A 300 Level Course: POST-SIWES SEMESTER

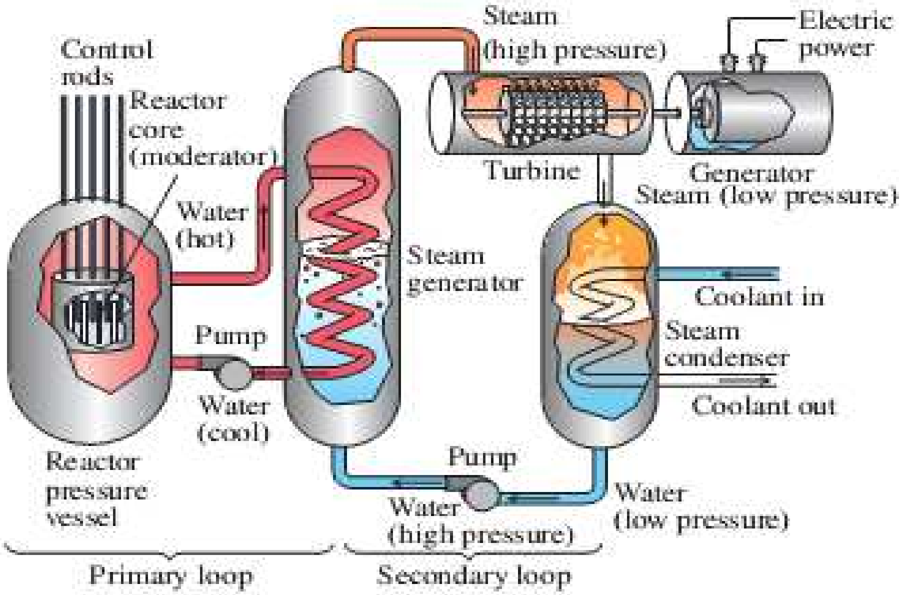
PHYS 350: MEDICAL REACTOR PHYSICS I

Credit: 2 units. Duration of Course: 8 weeks of didactic lectures

Lecturer: Opadele A.E Contact: opadelea@babcock.edu.ng

TOPIC

NUCLEAR REACTORS AND GENERAL OPERATIONS



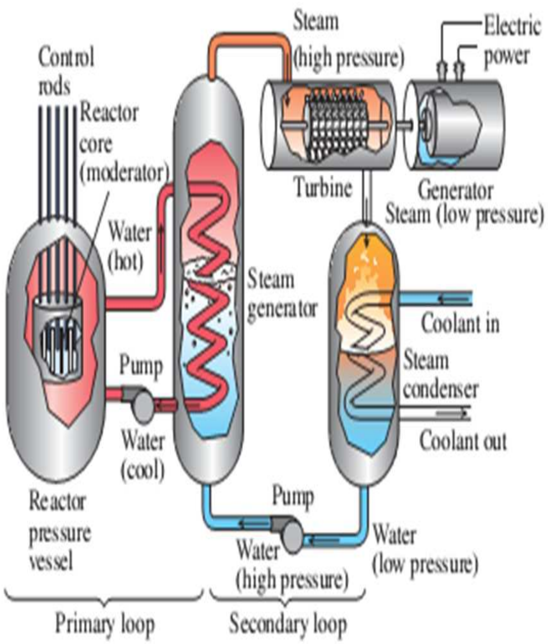
OVERVIEW OF NUCLEAR REACTOR

A nuclear reactor is a system in which a controlled nuclear chain reaction is used liberate energy.

The first reactor was built by E. Fermi & Co's and this aroused the worldwide interest in construction of reactors.

Nuclear reactor is like a furnace where fuel (Uranium or Plutonium) burns giving neutrons, radio-isotopes and enormous energy in the form of heat to produce electricity.

The installation of a nuclear reactor is quite complex and the physics of a reactor system is weighty.



