ATME College of Engineering

Electrical Power Generation & Economics– BEE405A
Module-3_Nuclear Power Plants

Presented by,

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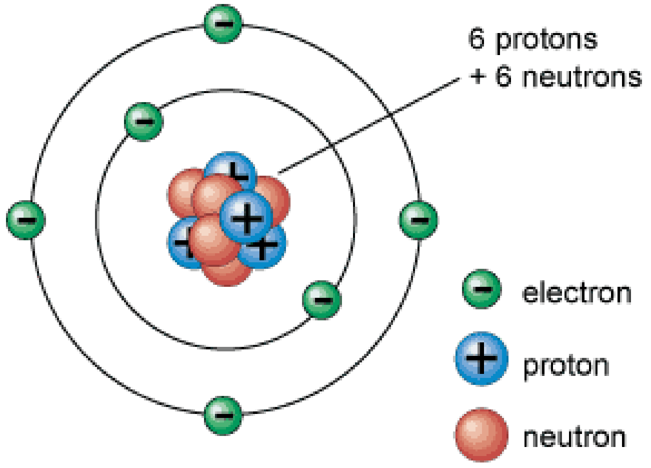
Course Outline

Module-3: Nuclear Power Plants

- Introduction, Economics of nuclear plants, Merits and demerits, selection of site, Nuclear reaction, Nuclear fission process, Nuclear chain reaction, Nuclear energy, Nuclear fuels, Nuclear plant and layout, Nuclear reactor and its control, Classification of reactors, Power reactors in use, Effects of nuclear plants, Disposal of nuclear waste and effluent, Shielding

Atomic Structure

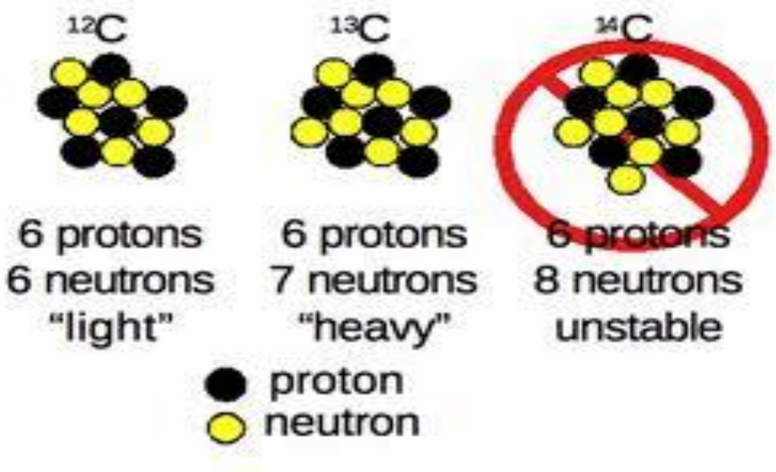
- Power locked in structure of atoms & the basic particle of matter.
  - Positively charged - Protons
  - Non-charged - Neutrons.
  - Negatively charged- Electrons



Carbon atom

- Atoms always contain equal numbers of protons and electrons, making them electrically neutral.

- Atoms can have different numbers of neutrons in their nuclei.
- Nuclei from the same element with different numbers of neutrons are called isotopes.
- Most isotopes are stable
- Some spontaneously break apart, emitting energy and particles. This is radiation.



TYPES OF NUCLEAR MATERIALS

a) Special Nuclear Material consists of uranium-233 or uranium-235, enriched uranium, or plutonium.

(b) Source Material is natural uranium or thorium or depleted uranium

that is not suitable for use as reactor fuel.

(c) Byproduct Material, in general, is nuclear material (other than special nuclear material) that is produced or made radioactive in a nuclear reactor.

Byproduct material also includes the waste produced by extracting or concentrating uranium or thorium from an ore processed primarily for its source material content.

Nuclear fission fuels are classified as fertile or fissile by the behaviour or their nuclei in fission reactions

Fissile materials:

These are composed of atoms that can be split by neutrons in a self-sustaining chain-reaction to release enormous amounts of energy.

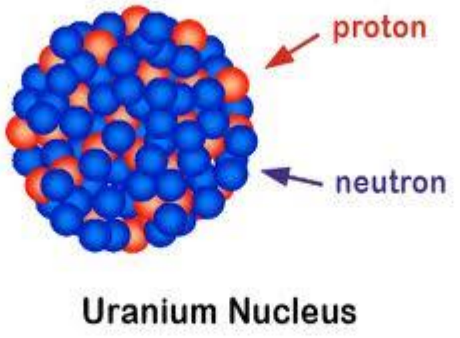
The most important fissile materials for nuclear energy and nuclear weapons are an isotope of plutonium, plutonium-239, and an isotope of uranium, uranium-235. Uranium-235 occurs in nature.

Fertile Material

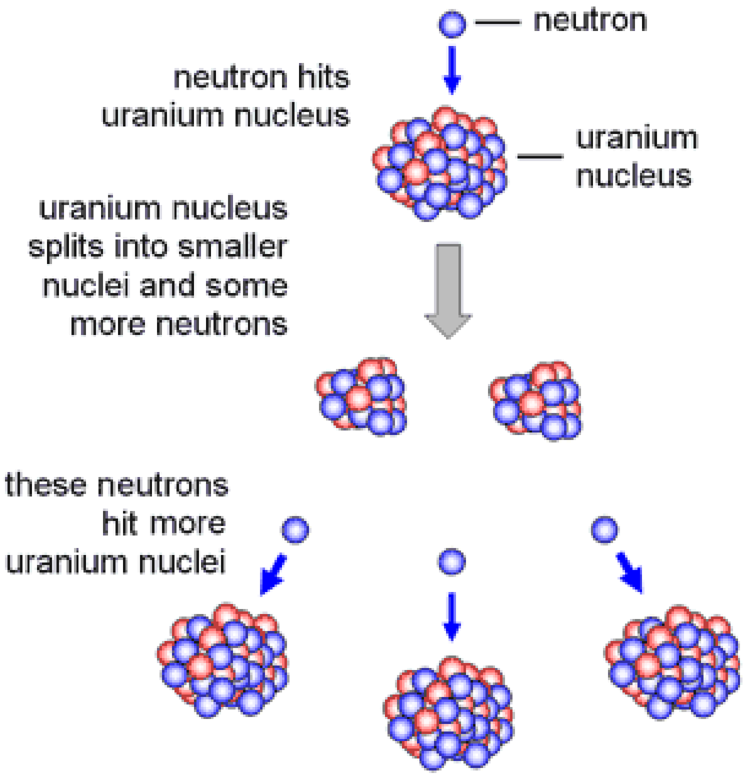
A material, which is not itself fissile (fissionable by thermal neutrons), that can be converted into a fissile material by irradiation in a reactor. There are two basic fertile materials: uranium-238 and thorium-232

