“Nuclear Power Generation”

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Contents

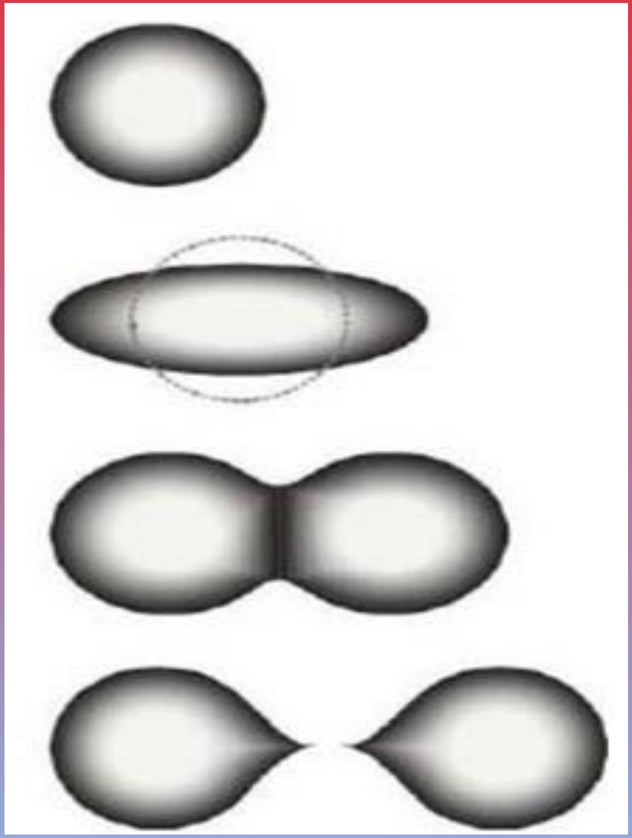
Introduction

- Nuclear power is energy which is produced with the use of a controlled nuclear reaction.

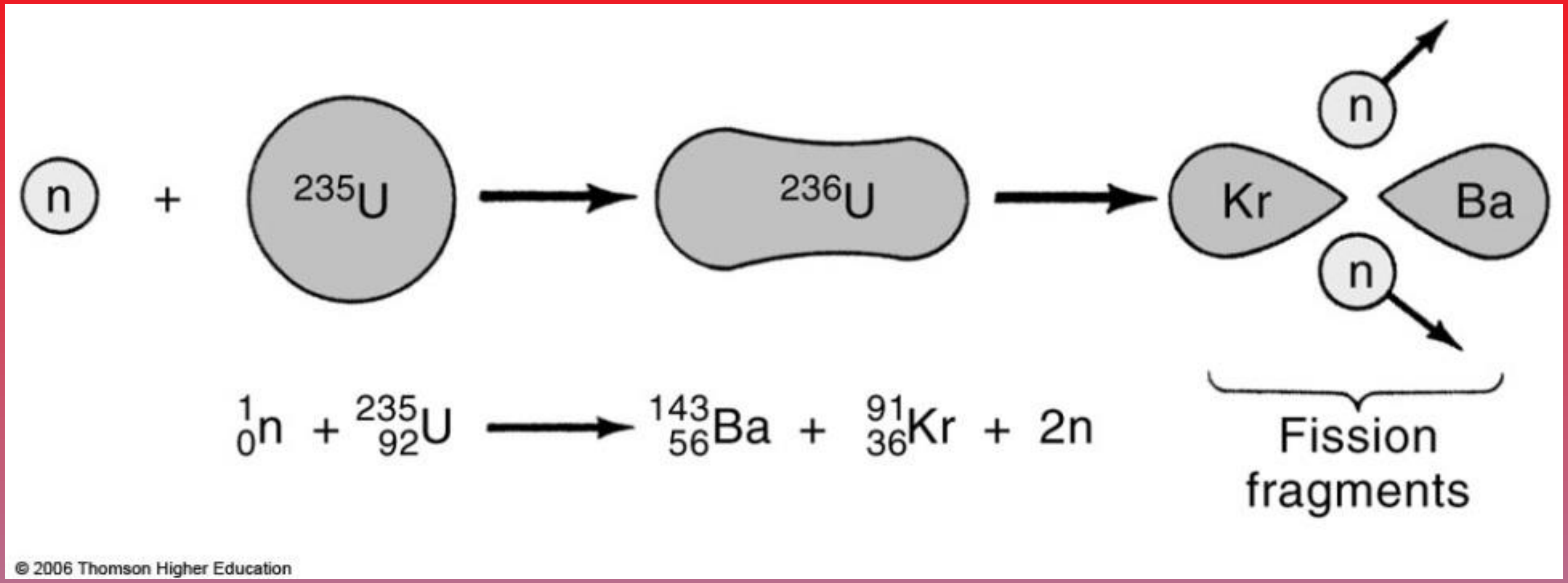
- Nuclear power plants provide about 6% of the world's energy and 13–14% of the world's electricity with the U.S.A France and Japan together accounting for about 50% of nuclear generated electricity