GENERAL FEATURES OF A NUCLEAR REACTOR

All reactors consists of the following major components *but not restricted to*:

1) Fuel

2) Moderator

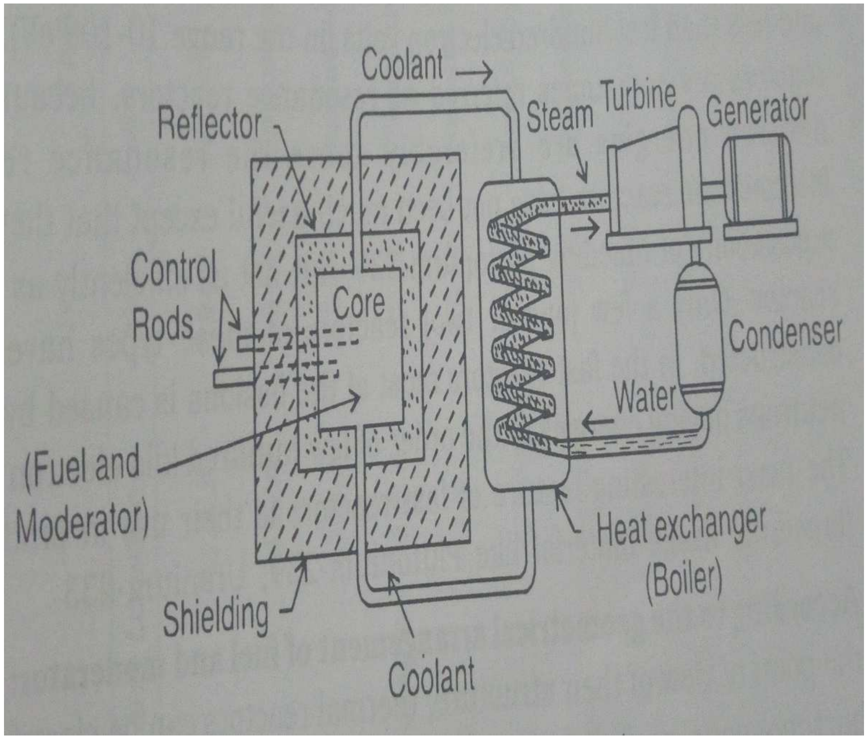
3) Control Materials or Control Rods

4) Coolants

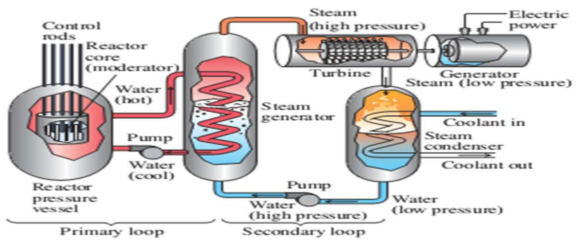
5) Reactor Shield

6) Reflector

{FMCcRr}



GENERAL FEATURES OF A NUCLEAR REACTOR



1) FUEL

The fissile material used in a reactor is called the reactor fuel.

The commonly used fuels are Uranium isotopes $({}^{233}_{92}U, {}^{235}_{92}U, {}^{238}_{92}U)$, Thorium isotope $({}^{232}_{92}Th)$ and Plutonium $({}^{239}_{94}Pu)$.

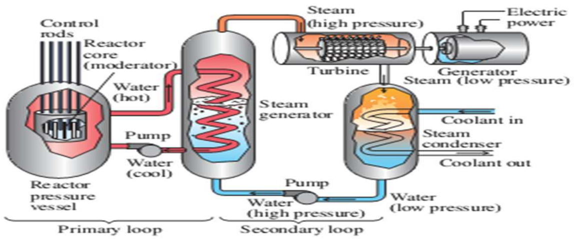
Plutonium is a much better fuel in comparison to Uranium and Thorium, because fission chain reaction can be produced in Plutonium both by fast and slow neutrons.

Plutonium can be obtained from Uranium-238 through the absorption of neutrons according to the decay scheme.

$$ {}^{238}_{92}U + {}^{1}_{0}n \rightarrow {}^{239}_{92}U^{*} \rightarrow {}^{239}_{93}Np \rightarrow {}^{239}_{94}Pu $$

The central region of the nuclear reactor where the fission reaction takes place is known as **reactor core**.

