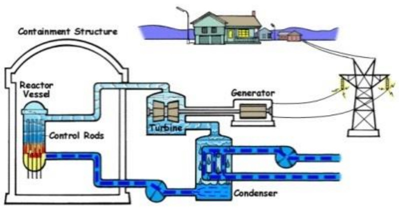
Thermal Power Stations II



Lecture (3) on

Nuclear Reactors

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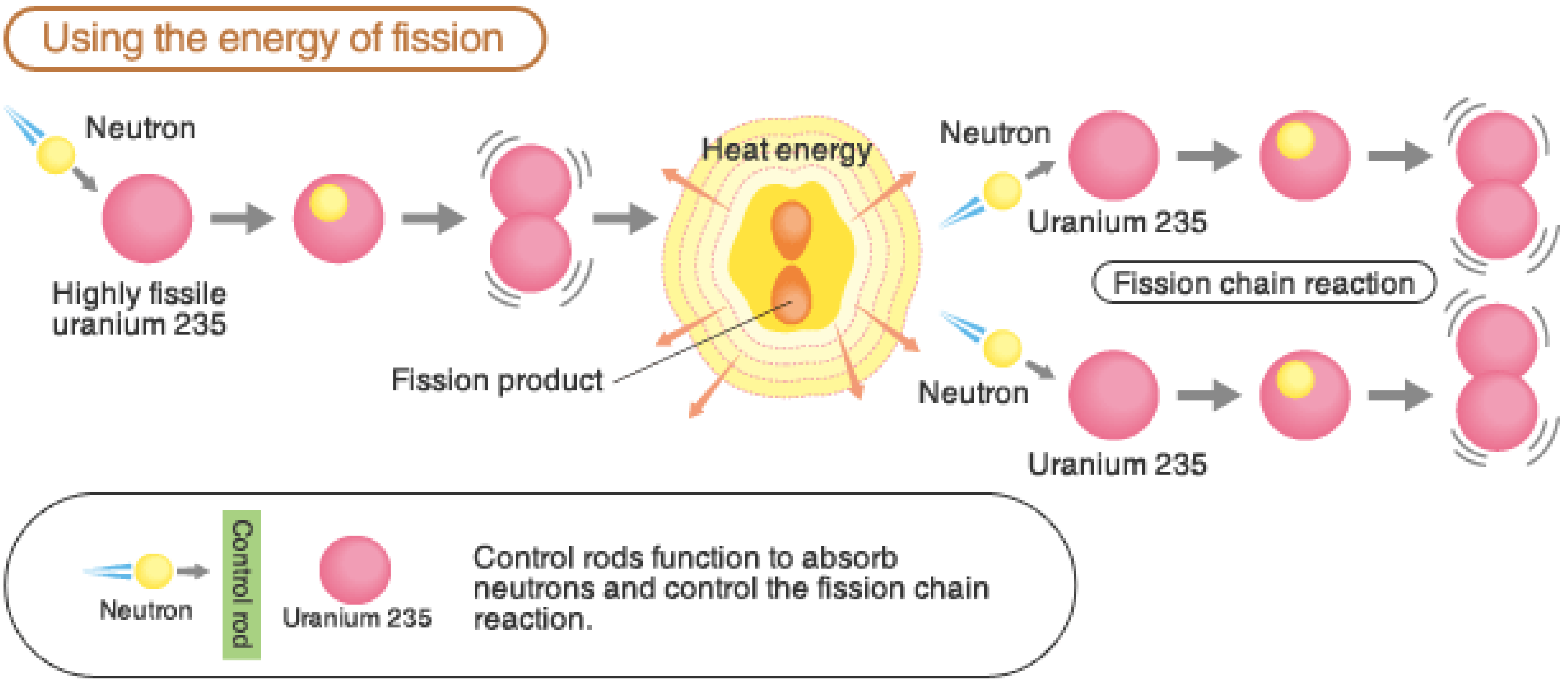
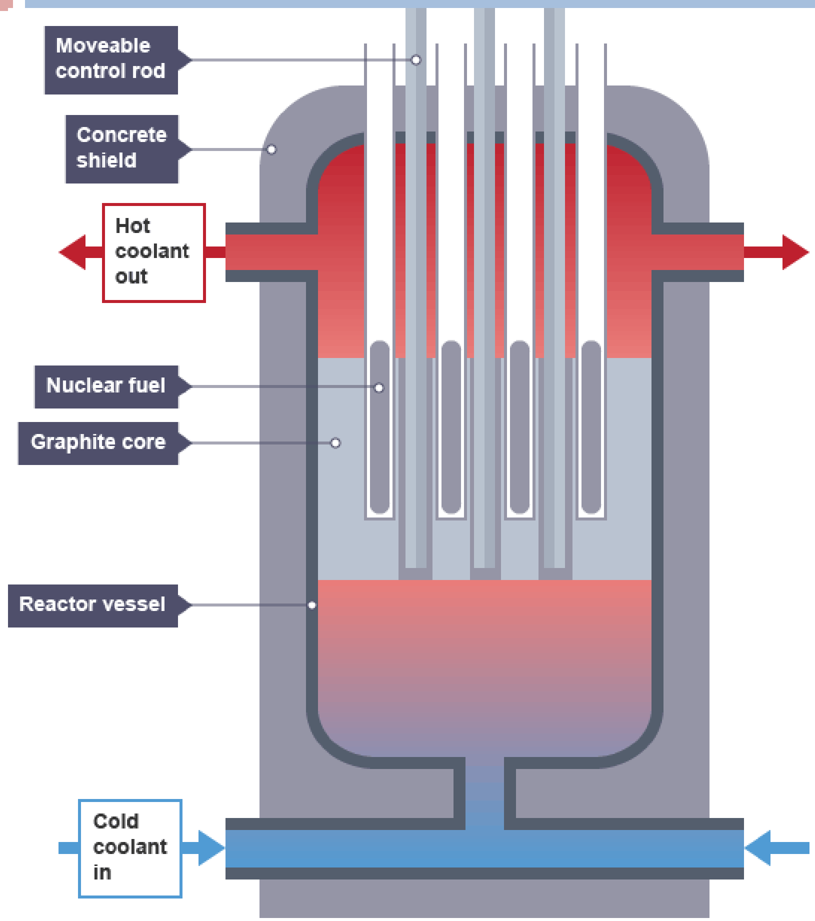
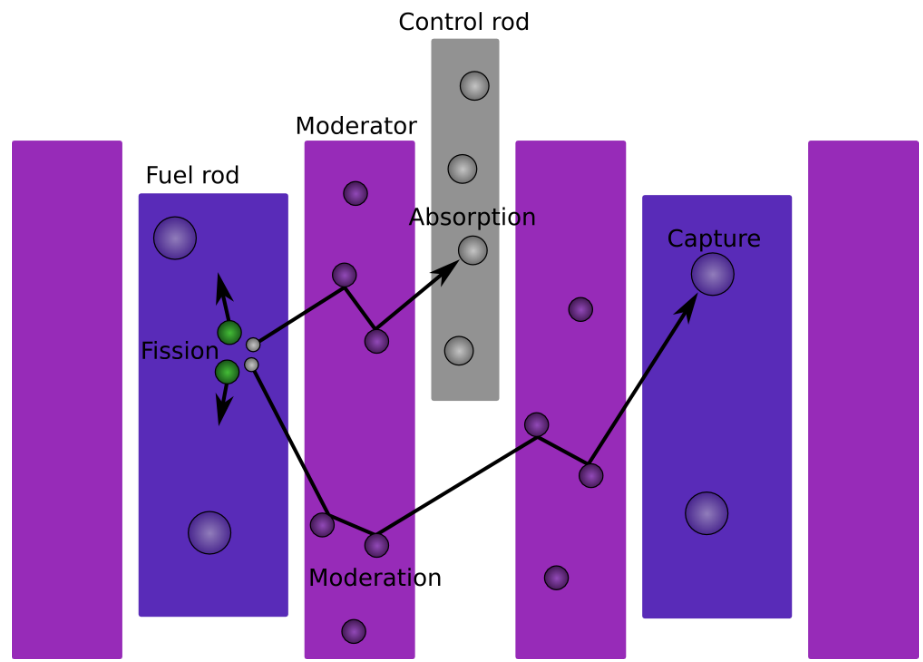
Nuclear Fission Mechanism