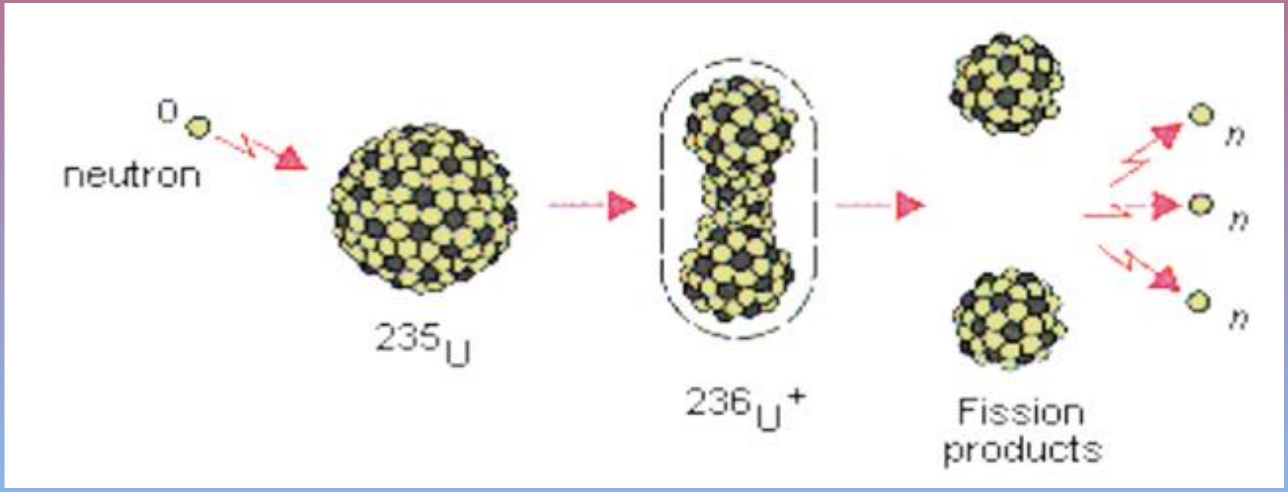
Fission Reactions

- Fission may be defined as the process of splitting an atomic nucleus into fission fragments
- The fission fragments are generally in the form of smaller atomic nuclei and neutrons
- Large amounts of energy are produced by the fission process



Fission Reactions





Fission Reactions

Some Examples of Fission Reactions

$^{235}_{92}U + {}^{1}_{0}n \longrightarrow {}^{141}_{56}Ba + {}^{92}_{36}Kr + 3\,{}^{1}_{0}n + \text{Energy}$

$^{235}_{92}U + {}^{1}_{0}n \longrightarrow {}^{131}_{50}Sn + {}^{103}_{42}Mo + 2\,{}^{1}_{0}n + \text{Energy}$

$^{235}_{92}U + {}^{1}_{0}n \longrightarrow {}^{137}_{52}Te + {}^{97}_{40}Zr + 2\,{}^{1}_{0}n + \text{Energy}$

$^{235}_{92}{}^{U} + {}^{1}_{0}n \longrightarrow {}^{138}_{54}Xe + {}^{95}_{38}Sr + 3\,{}^{1}_{0}n + \text{Energy}$

$^{235}_{92}U + {}^{1}_{0}n \longrightarrow {}^{152}_{60}Nd + {}^{81}_{32}Ge + 3\,{}^{1}_{0}n + \text{Energy}$

Fission Reactions

There are two types of fission reaction exist as:

(i) Spontaneous Fission

- Spontaneous fission is a naturally occurring nuclear decay event that a few different elements undergo