Nuclear Fuels

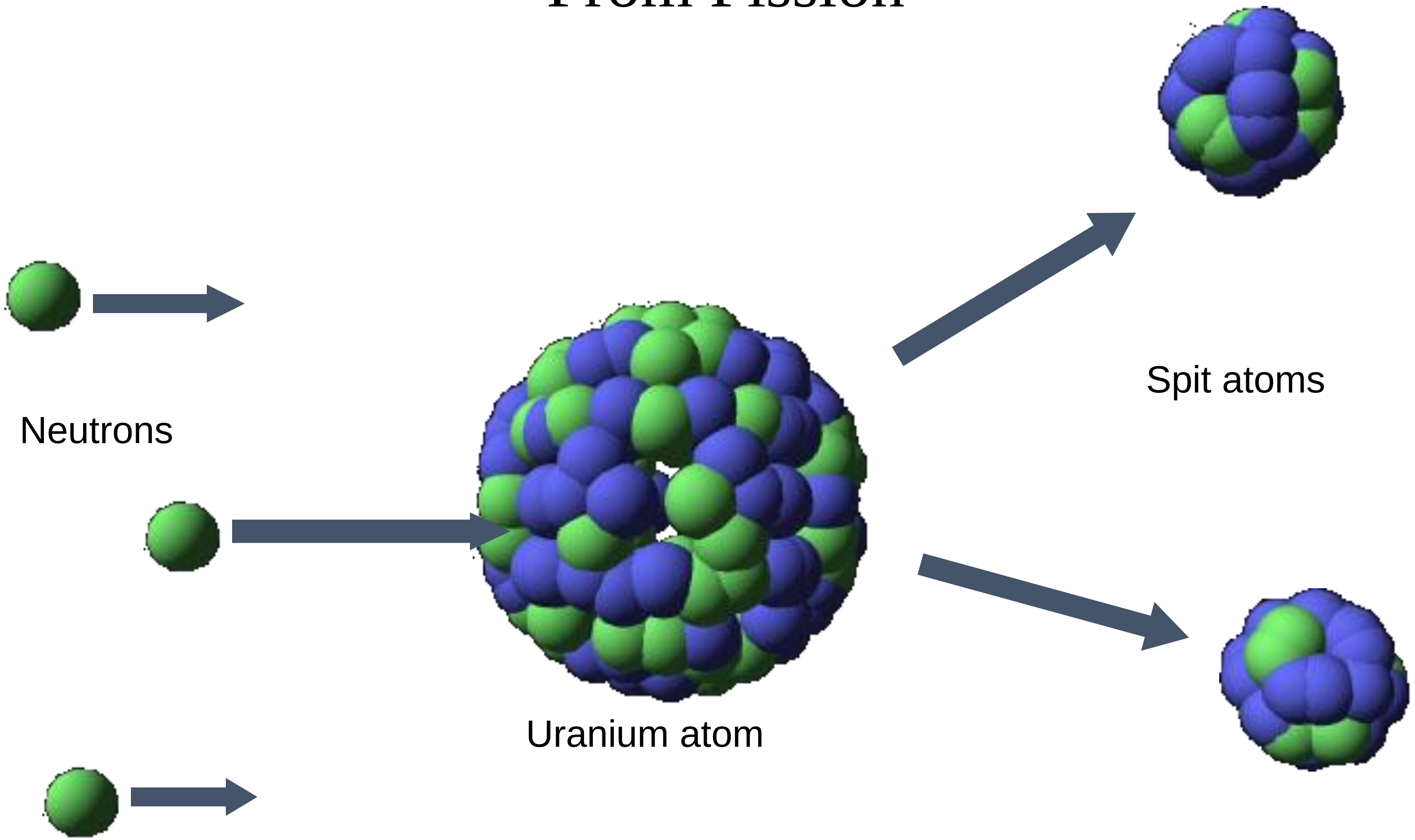
- Uranium-235 and Plutonium-239
- The fuel used by the first nuclear weapons is Uranium-235, a naturally occurring isotope.
- Uranium-235 has an extremely large nucleus that can be split when it is hit with a high-speed neutron.



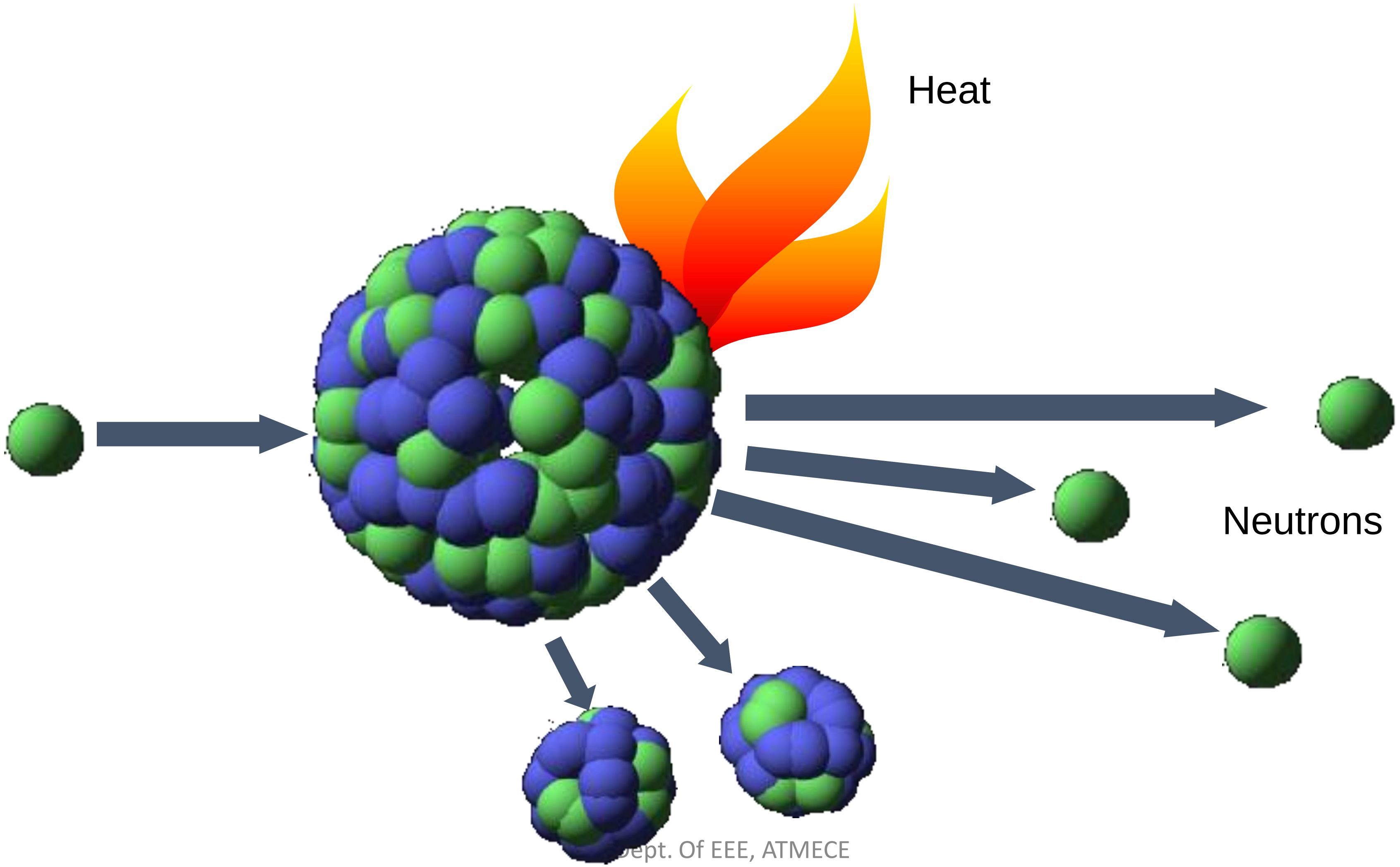
- Fission chain reaction
- When unstable heavy nuclei are bombarded with high energy neutrons, it splits into several smaller fragments.
- These fragments, or fission products, are about equal to half the original mass. This process is called Nuclear Fission.
- Each time a nucleus splits, a large amount of energy is released.
- Multiplied across the entire chain reaction…