Nuclear Fission Mechanism



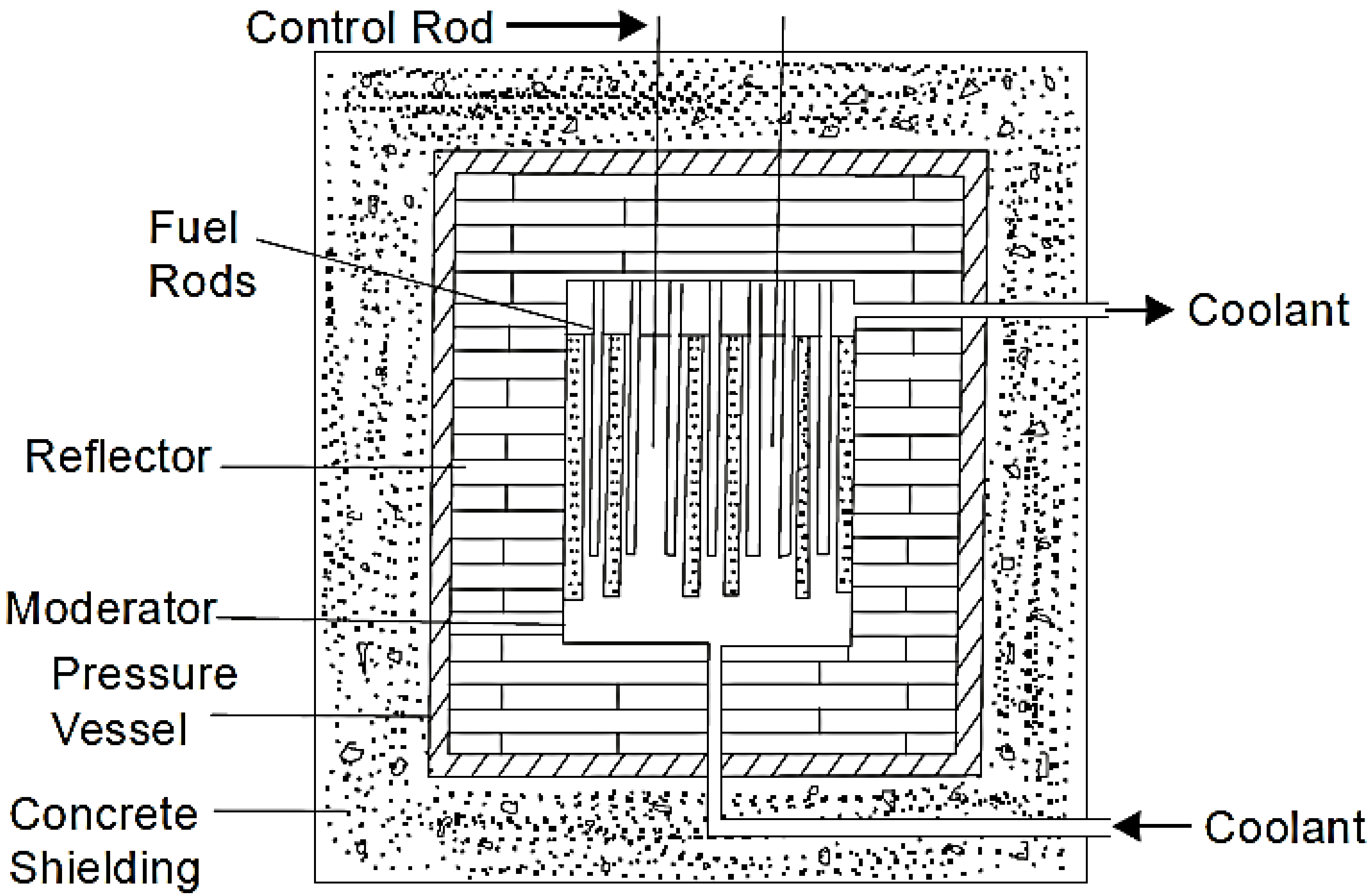


Parts of A Nuclear Reactor

A nuclear reactor is an apparatus in which heat is produced due to nuclear fission chain reaction. The following figure shows the various parts of reactor, which are as follows :

1. Nuclear Fuel
2. Moderator
3. Control Rods
4. Reflector
5. Reactors Vessel
6. Biological Shielding
7. Coolant.

Parts of A Nuclear Reactor



Parts of A Nuclear Reactor

Nuclear Fuel

- Fuel of a nuclear reactor should be fissionable material which can be defined as an element or isotope whose nuclei can be caused to undergo nuclear fission by nuclear bombardment and to produce a fission chain reaction. It can be one or all of the following

U_{233}, U_{235} and Pu_{239}

- The fuel should be protected from corrosion and erosion of the coolant and for this it is encased in metal cladding generally stainless steel or aluminum. Adequate arrangements should be made for fuel supply, charging or discharging and storing of the fuel.