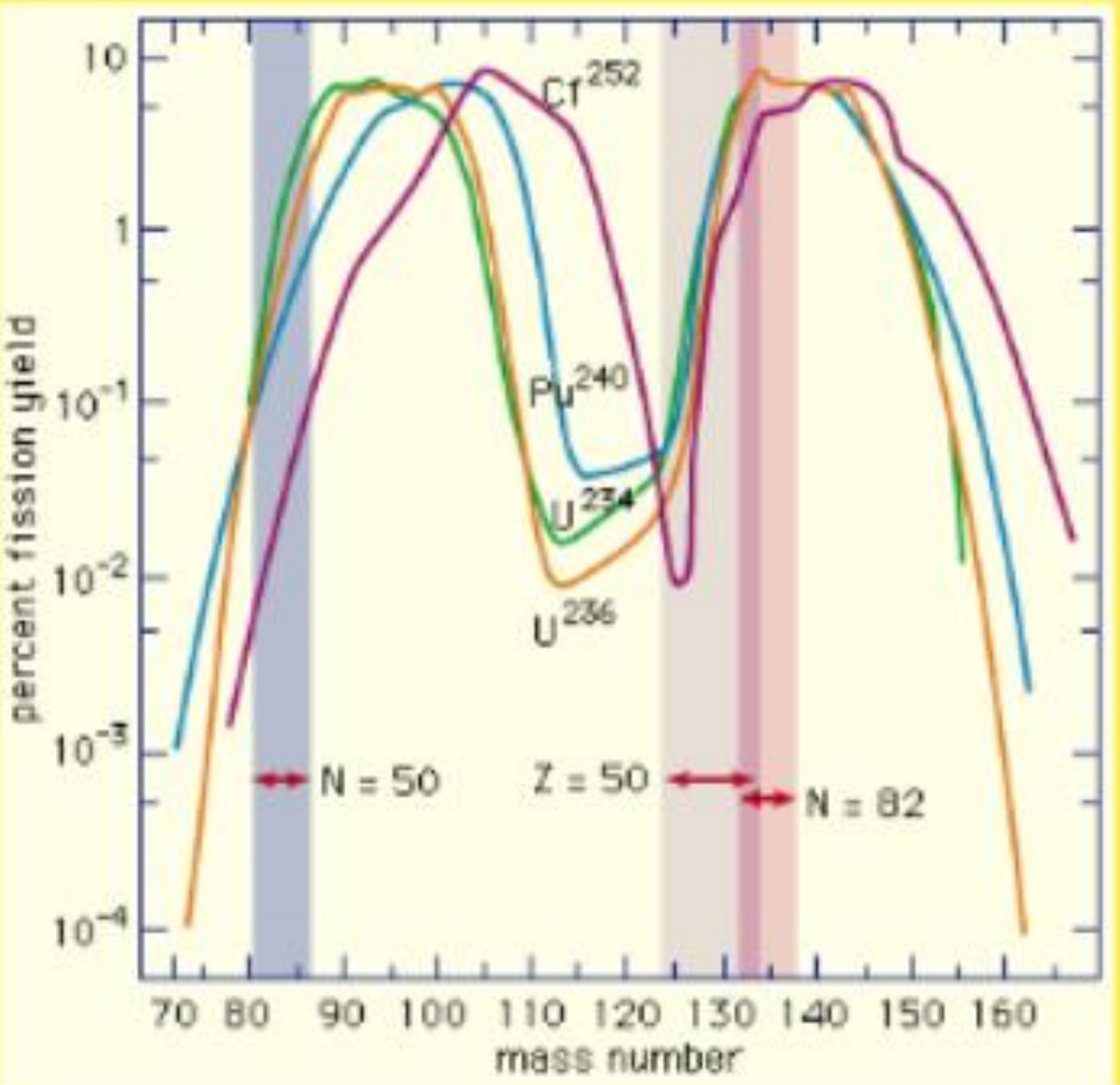
- Uranium and plutonium, which are radioactive, are the most well known of the fissionable elements, and they can do this in nature

(ii)Induced Fission

- Nuclear fission can be induced by bombarding atoms with neutrons.
- The nuclei of the atoms then split into 2 equal parts.
- Induced fission decays are also accompanied by the release of neutrons.

Important Characteristics of Fission Reactions

Mass Distribution of Fragments



The light mass group shifts to higher masses as the mass of the fissioning nucleus increases, while the heavy group remains nearly stationary. The shaded areas show the location of the closed shells of 50 protons, 50 neutrons, and 82 neutrons (see text).