Nuclear Energy Comes From Fission



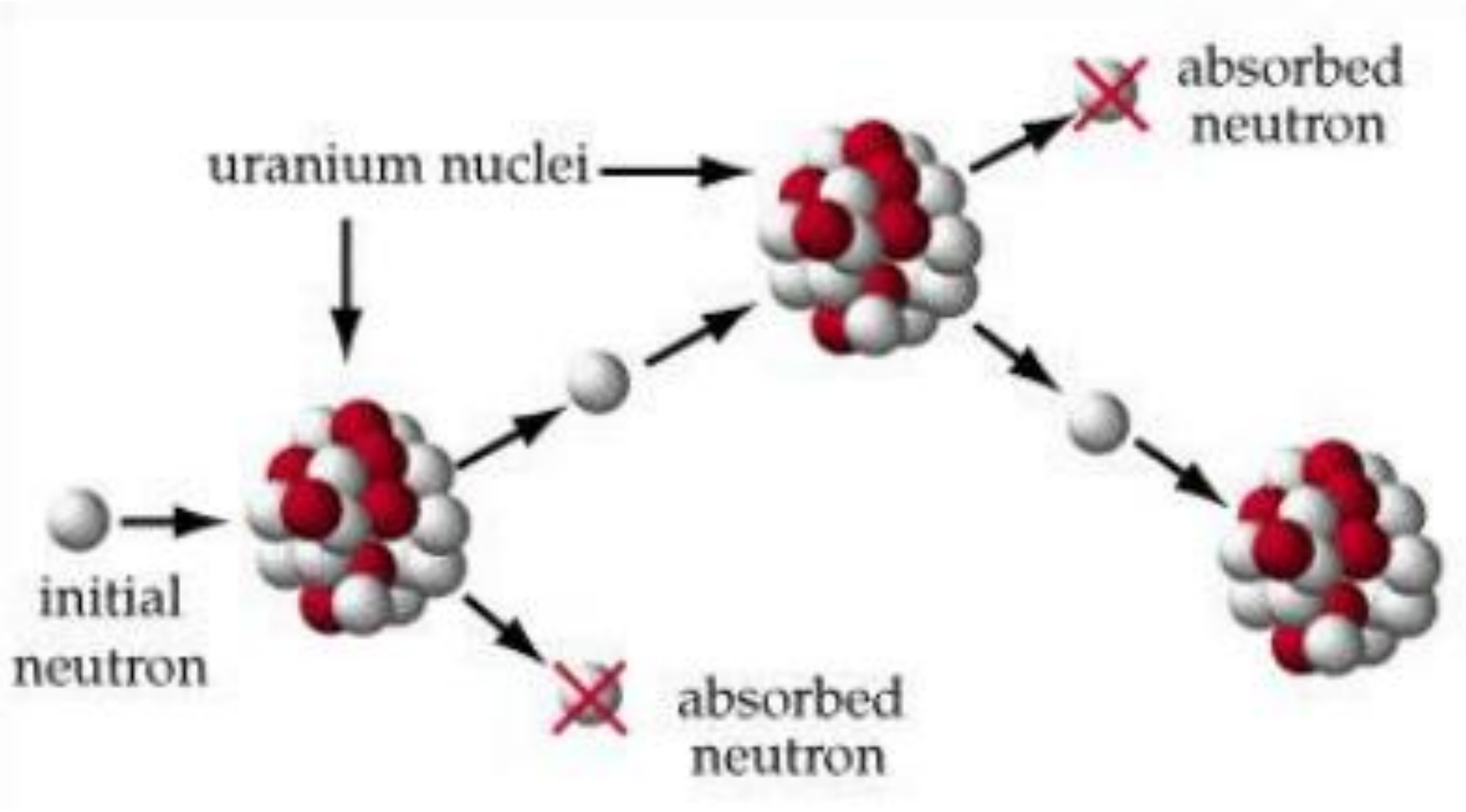
Splitting Atoms Releases Neutrons, Making Heat



Controlled Nuclear Fission

- To maintain a sustained controlled nuclear reaction, for every 2 or 3 neutrons released, only one must be allowed to strike another (uranium) nucleus.
- If this ratio is less than one then the reaction will die out.
- if it is greater than one it will grow uncontrolled (an atomic explosion).
- A neutron absorbing element must be present to control the amount of free neutrons in the reaction space.
- Most reactors are controlled by means of control rods that are made of a strongly neutron-absorbent material such as boron or cadmium.

Controlled Nuclear Fission



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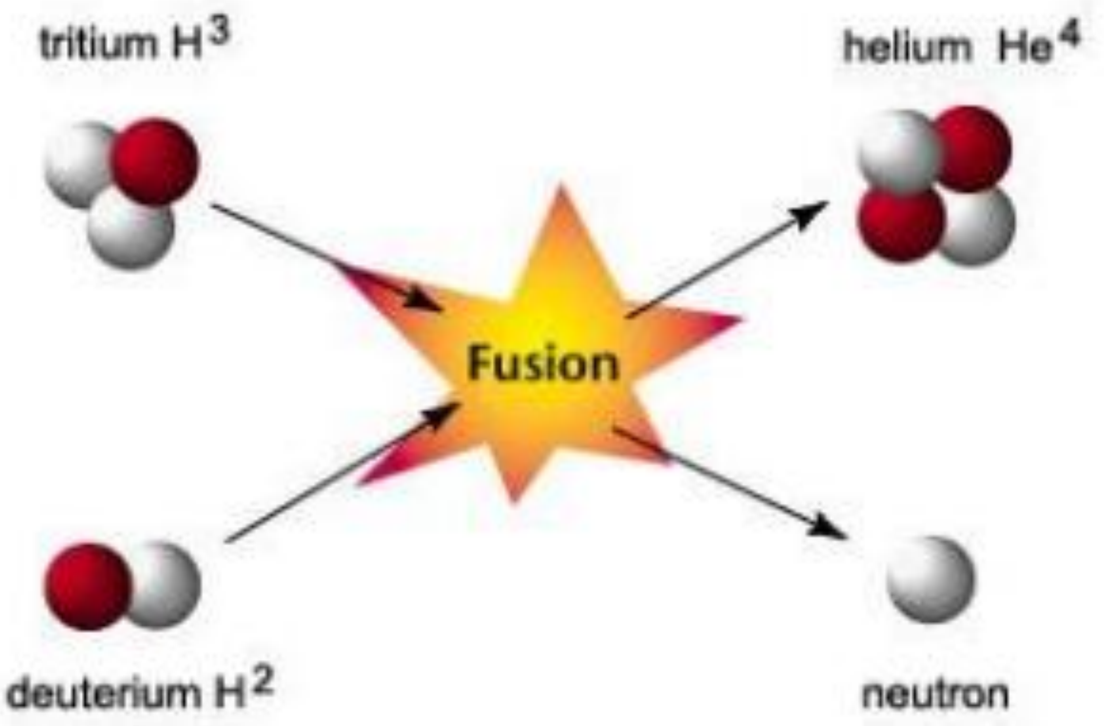
NUCLEAR FUSION

- In nuclear physics and nuclear chemistry,
- Nuclear fusion is the process by which multiple like-charged atomic nuclei join together to form a heavier nucleus.
- It is accompanied by the release or absorption of energy, which allows matter to enter a plasma state.
- The power that fuels the sun and the stars is nuclear fusion.