Parts of A Nuclear Reactor

Nuclear Fuel

- In order to prevent the contamination of the coolant by fission products, a protective coating or cladding must separate the fuel from the coolant stream. Fuel element cladding should possess the following properties :

1. It should be able to withstand high temperature within the reactor.
2. It should have high corrosion resistance.
3. It should have high thermal conductivity.
4. It should not have a tendency to absorb neutrons.
5. It should have sufficient strength to withstand the effect of radiations to which it is subjected.

Parts of A Nuclear Reactor

Nuclear Fuel

- Uranium oxide (UO_2) is another important fuel element. Uranium oxide has the following advantages over natural uranium:

1. It is more stable than natural uranium.
2. There is no problem or phase change in case of uranium oxide and therefore it can be used for higher temperatures.
3. It does not corrode as easily as natural uranium.
4. It is more compatible with most of the coolants and is not attacked by H_2, N_z.
5. There is greater dimensional stability during use.

Parts of A Nuclear Reactor

Nuclear Fuel

- Uranium oxide possesses following disadvantages :
  1. It has low thermal conductivity.
  2. It is more brittle than natural uranium and therefore it can break due to thermal stresses.
  3. Its enrichment is essential.

- Table indicates some of the physical properties of nuclear fuels.0

Fuel	Thermal con-ductivity K-cal/m. hr°C	Specific heat kcal/kg °C	Density kg/m^3	Melting point (°C)
Natural uranium	26.3	0.037	19000	1130
Uranium oxide	1.8	0.078	11000	2750
Uranium carbide	20.6	—	13600	2350

Parts of A Nuclear Reactor

Moderator

- In the chain reaction the neutrons produced are fast moving neutrons. These fast moving neutrons are far less effective in causing the fission of U_{235} and try to escape from the reactor.
- To improve the utilization of these neutrons their speed is reduced. It is done by colliding them with the nuclei of other material which is lighter, does not capture the neutrons but scatters them.
- Each such collision causes loss of energy, and the speed of the fast moving neutrons is reduced. Such material is called Moderator.

Parts of A Nuclear Reactor

Moderator

- The slow neutrons (Thermal Neutrons) so produced are easily captured by the nuclear fuel and the chain reaction proceeds smoothly.
- Graphite, heavy water and beryllium are generally used as moderator.
- Reactors using enriched uranium do not require moderator. But enriched uranium is costly due to processing needed.

Parts of A Nuclear Reactor

Moderator

A moderator should process the following properties :

1. It should have high thermal conductivity.
2. It should be available in large quantities in pure form.
3. It should have high melting point in case of solid moderators and low melting point in case of liquid moderators.
4. It should provide good resistance to corrosion.
5. It should be stable under heat and radiation.
6. It should be able to slow down neutrons.

Parts of A Nuclear Reactor

Control Rods

The Control and operation of a nuclear reactor is quite different form a fossil and fuelled (coal or oil fired) furnace. The furnace is fed continuously and the heat energy in the furnace is controlled by regulating the fuel feed, and the combustion air whereas a nuclear reactor contains as much fuel as is sufficient to operate a large power plant for some months. The consumption of this fuel and the power level of the reactor depends upon its neutron flux in the reactor core. The energy produced in the reactor due to fission of nuclear fuel during chain reaction is so much that if it is not controlled properly the entire core and surrounding structure may melt and radioactive fission products may come out of the reactor thus making it uninhabitable. This implies that we should have some means to control the power of reactor. This is done by means of control rods.

Parts of A Nuclear Reactor

Control Rods

- Control rods in the cylindrical or sheet form are made of boron or cadmium.
- These rods can be moved in and out of the holes in the reactor core assembly. Their insertion absorbs more neutrons and damps down the reaction and their withdrawal absorbs less neutrons.
- Thus power of reaction is controlled by shifting control rods which may be done manually or automatically.