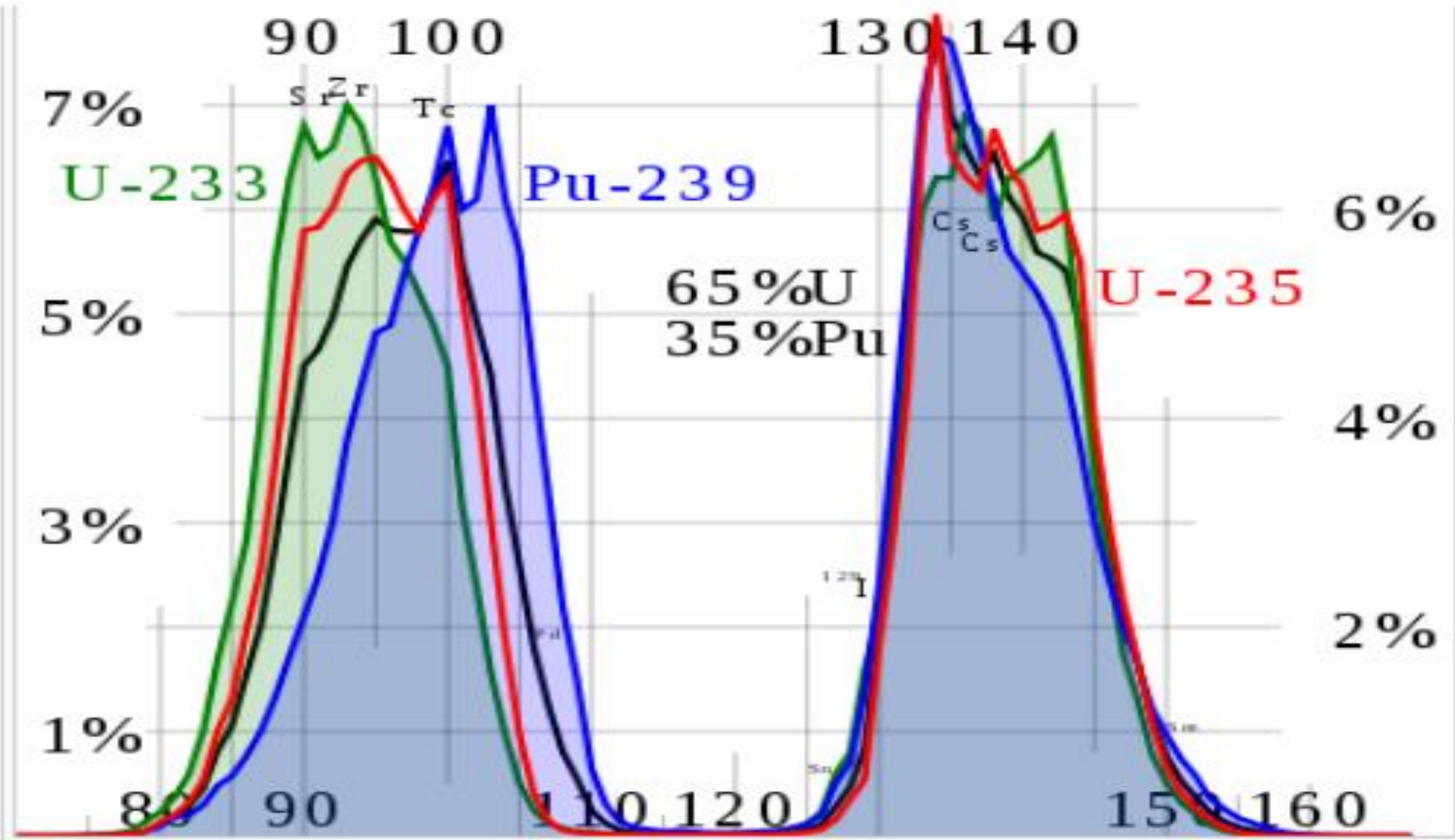
Important Characteristics of Fission Reactions

Mass Distribution of Fragments

- Fission fragments have a double bell distribution as a function of A (Mass Number).
- Note that they are unstable, as are neutron rich they decay towards stable nuclei by a chain of beta decays.
- This yields the so called “fission products”.

Important Characteristics of Fission Reactions

Mass Distribution of Fragments



Fission product yields by mass for thermal neutron fission of U-235, Pu-239, a combination of the two typical of current nuclear power reactors, and U-233 used in the thorium cycle

Important Characteristics of Fission Reactions

Mass Distribution of Fragments

- Fission product yields by mass for thermal neutron fission of ^{235}U, ^{239}Pu, a combination of the two typical of current nuclear power reactors, and ^{233}U used in the thorium cycle.