NUCLEAR FUSION

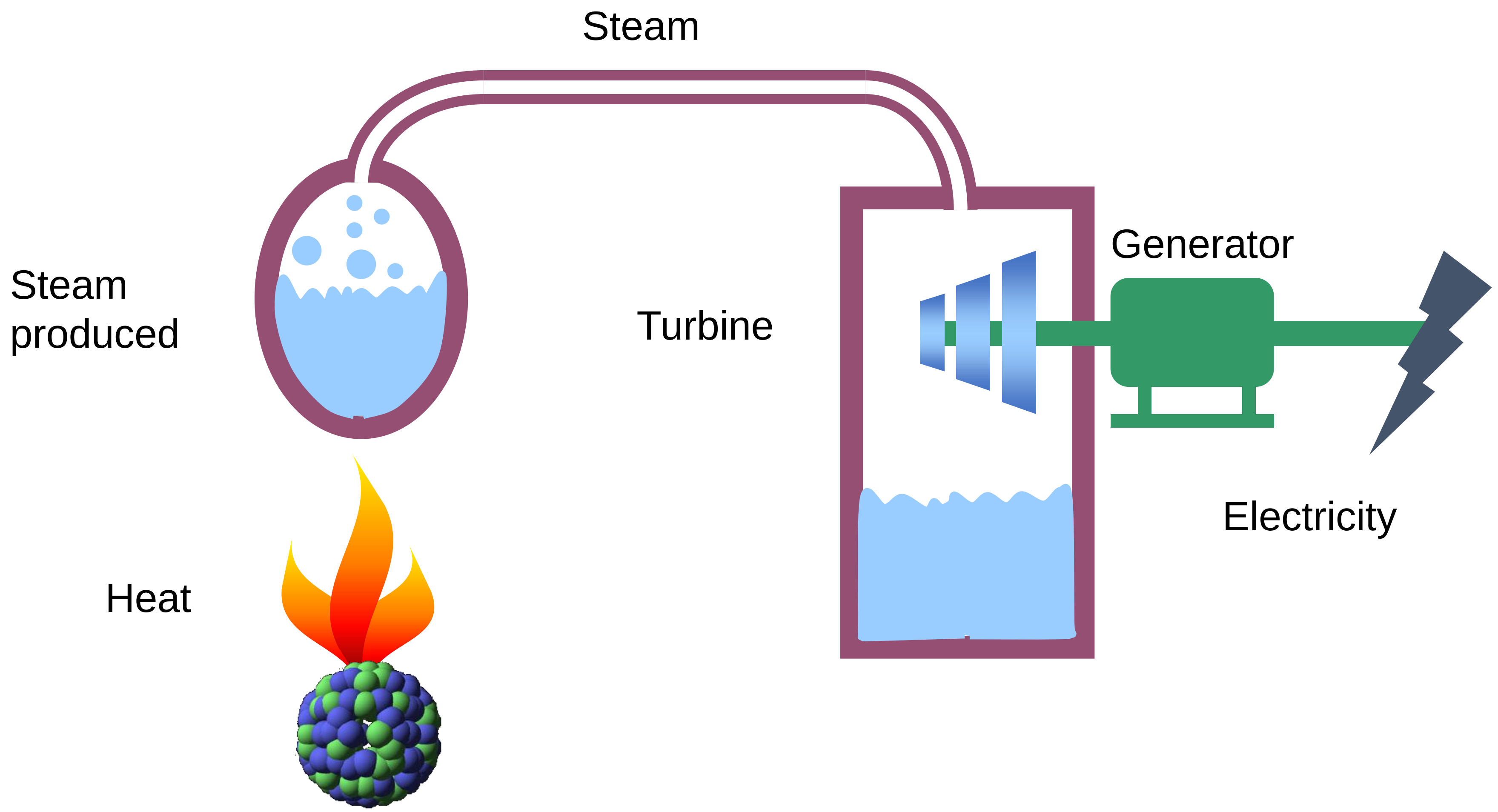
- In a hydrogen bomb, two isotopes of hydrogen, deuterium and tritium are fused to form a nucleus of helium and a neutron.
- This fusion releases 17.6 MeV of energy.



Comparison of Fusion and Fission Processes

Sl. No.	Fusion	Fission
1	Light elements fuse together with release of energ	Energy is released by the bombardment of heavy nuclear with neutrons. The nucleus splits into fragments of equal mass
2	Heavy mass will be converted in to energy	Light mass will be converted into energy
3	Amount of radioactive material consumed in a fusion process is very low	In fission process it is very high
4	Health hazard is very less	Health hazard is high due to higher radio active materials
5	Construction of controlled fusion reactors is very difficult	It is possible to construct self-sustained fission reactors and have positive energy release
6	Very very high temperature are required for fusion process (≥ 30 million degrees)	Manageable temperatures are obtained

Fundamental Process involved in Power Generation



Selection of site

- Near to load center at a reasonable distance
- Availability of transportation facilities
- Availability of water
- Distance from populated area
- Disposal of waste

Merits and Demerits

Merits

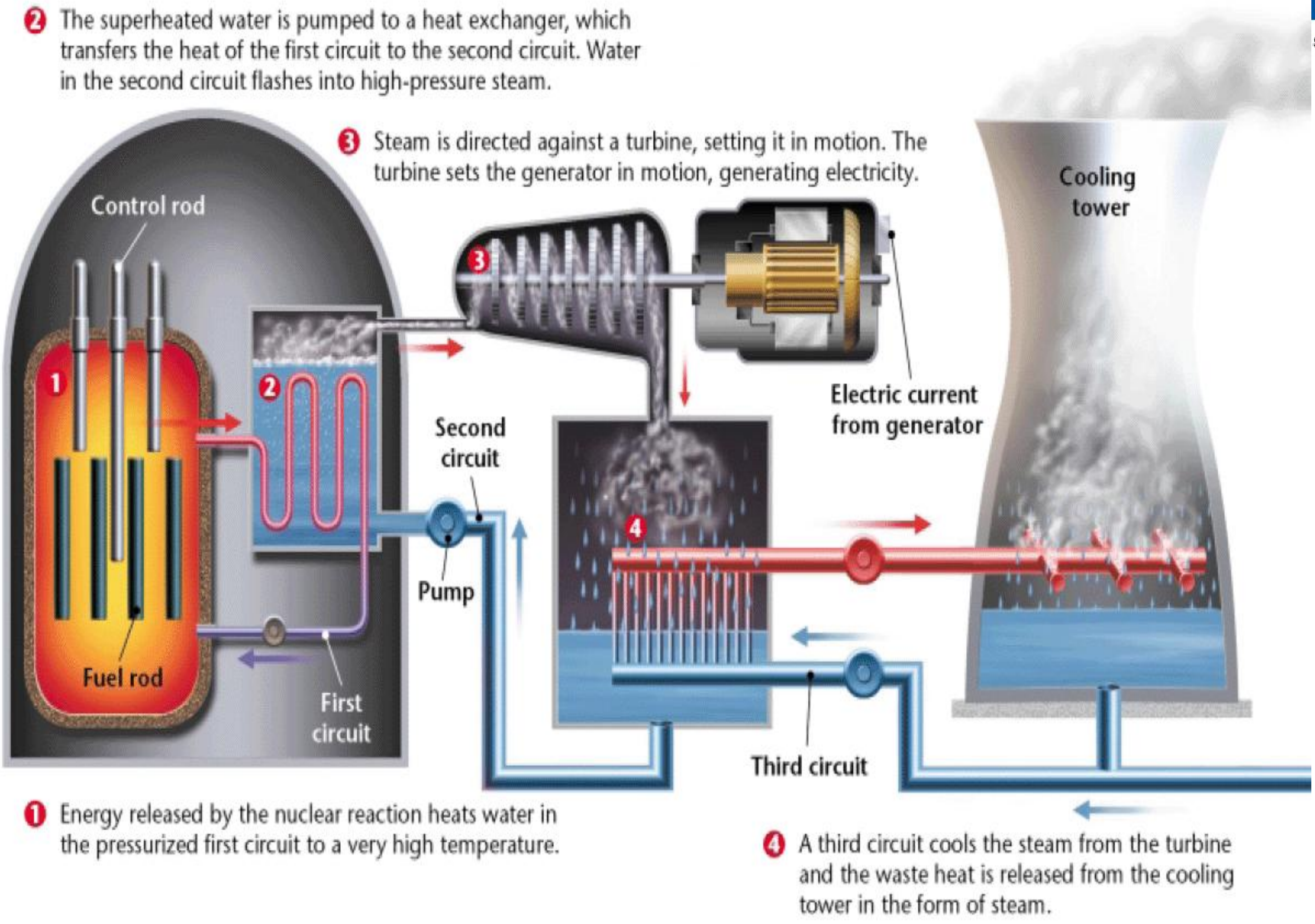
- Space required is less
- Very small quantity of fuel
- Reliability of operation
- Weather condition is not effected
- Meet large demand
- Flexible control
- Can be located near to load center

Demerits

- High initial cost
- Not well suited for varying loads
- Disposal of waste
- Maintenance cost is high
- Required trained person to handle
- Cooling water requirement of nuclear plant is more than coal plant

Layout or schematic arrangement of Nuclear power plant

- Nuclear reactor
- Heat exchanger
- Steam turbine
- Alternator
- Condenser


2 The superheated water is pumped to a heat exchanger, which transfers the heat of the first circuit to the second circuit. Water in the second circuit flashes into high-pressure steam.
3 Steam is directed against a turbine, setting it in motion. The turbine sets the generator in motion, generating electricity.
Control rod
Cooling tower
Electric current from generator
Second circuit
Pump
Fuel rod
First circuit
Third circuit
1 Energy released by the nuclear reaction heats water in the pressurized first circuit to a very high temperature.
4 A third circuit cools the steam from the turbine and the waste heat is released from the cooling tower in the form of steam.