Parts of A Nuclear Reactor

Control Rods

Control rods should possess the following properties :

1. They should have adequate heat transfer properties.
2. They should be stable under heat and radiation.
3. They should be corrosion resistant.
4. They should be sufficient strong and should be able to shut down the reactor almost instantly under all conditions.
5. They should have sufficient cross-sectional area for the absorption.

Parts of A Nuclear Reactor

Reflector

- The neutrons produced during the fission process will be partly absorbed by the fuel rods, moderator, coolant or structural material etc.
- Neutrons left unabsorbed will try to leave the reactor core never to return to it and will be lost.
- Such losses should be minimized. It is done by surrounding the reactor core by a material called reflector which will send the neutrons back into the core. The returned neutrons can then cause more fission and improve the neutrons economy of' the reactor. Generally the reflector is made up of graphite and beryllium.

Parts of A Nuclear Reactor

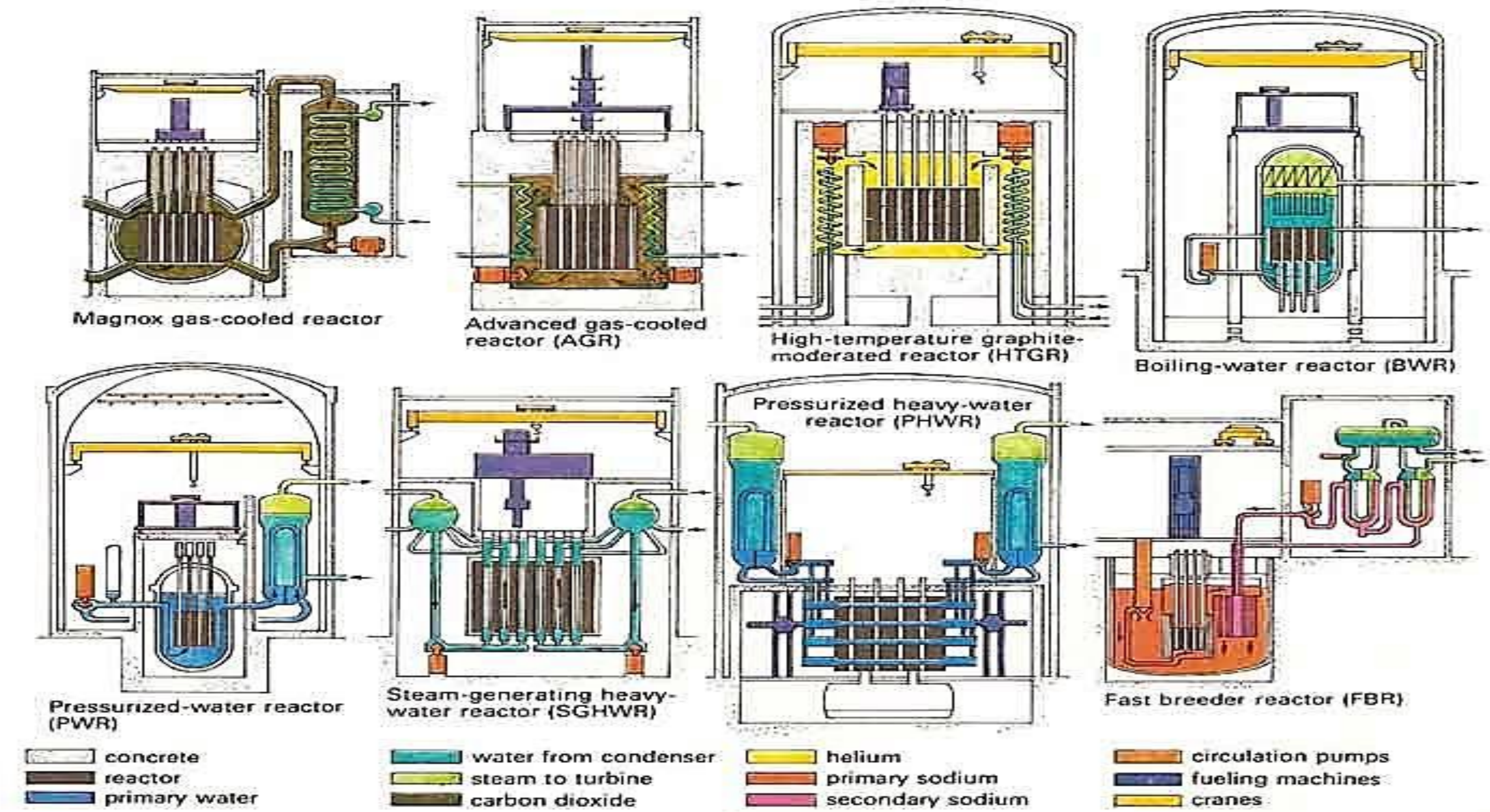
Reactor Vessel

It is a. strong walled container housing the cure of the power reactor. It contains moderator, reflector, thermal shielding and control rods.