Number of Emitted Neutrons

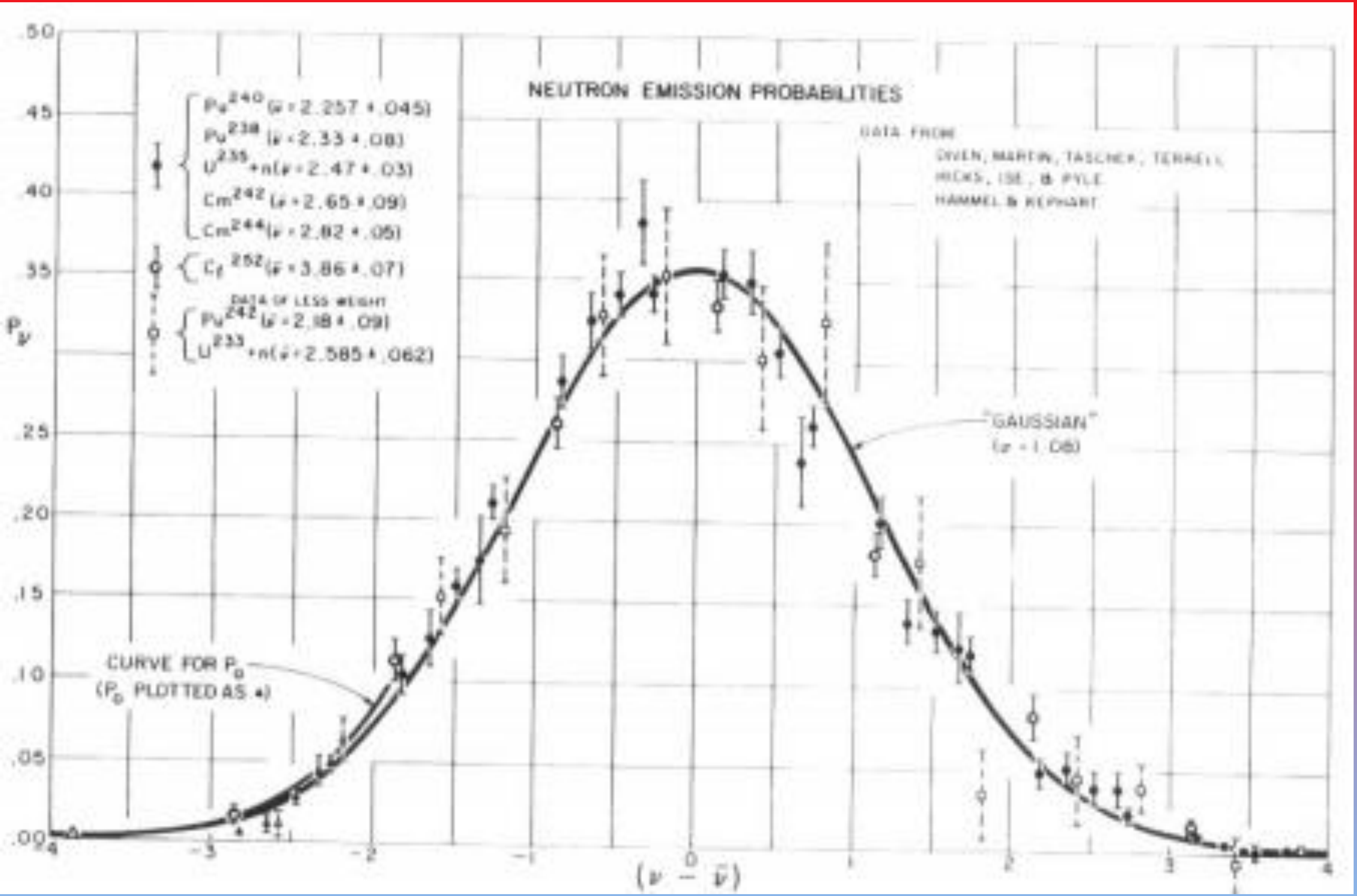
(i) Prompt Neutrons: They are those accompanying the two nuclear fragments as the 2n in

$$^{235}U + n \rightarrow {}^{93}Rb + {}^{141}Cs + 2n$$

In the case of ^{235}U, there are on the average 2.42 prompt neutrons

(ii) Delayed Neutrons: These are associated with the beta decay of the fission products. Delayed neutrons are essential for the control of nuclear reactors.