Classification of nuclear reactors

- **Type of core**
- Homogeneous Reactor
- Heterogeneous reactor
- **Moderator used**
- Graphite Reactor
- Beryllium
- Light water
- Heavy Water
- **Coolant Used**
- Ordinary water, heavy water, gas cooled, liquid metal, organic liquid
- **Neutron energy**
- Thermal reactor and fast reactor
- **Fuel metal used**
- Enrich Uranium, Natural Uranium,Plutonium

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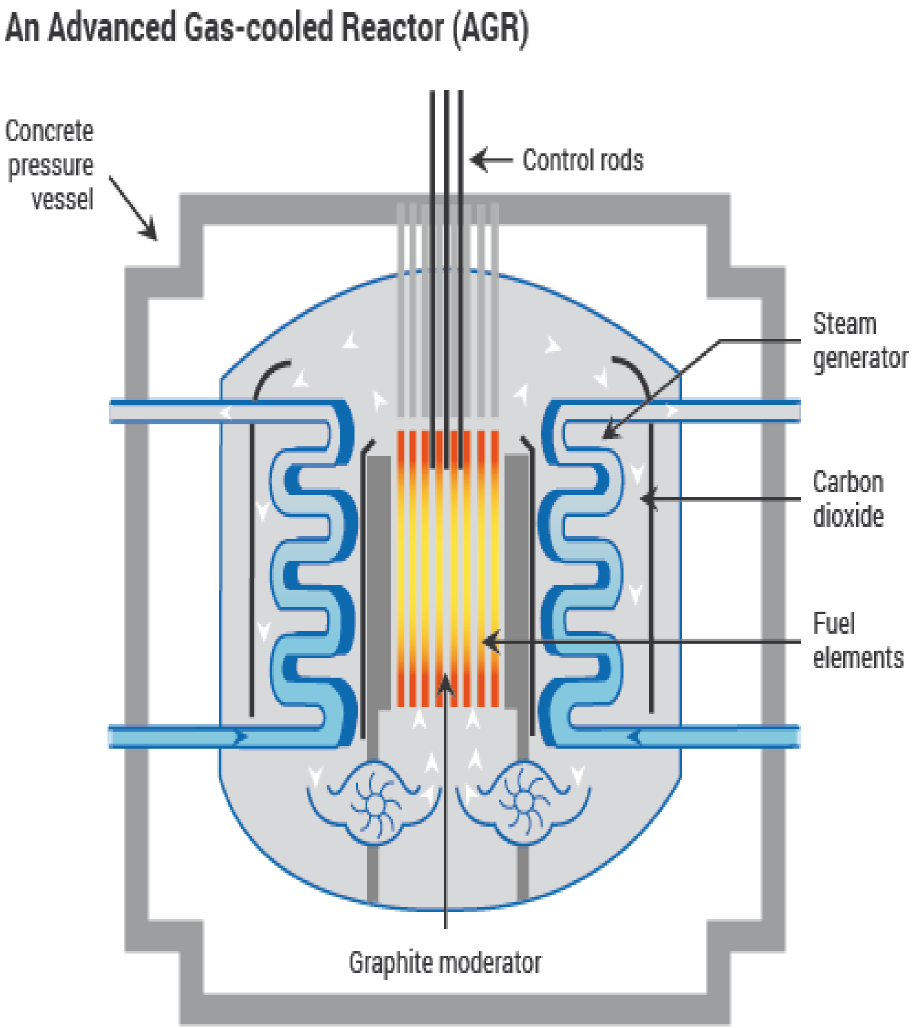
Nuclear Reactor

1. Reactor core
2. Moderator
3. Control rods
4. Reflector
5. Thermal shielding
6. Reactor vessel



Main components of Nuclear Reactor and Their functions

1. **Reactor Core:**

- It is a key component of the nuclear reactor
- It is a bounded region, Nuclear fission and chain reaction takes place
- It contains Nuclear fuel assembly, Moderator and control rods
- It is located inside a reactor pressure vessel with neutron reflector

Main components of Nuclear power plant and Their functions

2. Moderator

- It is a important component of nuclear power plant maintains neutron population in thermal energy range
- Thermal Neutrons on fission reaction leads to release of fast neutrons
- A moderator is a medium which is used to absorb a portion of kinetic energy of fast neutrons so that they fall in the category of thermal neutrons which help to sustain a controlled chain reaction

- **Moderator used**
- Graphite Reactor, Beryllium, Light water, Heavy Water

Properties of Moderator

- High Thermal Conductivity
- Available in large quantity
- Good resistance to corrosion
- Stable under heat and radiation
- Capable of slow down the neutrons

3. Control Rods

- Used to control the fission rate in nuclear reactors
- Made of Boron, Silver, Indium & Cadmium
- Used in assemblies inserted through guide tubes within a fuel element.
- Control rods have to and fro motion to remove or to insert the rods in the fuel element to increase or decrease the fission process

Coolant

- Used to remove heat from the nuclear reactor core and transfer it to the environment
- Ordinary water (under high pressure) and Deuterium oxide are used as coolant commonly

Properties

- A good coolant should not absorb neutrons
- Non Oxidizing
- Non toxic
- Non Corrosive
- High Stability
- Good heat transfer capability

Reflectors

- Fission process results in emission of heat along with 3 free neutrons
- Many of the neutrons simply escape from the reactor core without serving useful purpose
- Lead to affect the progression of the chain reaction
- To avoid the neutron loss, Inner surface of the reactor core is surrounded by a material helps to reflect the escaping neutrons back to the core
- Steel, beryllium or graphite are common reflector materials