Biological Shielding

- Shielding the radioactive zones in the reactor roan possible radiation hazard is essential to protect, the operating men from the harmful effects. During fission of nuclear fuel, alpha particles, beta particles, deadly gamma rays and neutrons are produced. A protection must be provided against them. Thick layers of lead or concrete are provided round the reactor for stopping the gamma rays.
- Thick layers of metals or plastics are sufficient to stop the alpha and beta particles.

Reactor Classification



Reactor Classification

Reactors can be classified in many ways-type of fission, fuel used, moderator material, distribution of fuel and moderator, purpose for which it is being used etc. Some of the possible ways in which classifications can be done are listed in the following slides. The number of the possible combinations can be very large. However, only a few of the possible combinations are appropriate and practicable.

Reactor Classification

Purpose

- **Research and development reactors:** For testing new reactor designs and research.
- **Production:** For converting fertile materials into fissile materials.
- **Power:** For electric energy generation.

Type of fission

- **Slow:** Neutron kinetic energy less than 0.1 eV.
- **Intermediate:** Neutron kinetic energy between 0.1 eV and 0.1 MeV.
- **Fast:** Neutron kinetic energy 1 MeV or so

Fuel used

- Natural uranium
- Enriched uranium
- Plutonium

Reactor Classification

State of fuel

- Solid
- Liquid

Fuel cycle

- **Burner (Thermal):** Designed for producing heat only without any recovery of converted fertile material.
- **Converter:** Converts fertile material into' a fissile material different from the one initially fed into the reactor is less than 1.
- **Breeder:** Converts fertile material into fissile material, which is the same as that initially fed into the reactor is more than 1.

Arrangement of fissile and fertile material

- **One region:** Fissile and fertile material mixed.
- **Two region:** Fissile and fertile material separate.

Reactor Classification

Arrangement of fuel and moderator

- **Homogeneous:** Fuel and moderator mixed.
- **Heterogeneous:** Fuel in discrete lumps in moderator.

Moderator material

- Heavy water
- Graphite
- Ordinary water
- Beryllium
- Organic

Heavy water (deuterium oxide (^2H_2O)) is a form of water that contains a larger than normal amount of the hydrogen isotope deuterium (^2H or D, also known as *heavy hydrogen*), rather than the common hydrogen-1 isotope (^1H or H, also called protium) that makes up most of the hydrogen in normal water.

Reactor Classification

Cooling System

- **Direct:** The liquid fuel circulated from the reactor to heat exchanger where steam is generated.
- **Indirect:** Coolant passed through the reactor and then through the heat exchanger for steam generation.

Coolant Used

- Gas,
- Water,
- Heavy water,
- Liquid metal

Advanced Gas Cooled Reactor (AGR)

- This reactor uses uranium dioxide as fuel.
- To eliminate radiation hazards the fuel element must be canned so that it does not contaminate the coolant. In AGR the fuel elements are canned in stainless steel.
- The pressure vessel is made of prestressed concrete and it contains both the reactor core and heat exchanger.
- The reactor can be refueiled on load and this is an operational advantage.
- The coolant is CO_2 which passes through heat exchanger and raises steam. Graphite is used as moderator.