Number of Emitted Neutrons

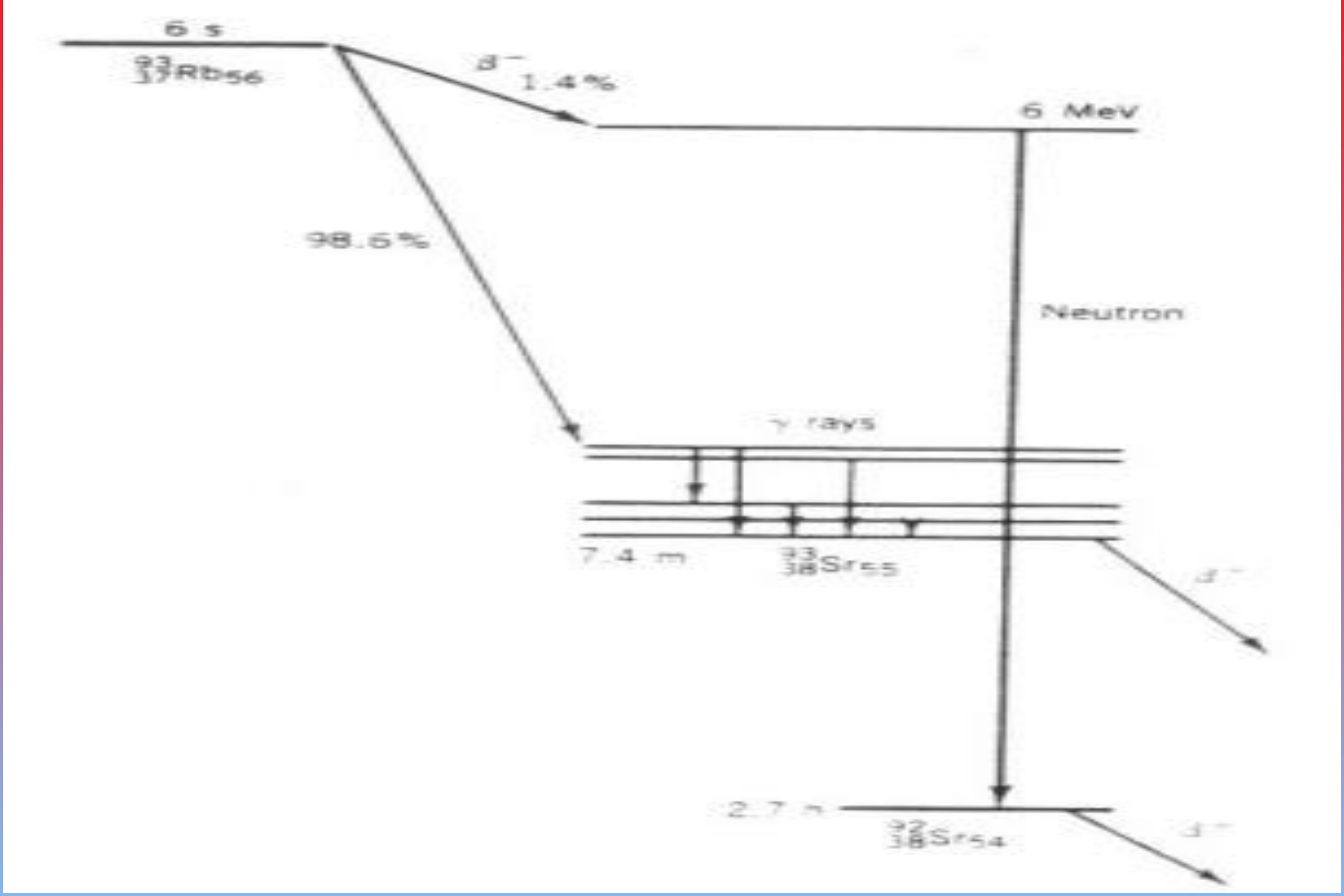


Number of Emitted Neutrons

- Distribution of fission neutrons.
- Even though the average number of neutrons ν changes with the fissioning nucleus.
- The distribution about the average is independent of the original nucleus.