GENERAL FEATURES OF A NUCLEAR REACTOR



2) Moderator

The fast neutrons produced in fission are slowed down to thermal energies by the use of materials called moderators.

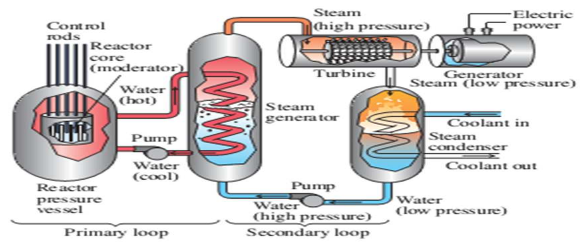
The moderators are particularly used for thermal reactors.

The material of a moderator is of low mass number so that neutron may loose significant amount of energy on colliding with the moderator nuclei till they come to thermal equilibrium with the material.

The moderators have small neutron absorption cross-section and large scattering cross-section.

Most commonly used moderators are graphite, heavy water (D_2O), light water (H_2O), beryllium oxide, Zirconium hydride (ZrH_2) and some organic liquids like polyphenyls.

GENERAL FEATURES OF A NUCLEAR REACTOR



3) Control Materials or Control Rods

They are used for controlling the chain reactions and to maintain the multiplication factor to ensure the safe operation.

They are usually made of materials such as: Cadmium, Boron, Hafnium and Gadolinium e.t.c

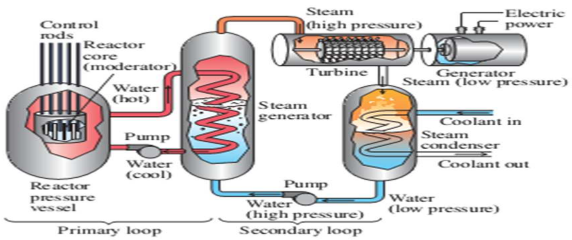
These materials have a large neutron absorption cross-section.

The shape of the control rods varies from reactor to reactor.

The control rods are moved in or out of the reactor to control the growth of neutron population (neutron flux).

For example: in a boiling water thermal reactor, Boron is used as a control rod.

GENERAL FEATURES OF A NUCLEAR REACTOR



4) COOLANTS

Materials that are used to remove the heat generated due to fission in the core or other parts of the reactor are referred to as: **coolants**.

They can be either liquids or gas.

A reactor coolant should have low neutron absorption cross-section, high thermal capacity, radiation stability and not react chemically with other materials within the reactor.

In thermal reactors, water, steam, heavy water, carbon-dioxide, dry-air, nitrogen and helium are often used as coolants.

In fast reactors, liquid sodium or liquid helium can be deployed as coolants.

GENERAL FEATURES OF A NUCLEAR REACTOR

5) REACTOR SHIELD

Most of the nuclear reactors are sources of neutrons and gamma-rays.

The shield is used to protect personnel and scientists working around the reactor from hazardous radiation.

The reactor vessel is surrounded by radiation shield.

It is generally a thick concrete wall about (2m thick) capable of absorbing both neutron and gamma radiations.

Also, alternate layers of heavy and light elements are used.

Such an arrangement is known as biological shield or radiation shield.