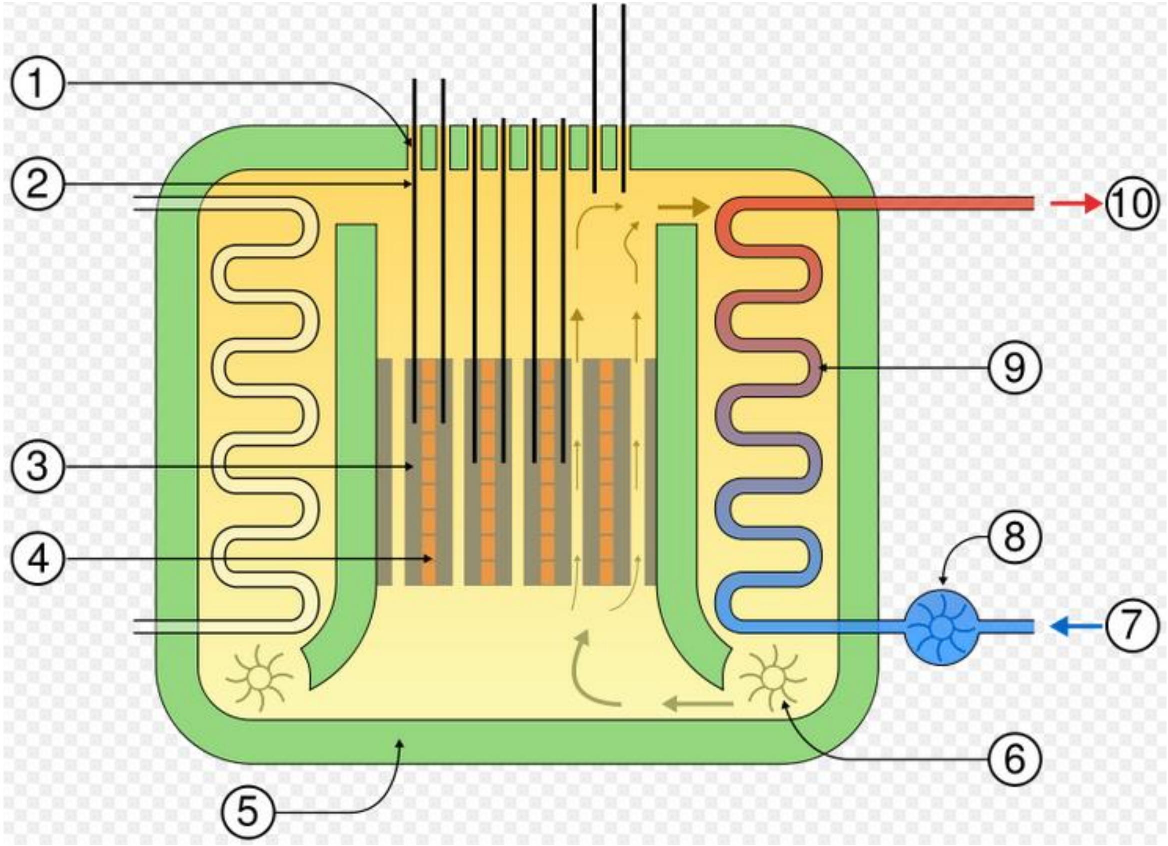
Advanced Gas Cooled Reactor (AGR)

- The steam pressure is around 150 atmospheres and temperature around 550°C.
- The rate of flow of CO_2 gas can be controlled to maintain the gas, fuel elements and core temperature constant as load varies.
- The control rods are distributed in a symmetrical manner.
- A gas cooled reactor is economical when load factor is more than 75%.
- Its overall efficiency is about 40%.

The reactors installed at Calder Hall and Berkely in U.K. in 1957 are gas cooled reactors. The advanced gas cooled reactors include those at Oak Bridge USA and Dungeness B in U.K. The advanced gas cooled reactor differs from the gas cooled reactor in the facts that in advanced gas cooled reactor, the coolant and core temperatures are higher and special measures are necessary to cool the graphite moderator.

Advanced Gas Cooled Reactor (AGR)

1. Charge tubes.
2. Control rods.
3. Graphite moderator.
4. Fuel assemblies.
5. Concrete pressure. vessel and radiation shielding.
6. Gas circulator.
7. Water.
8. Water circulator.
9. Heat exchanger.
10. Steam.

