactors. **(April/May 2014)**

Fast reactors, Thermal reactors, natural fuel reactors, Enriched Uranium reactors, water moderated reactors, heavy water moderated reactor, graphite moderated reactor, and gas cooled reactors and Sodium cooled reactors.

41. What is breeding in nuclear reactor?

The process of producing fissionable material from a fertile material such as uranium 238 (U^{238}) and thorium 232 (Th^{232}) by neutron absorption is known as breeding.

42. What are the advantages of breeder reactors?

- It gives high power density than any other reactor
- High breeding is possible
- High burn-up of fuel is achievable
- The operation of the reactor is not limited by Xe poisoning

43. What are the demerits of breeder reactor?

- Highly enriched fuel is required
- Control is difficult and expensive
- Safety must be provided against melt down
- Handling of sodium is a major problem

44. What are the advantages of Sodium in fast-breeder reactors?

- Sodium has very low absorption cross-sectional area
- It possess good heat transfer properties at high temperature and low pressure
- It does not react with any of the structural materials used in primary circuits

45. What is pressurized water reactor (PWR)?

A pressurized water reactor is a light water cooled and moderated reactor having an unusual Core design using both natural and highly enriched fuel.

The PWR belongs to the light water type. The moderator and the coolant are both light water (H_2O). The cooling water circulates in two loops, which are fully separated from one another. PWR keep water under pressure, so the water heats but does not boil even at the high operating temperature.

46. What is boiling water reactor (BWR)?

The **boiling water reactor** (**BWR**) is a type of light **water** nuclear **reactor** used for the generation of electrical power. It is the second most common type of electricity-generating nuclear **reactor** after the pressurized **water reactor** (PWR), also a type of light **water** nuclear **reactor**.

47. Define Nuclear Power plant safety.

Radiation doses can be controlled through the following procedures:

1. The handling of equipment via remote in the core of the reactor
2. Physical shielding

3. Limit on the time a worker spends in areas with significant radiation levels
4. Monitoring of individual doses and of the working environment
5. Safety mechanism of a Nuclear power reactor

48. State some advantages of Pressurized Water reactor?

1.The pressurized water reactor is compact
2.In this type, water is used as coolant, moderator and reflector water is cheap and available in plenty
3.It requires less number of control rods.

49. What are the advantages of gas cooled reactor nuclear power plant?

1. Fuel processing is simple
2. The use of $C0_2$ as coolant completely eliminates the possibility of explosion in reactor.
3. No corrosion problem

50. Name the coolants commonly used for fast breeder reactors?

- Liquid metal (Na (or) Na K)
- Helium (He)
- Carbon dioxide.

51. What is meant by radioactivity?

It refers to the German name of Radio-Activity. Radioactivity is the spontaneous disintegration of atomic nuclei. The nucleus emits particles or electromagnetic rays during this process.

52. What is the unit of Radioactivity?

1. Roentgen 2.RAD (Radiation Absorbed Dose)
3. RBE (Relative Biological Effectiveness) 4.REM (Roentgen Equivalent in Man)
5. Gray (GY)-100 rads 6.Sievert (SV)

53. What are the types of Radioactive decay?

1. Alpha decay 2.Beta decay
3. Gamma decay 4.Poistron emission(Beta positive decay)
5. Electron capture

54. What is the purpose of reprocessing of nuclear waste?

The used fuel contains 96% uranium, 1% plutonium and 3% radioactive wastes. Reprocessing is used to separate the waste from the uranium and plutonium which can be recycled into new fuel. The reprocessing effectively reduces the volume of waste and limits the need to mine new supplies of uranium, so that extending the time of resources.

55. What is Neutron life time?

The neutron lifetime, is defined as the average time between the emission of neutrons and either their absorption in the system or their escape from the system. The term lifetime is used because the emission of a neutron is often considered its birth, and the subsequent absorption is considered its death.

56. List the four types of radiation associated with nuclear fission.

1. Alpha radiation 2. Beta radiation
3. Gamma radiation 4. Neutron radiation

57. What is Uranium-235 chain Reactor?

In a chain reaction, particles released by the splitting of the atom go off and strike other uranium atoms splitting those. Those particles are given off split still other atoms in a chain reaction. If a least one neutron from U-235 fission strikes another nucleus andcauses it to fission, Then the chain reaction will continue.