GENERAL FEATURES OF A NUCLEAR REACTOR

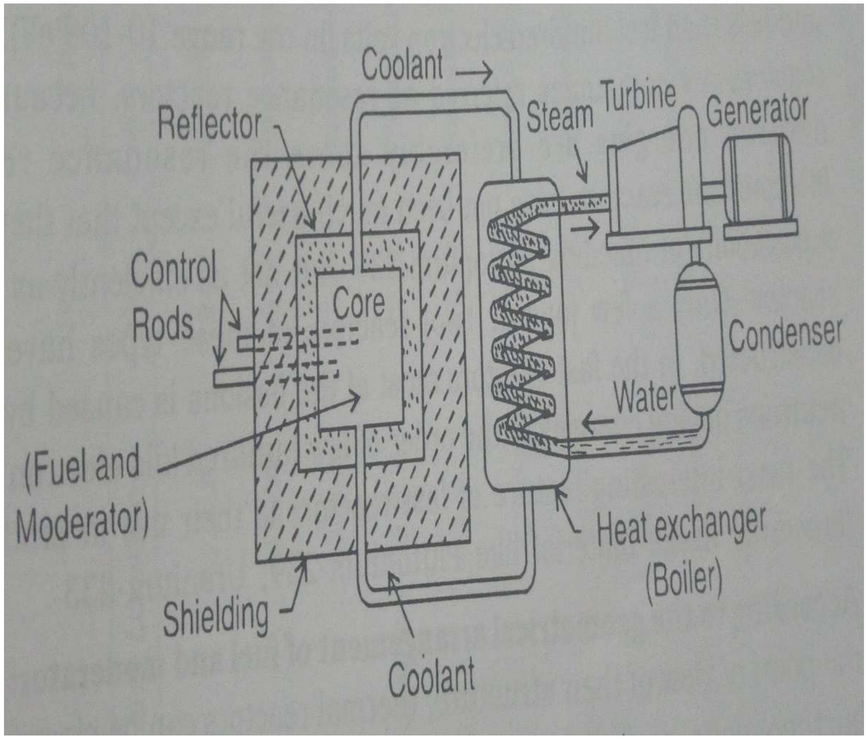
6) REFLECTOR

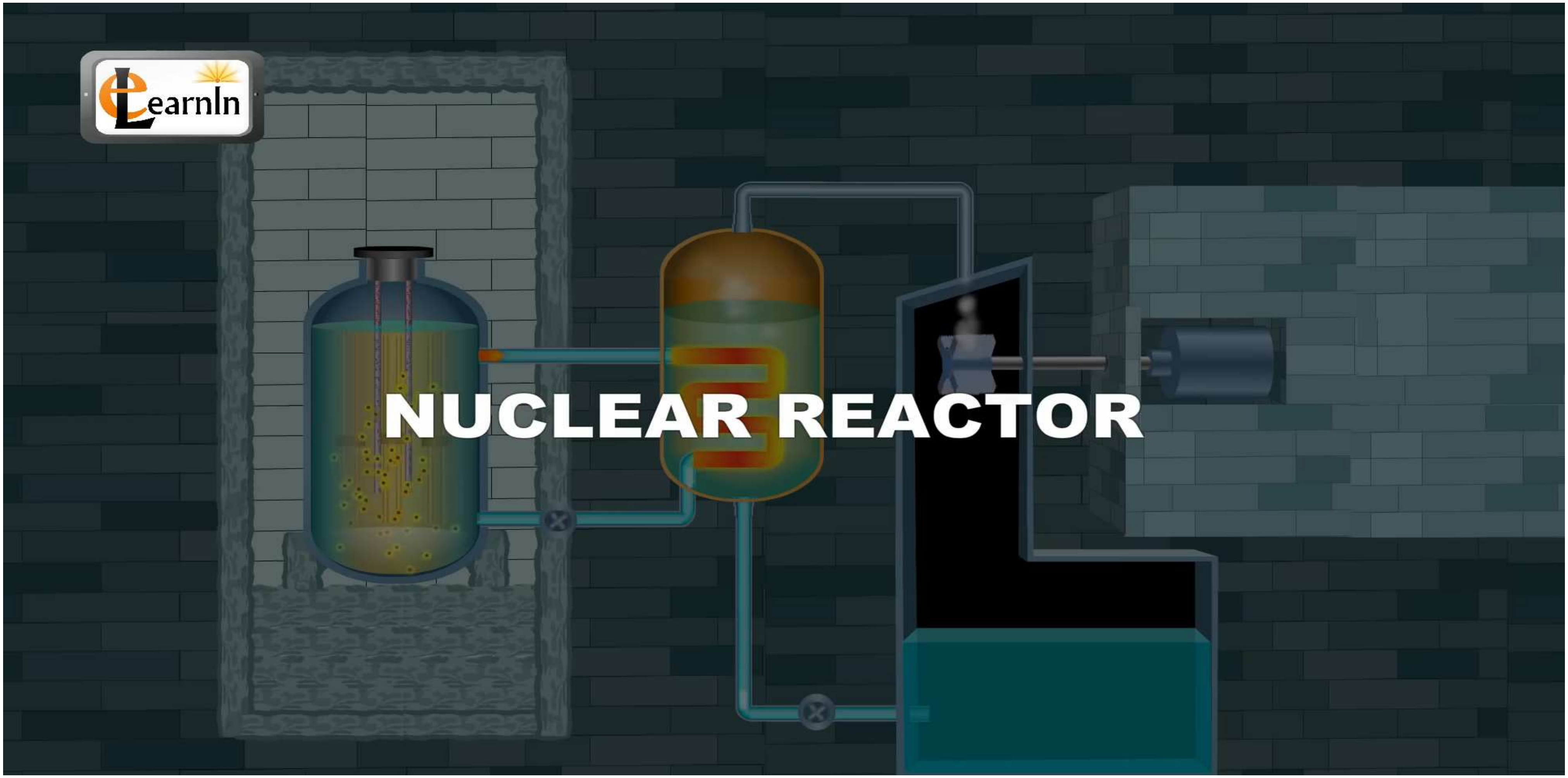
In order to check the escape of neutrons from the core, a region of non-fissionable material is put next to the core.