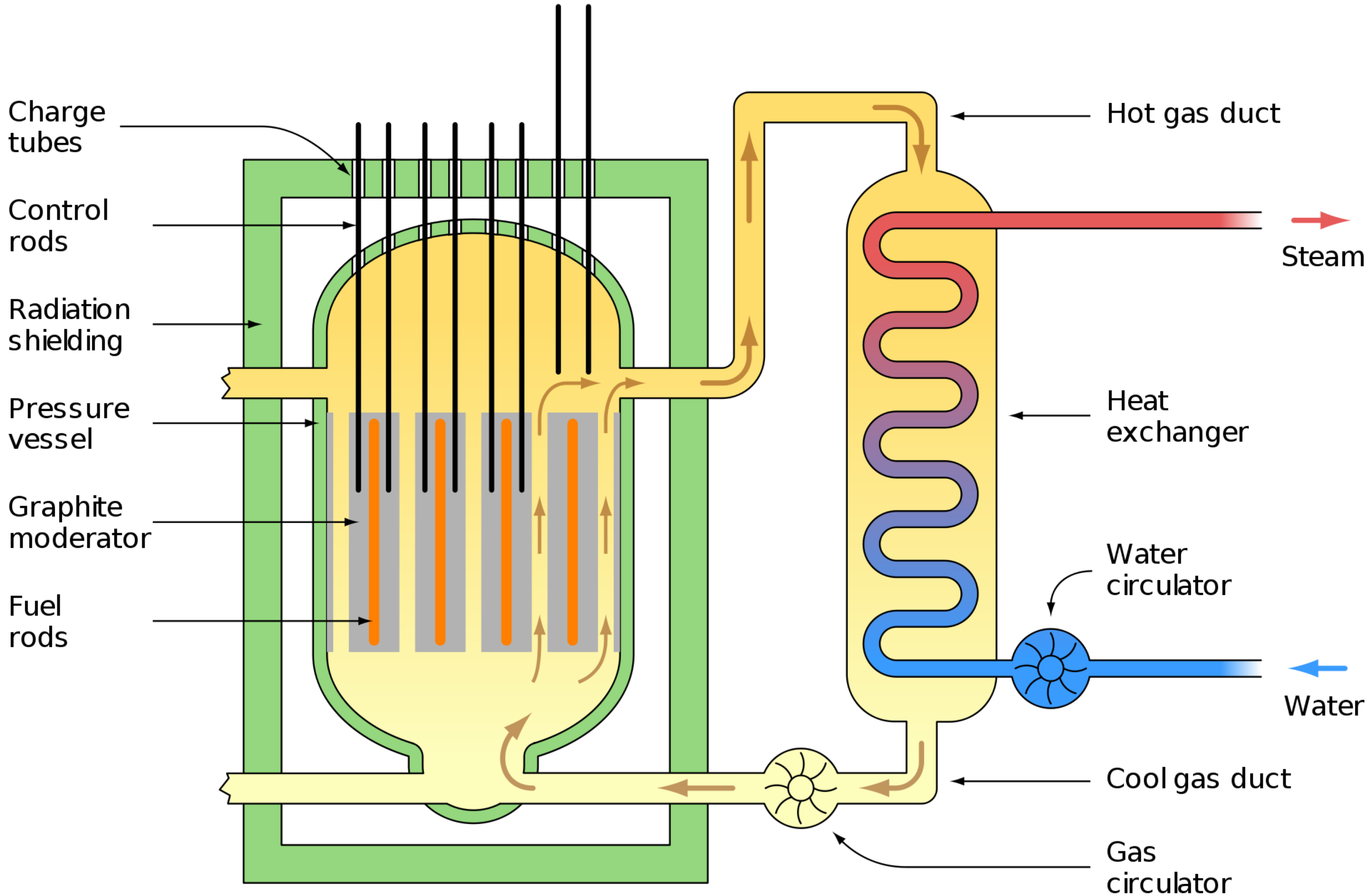


Advanced Gas Cooled Reactor (AGR)

Current AGR Reactors

AGR Power Station	Net MWe	Construction started	Connected to grid	Commercial operation	Accounting closure date
Hinkley Point B	1220	1967	1976	1976	2023
Hunterston B	1190	1967	1976	1976	2023
Hartlepool	1210	1968	1983	1989	2024
Heysham 1	1150	1970	1983	1989	2019
Dungeness B	1110	1965	1983	1985	2028
Heysham 2	1250	1980	1988	1989	2023
Torness	1250	1980	1988	1988	2023

Magnox Reactor



Magnox Reactor

- This is also a gas cooled reactor and similar to AGR.
- However, it uses natural uranium as fuel.
- The fuel elements are canned in a special magnesium alloy called magnox. The steam temperature and pressure are around 400 C and 40 atmospheres respectively.
- The overall efficiency is about 30%.

Thank you