58. Define Alpha radiation.

This is basically the atomic nucleus of the element (He) consisting of two protons and two neutrons. It is not very penetrative and the danger to man arises if an alpha emitting element, such as plutonium, then the alpha radiation be very damaging.

59. Define Beta radiation.

Beta radiation consists of electrons or their positively charged counterparts. This can penetrate the skin, but not very far.

60. Define Gamma radiation.

Gamma radiation is penetrative in a manner similar to X-rays and has similar physical properties. It can be stopped only by thick shields of lead or concrete.

61. Define Neutron radiation.

Neutron radiation consists of the neutrons emitted during the fission process. Neutrons are also very penetrative, but less so then gamma-radiation.

62. What are the requirements to sustain fission process?

- The number of neutrons produced must be able to create the rate of fission
- The bombarded neutrons must have sufficient energy to cause fission
- Fission process must generate energy
- The fission process must be controlled

63. Define multiplication factor of a fission process.

$$k = \frac{\text{Number of neutrons of any one generation}}{\text{Number of neutrons of immediately preceding generation}}$$

64. What are the desirable properties of a good moderator?

- It must be as light as possible.
- It must slowdown the neutron as quick as possible
- It must have resistance to corrosion
- It must have good machinability
- It must have good conductivity and high melting point

65. What are the desirable properties of a coolant?

- It should not absorb neutron
- Have high chemical and radiation stability
- Non-corrosive
- Have high boiling point
- Non-toxic

66. What are the advantages using CO_2as coolant?

- Gases do not react chemically with the structural materials
- Gas can attain any temperature for a particular pressure
- They do not absorb neutron
- The leakage of gas will not affect the reactivity
- The gas coolant provides best neutron economy

67. What are the materials used in nuclear power plants? **(April/May 2014)**

- Graphite Liquid metal (Na (or) Na K), Helium (He), Carbon dioxide.
- In a boiling water reactor, Light water plays the role of moderator and coolant as well
- Molten salt is a primary coolant for a molten salt reactor.

68. What are the limitations of nuclear power plant Nov' 2015

- Radioactive minerals are unevenly distributed around the world and are found in limited quantities.
- Supply of high quality uranium, one of the raw materials, will last only for few decades.
- Nuclear waste from nuclear power plant creates thermal (heat) pollution which may damage the environment.
- A large amount of nuclear waste is also created and disposal of this waste is a major problem.
- The danger of accidental discharge of radio activity also exists.
- Starting a nuclear plant requires huge capital investment and advanced technology.
- Nuclear plants are opposed on moral grounds, by many groups, because of their close linkage with development of nuclear weapons.
- There are number of restrictions on the export or import of nuclear technology, fuels etc.

69. State the problems related to ash handling in thermal power station **April 2016**

- At concentrations of 8 to 10 kg water per kg of ash, the wet handling system requires very large amounts of water. Little, if any, of this water is recycled.
- The auxiliary power required to run the pumps is between 5 and 15 kWh/tonne. Using an average power requirement and an average ash production, the annual energy consumption is $1.25 * 10^8$ kWh/year. This represents a significant loss of salable electric power.
- The Bagger pumps used for transporting the slurry to the ash pile have a poor record of reliability.
- The ash piping is prone to clogging with ash deposits. The steel piping used in the transfer lines are suffering severe corrosive/erosive damage, requiring frequent maintenance.
- High-pressure drop in the piping and large static heads often require tandem pumping, which leads to operational problems and cavitations.
- The ash piles occupy large plots of land. Acquisition of additional land is becoming progressively more difficult.

70.Enlist the factors affecting the choice of selection of site and requirement of nuclear power stations. **April 2016**

Some important factors while site selection:

1. Use of land and water area: Construction is not allowed on shore zones belonging to the coastal area of a sea or of a water system which would otherwise affect ecology.

2. Availability of nuclear fuel, cooling water: The site should be such that the fuel required for nuclear power generation such as uranium and others should be available near the site or transporting such fuel should not be difficult and time consuming. Also PWR, BWR mostly use light water H_20 as their coolant as well as moderator so water facility should be available near to the site and in plenty.