Such materials are known as reflectors.

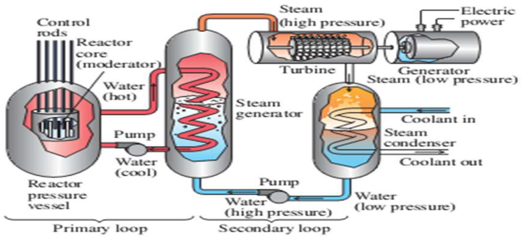
In thermal reactors, a moderator material is mostly used as a reflector.

In fast reactors, Nickel and Copper are used as reflectors.




eLearnIn
NUCLEAR REACTOR

CLASSIFICATIONS OF NUCLEAR REACTORS



Nuclear reactors are generally classified into the following:

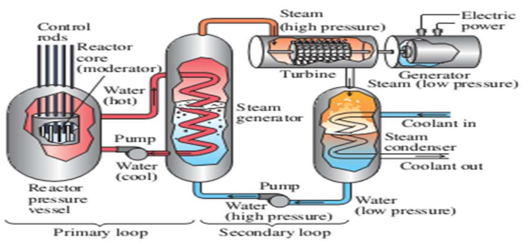
1) According to the materials used for fuel, moderator coolant and their physical state.

2) According to the average energy of neutrons which can cause fission.

3) According to the geometrical arrangement of fuel and moderator.

4) According to the main purpose of the reactor.

CLASSIFICATIONS OF NUCLEAR REACTORS



1) According to the materials used for fuel, moderator coolant and their physical state.

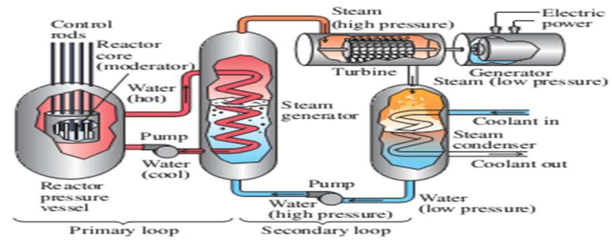
The reactors using different combination of fuel, moderator, coolant are being referred accordingly.

a) Graphite moderated gas cooled natural uranium fueled reactor: a thermal reactor which uses natural uranium as fuel, graphite as moderator and carbon-di-oxide gas as coolant.

b) Light water moderated and cooled enriched uranium reactors: a reactor where light water is used both as moderator and coolant with enriched uranium.

c) Gas cooled heavy water moderated reactors, Liquid metal cooled fast reactors and Gas cooled fast reactors e.t.c

CLASSIFICATIONS OF NUCLEAR REACTORS



2) According to the average energy of neutrons which can cause fission.