Thermal Shielding

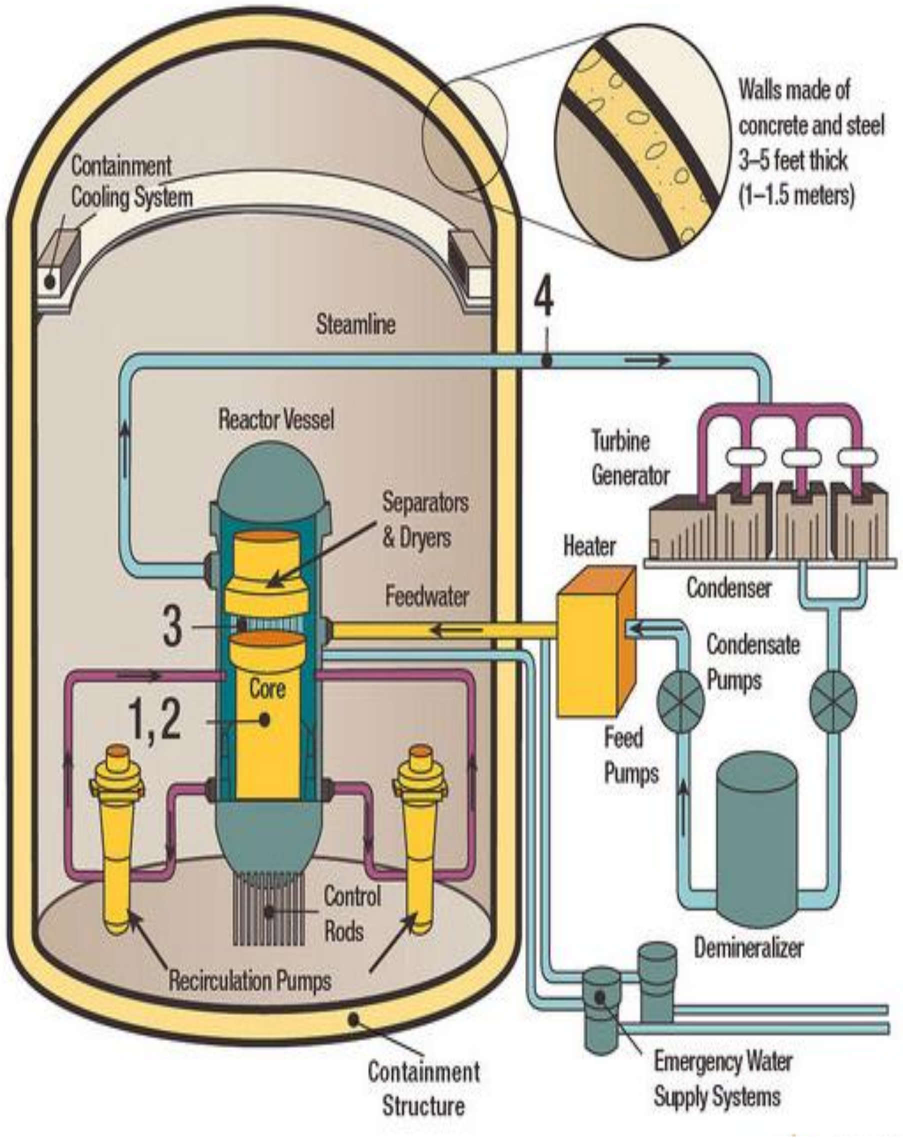
- Fission reaction results in Alpha, Beta & Gamma radiations
- Radiations are dangerous to environment
- Reactor is enclosed in steel and concrete capable of stopping these radiations.
- Coolant flows through the shielding to take away the heat.

Classification of Power Reactors

- Boiling water Reactor (BWR)
- Pressurized water Reactor (PWD)
- HEAVY water Reactor (CANDU type)
- Gas Cooled Reactor
- Fast Breeder Reactor

Power reactors –Boiling water Reactor (BWR)

- Utilizes Enriched U-235
- Operates at low pressure
- Water Boils at 285º C
- Holds upto140 tonnes
- Moderator- Light water
- Coolant- Light water
- Steam dryer are used



Advantages

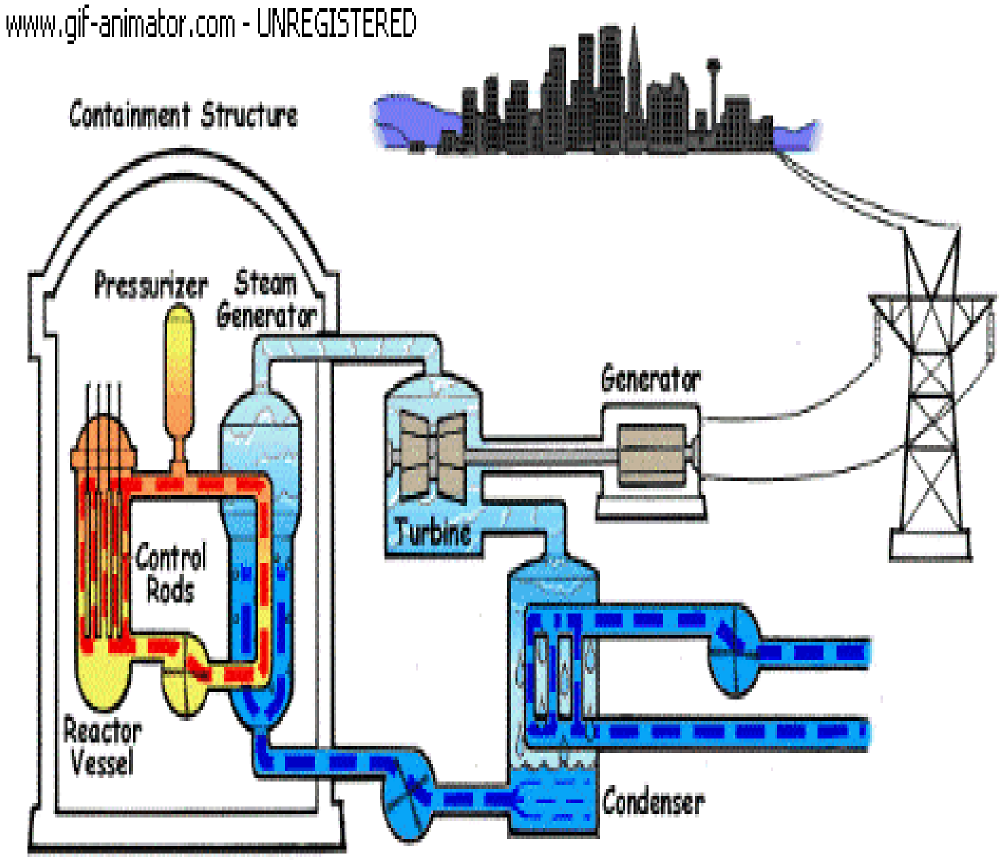
- Reactor vessel and associated components operate at a substantially lower pressure of about 70-75 bars.
- Designed to operate using natural circulation
- Simple in construction
- Reduction in cost and improved thermal efficiency

Disadvantages

- Better Steam ducts are required to avoid the contamination of turbines
- Waste of steam lowers the efficiency
- Not suitable for sudden increase in load

Power reactors –Pressurized water Reactor (PWD)

- Uses Enriched Uranium forms thin rods
- Water under pressure is used as both Moderator and as a Coolant
- coolant water Pressure maintained at 155 bars, must be high to suppress water boiling
- Circulating pump is used to absorb the heat in the core
- Coolant absorbs heat from the reactor and transfer it to the working fluid to generate steam



Power reactors –HEAVY water Reactor (CANDU type)

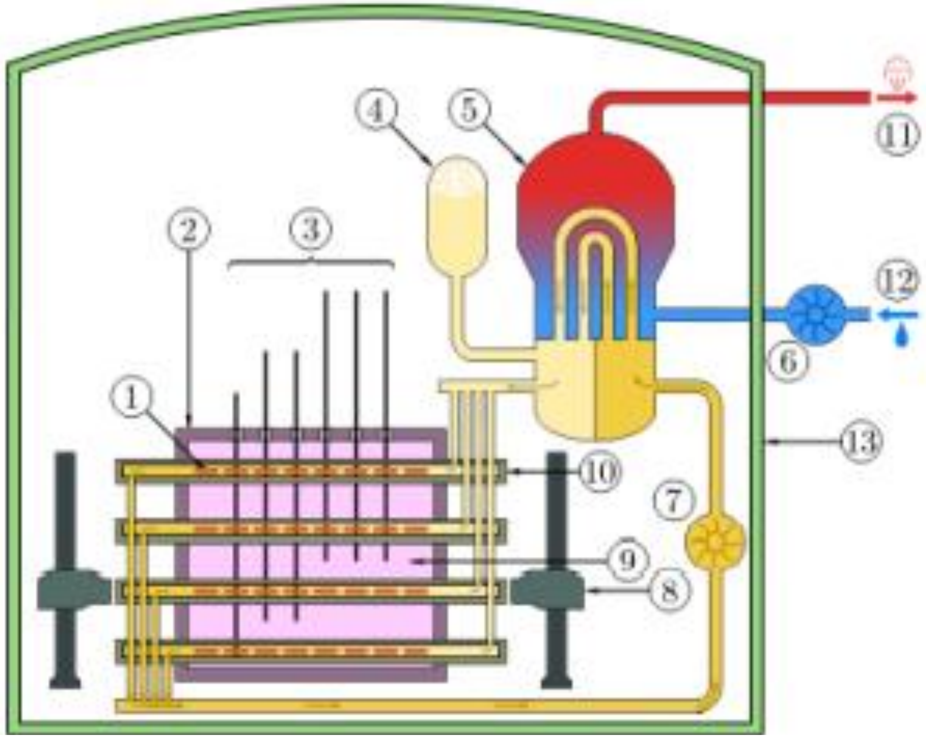
- CANDU stands for "CANada Deuterium Uranium".
- It's a Canadian-designed power reactor of PHWR type (Pressurized Heavy Water
- Reactor) that uses heavy water (deuterium oxide) for moderator and coolant, and natural uranium for fuel