3. Population and sources of livelihood in the region: A nuclear power plant site extends to about a kilometers' distance from the facility. It is defined as an area where only power plant related activities are allowed as a rule. Permanent settlement is prohibited and only very limited employee accommodation or recreational settlement is allowed.

4. Human activities and human facilities

5. Transport arrangements and Traffic arrangements

71. What are types of nuclear reaction April 2015

There are two main types of nuclear reactions: fusion and fission. In fusion reactions, two light nuclei are combined to form a heavier, more stable nucleus. In fission reactions, a heavy nucleus is split into two nuclei with smaller mass numbers.

72. What is the difference between Steam Turbine and Gas Turbine? Nov' 2015

• Steam turbine uses high pressure steam as the working fluid, while the gas turbine uses air or some other gas as the working fluid.

• Steam turbine is basically an expander delivering torque as the work output, while a gas turbine is a combined device of compressor, combustion chamber, and turbine executing a cyclic operation to deliver work as either torque or thrust.

• Steam turbine is only a component executing one step of the Rankine cycle, while gas turbine engine executes the whole Brayton cycle.

• Gas turbines can deliver either torque or thrust as the work output, while steam turbines almost all the time delivers torque as the work output.

• The efficiency of the gas turbines is much higher than the steam turbine due to higher operating temperatures of the gas turbines. (Gas turbines ~1500 ^{0}C and steam turbines ~550 ^{0}C)

• The space required for the gas turbines is much less than steam turbine operation, because steam turbine requires boilers and heat exchangers, which should be connected externally for heat addition.

• Gas turbines are more versatile, because many fuels can be used and working fluid, which has to be fed continuously, is readily available everywhere (air). Steam turbines, on the other hand, require large amounts of water for the operation and tend to cause problems in lower temperatures due to icing.

PONDICHERRY UNIVERSITY QUESTIONS

2 MARKS

1. Define solar constant in solar energy. (Nov 2012)
2. How the thermal efficiency of a steam plant can be increased. (Nov 2012)
3. Define super heater. (Nov 2013)
4. Define coal gasification. (Nov 2013)
5. Write the significance of combined cycle power plant. (April/May 2012)
6. List the disadvantages of gas turbine power plant. (Nov 2013)
7. List the advantages of gas turbine power plant. (April 2015)
8. List the types of gas turbine power plants. (Nov 2012)
9. What is meant by Nuclear fission? (April/May 2012)
10. Define Nuclear Fusion. (April/May 2012)
11. Name few types of reactors. (April/May 2014)
12. What are the materials used in nuclear power plants? (April/May 2014)
13. List the disadvantages of nuclear power plant? (Nov 2013)
14. What are types of nuclear reaction (April 2015)
15. Compare steam and gas turbine plant (Nov' 2015)
16. What are the limitations of nuclear power plant (Nov' 2015)
17. State the problems related to ash handling in thermal power station (April 2016)
18. Enlist the factors affecting the choice of selection of site and requirement of nuclear power stations. (April 2016)

11 MARKS

1. Explain in detail about Thermal power plant. Draw neat sketch and explain the function of thermal power plant. (Nov 2011) (Nov 2013) (Nov 2012)(April/May 2012)
2. Explain the operation of feed water and steam circuit in thermal power station. (May 2016)
3. Draw the schematic gas turbine power plant and explain. (Nov/Dec 2014) (April/May 2014) (Nov 2012) (April/May 2012)
4. Compare of Open and Closed Cycle Gas Turbines (April 2013, may 2016)
5. Explain the methods of improving the thermal efficiency of GAS turbine plant. (May 2016)
6. What are the fuels of Nuclear Power Plant? Draw the detailed flow chart of nuclear fuel cycle and energy routes and explain. (Nov/Dec 2014)
7. Explain in detail about the working principle of nuclear power station. (Nov 2013) (April 2013) (Nov/Dec 2014)
8. Explain the main parts of a nuclear reactor with their function. (April/May 2014)
9. Explain any two reactors with their advantages and disadvantages. (April 2015, May 2016)
10. A thermal power plant spends Rs. 30 Lakhs in one year as coal consumption. The coal has heating value of 6000 Kcal/kg and cost Rs. 600 per ton. If the thermal efficiency is 40% and electrical efficiency is 92%. Find the average load of the power plant. (May 2016)