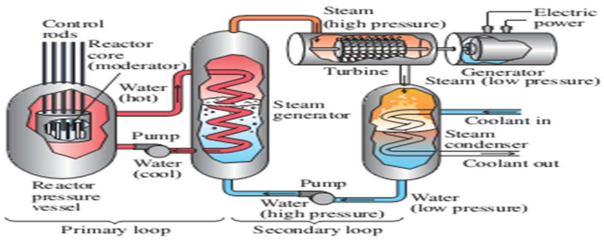
The majority of nuclear reactors are classified as thermal, intermediate and fast according to the neutron energy with which fission occur.

In thermal reactors, fission is induced by neutrons having energy around 0.025eV or thermal neutrons. They are used for research or production of electricity.

In medium or intermediate reactors, the average energy of the neutrons is more than thermal reactors (10 - 100eV).

In fast reactors, most of the fission is caused by fast neutrons having energies of the order of few hundred kilo electron volts. They are specifically used for breeding fissile materials like Plutonium-239 and Uranium-233.

CLASSIFICATIONS OF NUCLEAR REACTORS



3) According to the geometrical arrangement of fuel and moderator.

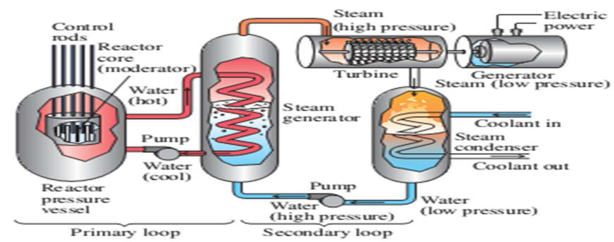
Thermal reactors can be classified as either homogenous or heterogeneous nuclear reactors due to their structure.

In homogenous reactors, the fuel and the moderator are in the same phase (same physical state) both in solid or both in liquid phase. The two are mixed.

In heterogeneous reactors, the fuel and the moderator are in different phases, meaning they are geometrically separated. The fuel can be in form of rod or plates which are uniformly dispersed in the moderator which may be liquid or otherwise.

Note: heterogeneous nuclear reactors are common nowadays!

CLASSIFICATIONS OF NUCLEAR REACTORS



4) According to the main purpose of the reactor.

a) Basic research: These reactors provide facilities for research in various branches of sciences, for testing new reactor designs and for producing radio-isotopes.

b) Breeder reactors: Reactors designed to convert a fertile isotope of Thorium-232 or Uranium- 238 into fission Uranium-233 or Plutonium-239 are called converters.