CANDU-specific Features and Advantage

- Use of Natural Uranium as a Fuel
- CANDU is the most efficient of all reactors in using uranium: it uses about 15% less uranium than a pressurized water reactor for each megawatt of electricity produced
- Use of natural uranium widens the source of supply and makes fuel fabrication easier. Most countries can manufacture the relatively inexpensive fuel
- There is no need for uranium enrichment facility
- Fuel reprocessing is not needed, so costs, facilities and waste disposal associated with reprocessing are avoided
- CANDU reactors can be fuelled with a number of other low-fissile content fuels, including spent fuel from light water reactors.
- This reduces dependency on uranium in the event of future supply shortages and price increases

Power reactors –HEAVY water Reactor (CANDU type)

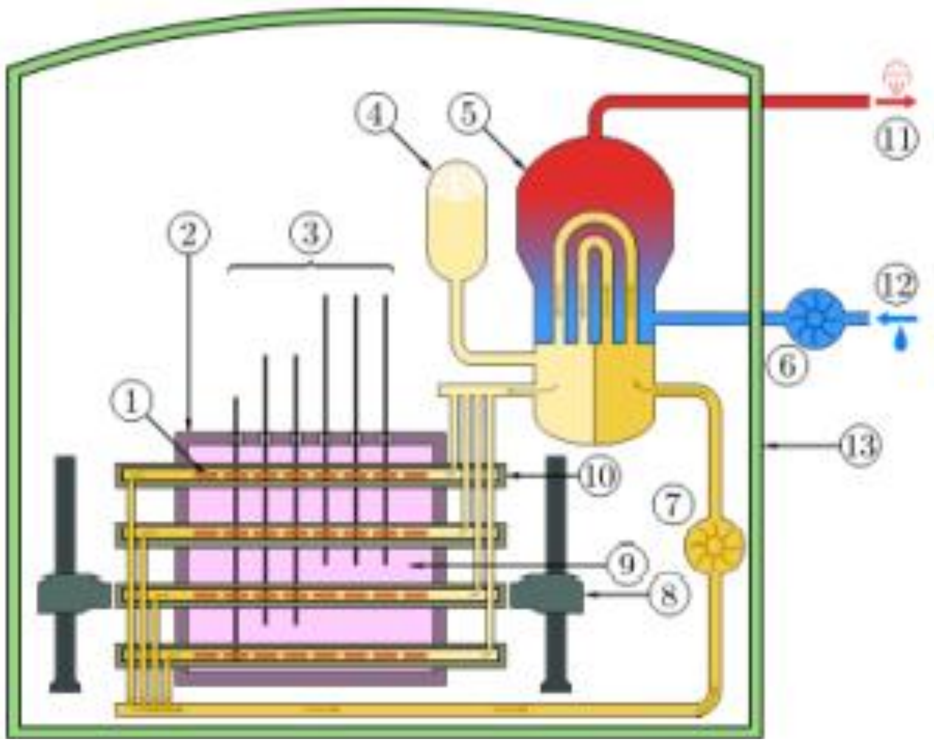
- Heavy Water ($D_2 0$) is used as moderator and as a coolant
- Extensively used in Canada
- Canadian Deuterium Uranium (CANDU) reactors
- Natural uranium used as a fuel



(1) Fuel bundle, (2) Calandria (Reactor Core), (3) Adjusters Rods, (4) Heavy Water Pressure Reservoir, (5) Steam Generator, (6) Light Water Pump, (7) Heavy Water Pump, (8) Fueling Machines, (9) Heavy Water Moderator, (10) Pressure Tube, (11) Steam going to Steam Turbine, (12) Cold Water Returning from Turbine, (13) Containment Building made of Reinforced Concrete

Power reactors –HEAVY water Reactor (CANDU type)

- The CANDU reactor is conceptually similar to most light water reactors
- Fission reactions in the nuclear reactor core occur by heating a fluid,
- In CANDU type heavy water is heated.
- The coolant is kept under high pressure to raise its boiling point and avoids significant steam formation in the core.
- The hot heavy water generated in this primary cooling loop is passed into a heat exchanger heating light water in the less-pressurized secondary cooling loop.
- This water turns to steam and powers a conventional turbine



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Advantages

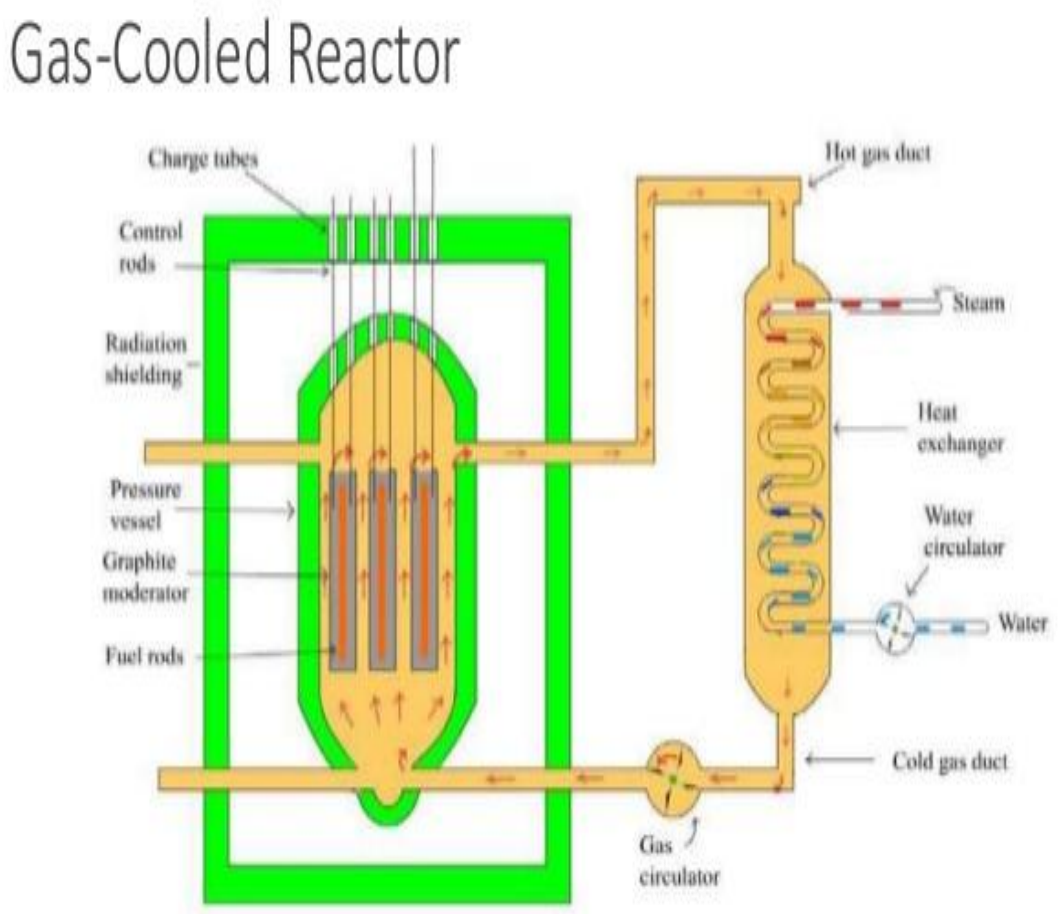
- Works at low pressure
- Moderators are more effective in slowing down the neutrons
- Simple construction

Disadvantages

- High Cost (Cost of Heavy Water is very High)
- Problem of leakage
- Proper safety design is required

Power reactors –Gas Cooled Reactor

- Helium (He) or Carbon dioxide is used as a Coolant
- Graphite is used as a moderator
- Natural uranium is used as a fuel



- Advantages

1. Safer than water cooled reactors
2. No corrosion
3. Graphite – stable at high temperature
4. CO_2 eliminates the possibilities of explosion

- Disadvantages

1. Fuel : More Quantity and costly
2. Power density : very low
3. More power usage for coolant circulation

Fissile and Fertile material

Fissile material, also called **Fissionable Material**, in nuclear physics, any species of atomic nucleus that can undergo the fission reaction.

Eg: uranium-235 (0.7 percent of naturally occurring uranium), plutonium-239, and uranium-233

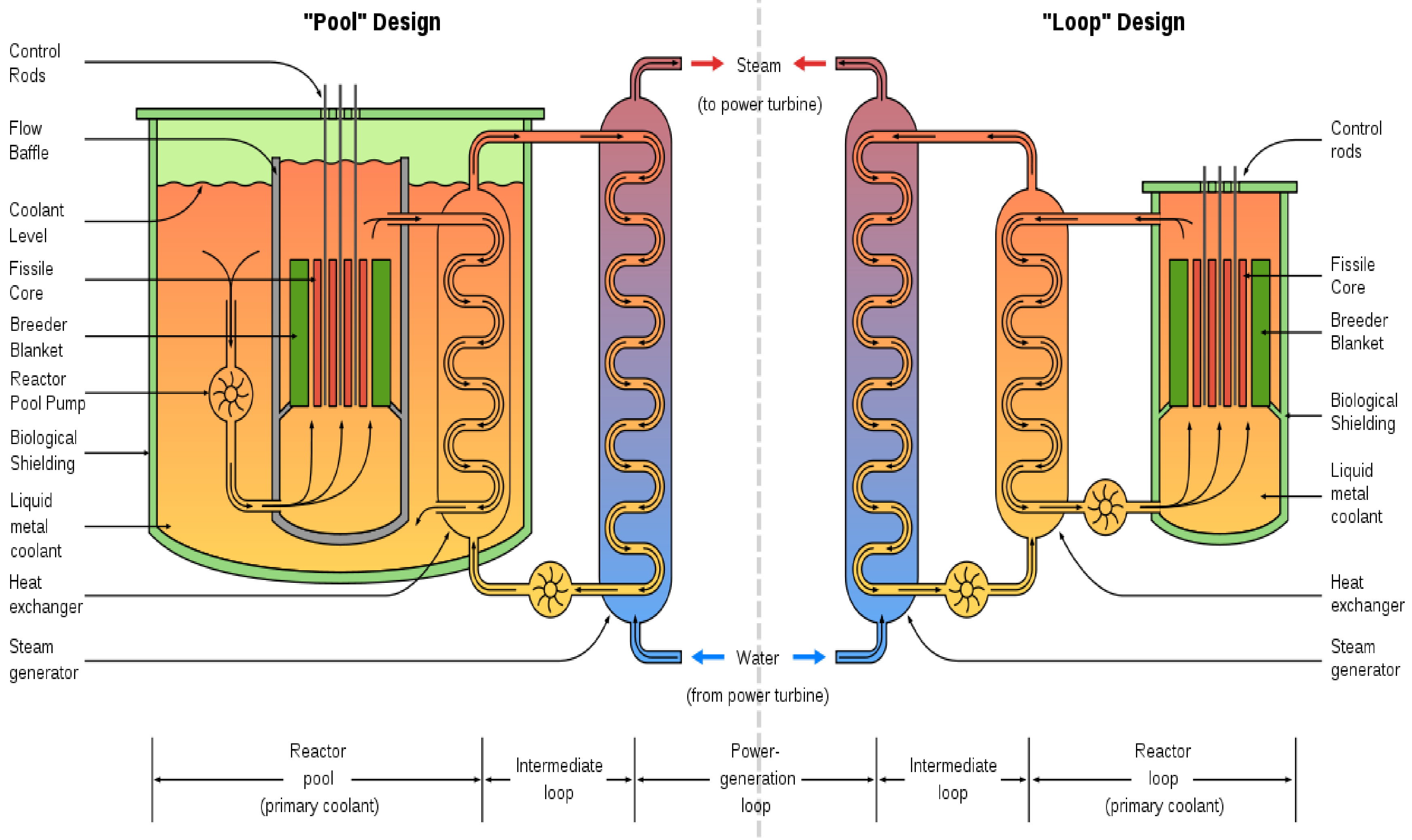
A **fertile material** is one that decays into fissile material after neutron absorption within a reactor.

eg: Uranium-238 and Thorium-232

Fast Breeder Reactor (Liquid Metal Cooled Reactor)

- The core consists of two parts.
- mixture of uranium dioxide and plutonium dioxide in the inner part, which leads to fission process
- outer part : predominant process is conversion of U-238 to Pu-239.
- In such a reactor, can able to achieve more fissile plutonium nuclei are produced in a unit time than the number of fissile nuclei which undergo fission (hence the name "breeder").
- neutrons are not thermalized, since fast neutrons are needed for the process ,Hence No moderators are used

Liquid Metal cooled Fast Breeder Reactors (LMFBR)



- **Liquid metal Sodium** (Na) is used as an excellent coolant
- Two Heat exchangers are used
- The primary loop design can be either pool type or loop type.
- In **pool type system** – reactor core, primary pumps and intermediate heat exchangers are placed in a pool
- In **loop type system** – placed outside the reactor vessel.

Effects of Nuclear Power plant

- Isotopes formed in nuclear power reactors have high toxicity
- Disposal, Transport and storage of liquid radioactive wastes are extremely significant
- Nuclear reactor produces α- rays, beta-rays and gamma-rays
- α- rays can cause internal hazard
- beta-rays have high penetrating power over exposure leads to skin burns and may result in malignant growth
- Gamma rays –are electromagnetic radiations have high energy, over exposure leads to blood disease, undesirable genetic effects, anemia etc.
- No practical harmful effect on the biosphere if the problem of radioactive waste storage is safely solved.

Disposal of nuclear waste

- Disposal of nuclear waste requires special attention
- Gas effluents are filtered and discharged at high levels
- Monitoring the loss of CO_2 is essential in the nuclear reactor, It should not exceed 1 ton per day.
- Liquid effluents are discharged after filtration, pH adjustment and dilution and also radioactivity is removed by ion-exchange process
- To avoid the leakage of the liquid effluents, special precautions are taken which include double containment of drains and design of concrete storage tanks

Contd..

- Solid waste such as pieces of fuel cans, control rods etc will be stored in shielded concrete vault.
- Waste elements are stored under water or air cooled shielded area for about 100 days
- After decay of the radioactive element, large storage chambers are used to shield and store for many years.

Shielding

- Shielding is provided to guard the delicate instruments from radioactivity
- Various materials used for shielding such as
  - Lead – Density 11.3gm/cubic cm
  - Concrete – 2.4 gm/cubic cm
  - Steel – 7.8 gm/cubic cm
  - Cadmium – 8.95 gm/cubic cm
- Effectiveness of the shielding materials depends upon the density of the material
- No single element is effective in shielding against all types of radioactive radiations

Thank You