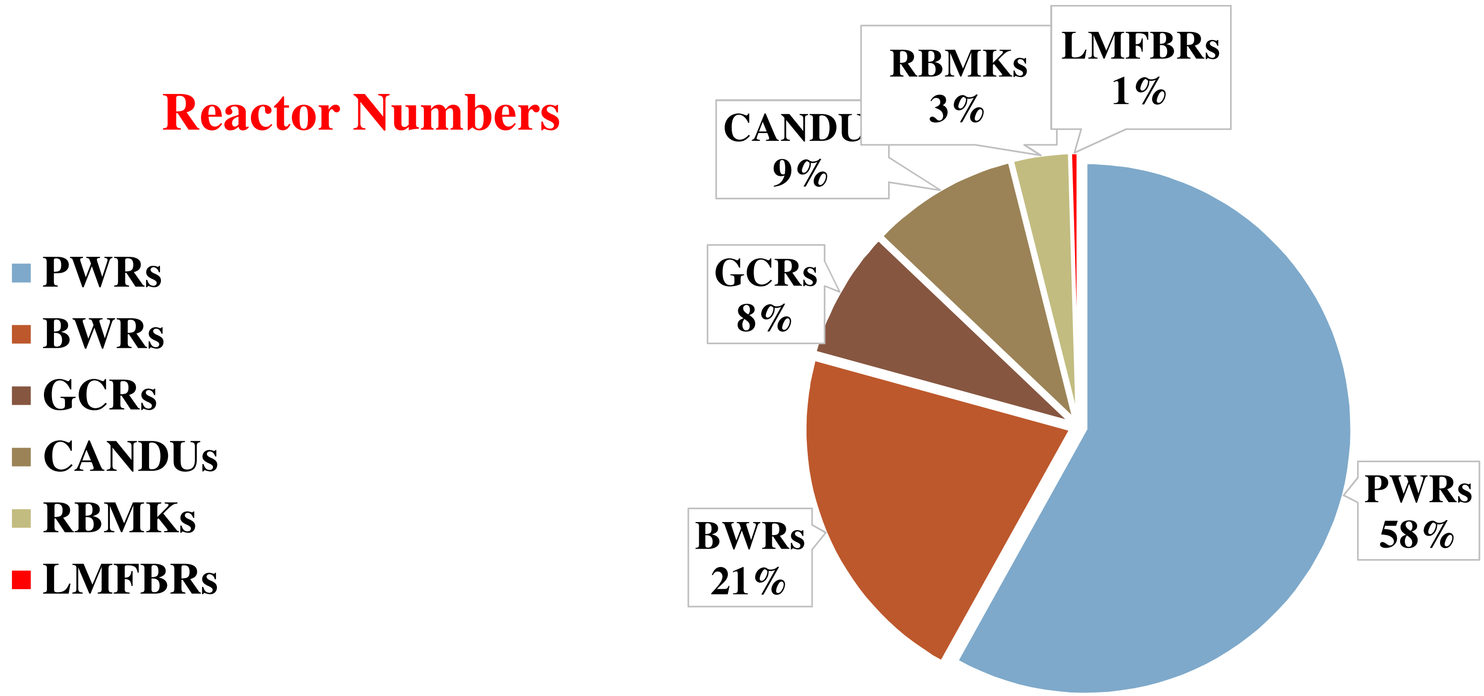
c) Power reactors: Reactors installed to produce power are called power reactors. They can be thermal or fast reactors.

Note: a single research reactor can simultaneously serve many purposes.

SOME EARLY REACTORS

Name	Location	Year	Fuel	Moderator	Coolant	Reflector	Remarks
CP-1	USA	1942	Natural Uranium	Graphite	Air	Graphite	World's first reactor
LoPO	USA	1944	Enriched Uranium	Light water	Light water	BeO	First enriched Uranium reactor
CP-3	USA	1944	Natural Uranium	Heavy water	Heavy Water	Graphite	First heavy water reactor
Clementine	USA	1946	Plutonium-239		Mercury	Graphite	First fast reactor
GLEEP	UK	1947	Natural Uranium	Graphite	Air	Graphite	
NRX	Canada	1947	Natural Uranium	Heavy water	Heavy water	Graphite	High Flux reactor
Cirus	India	1960	Natural Uranium	Heavy water	Light water	Graphite	First Indian heavy water reactor

Global Chart of Nuclear Reactors.
As of 2000, it was estimated that 434 nuclear power plants are operating worldwide to produce 350,442MWe of electric power



NEXT TOPIC: MEDICAL PHYSICS

Effects of Radiation on Living Cells: Somatic and Genetic Damages.

Uses of Radiation: Radiation Protection, Principles and Methods.

Personnel Monitoring using TLD and Film.

BIBLIOGRAPHY

1) Fundamentals of Nuclear Reactor Physics by Elmer E. Lewis

2) Nuclear Reactor Physics by Weston M. Stacey.

3) Introduction to Nuclear Physics and Chemistry by Bernard G. Harvey

4) Fundamentals of Nuclear Physics by Jagdish Varma, Roop Chand Bhandari and D.R.S Somayajulu.

5) University Physics with Modern Physics by Hugh D. Young and Roger A. Freedman.

About Lecturer:

Opadele A.E is a physics enthusiast with special interest in Medical Physics. He loves to present the complex theories in physics in seemingly simple approach for effectual understanding.

opadelea@babcock.edu.ng

abayomi_opadele

@abayomiopadele

Opadele Abayomi

If you have any questions, let me know