Number of Emitted Neutrons

Delayed Neutron Emission from ^{93}Rb(Rubidium)



Number of Emitted Neutrons

Delayed Neutron Emission from ^{93}Rb(Rubidium)

- Delayed Neutron Emission from ^{93}Rb.
- After the original β decay, the excited state of ^{93}Sr has enough energy to decay by neutron emission to ^{92}Sr(Strontium).
- The neutrons are delayed relative to the prompt fission neutrons by a time characteristic of the mean lifetime of ^{93}Rb

Radioactive Decay Processes

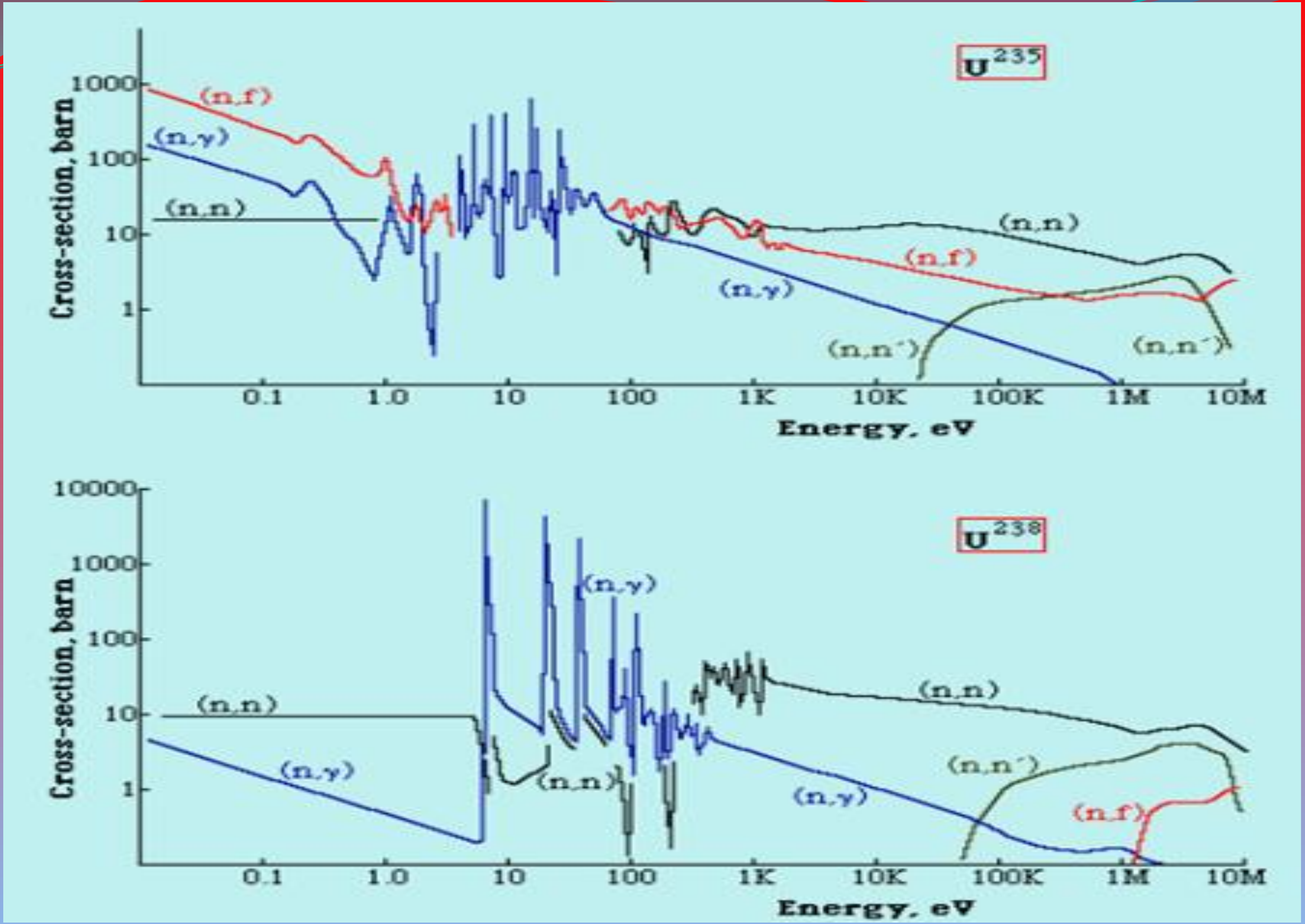
- The initial fission products are highly radioactive and decay toward stable isobars by emitting many β and γ radiations(which contribute ultimately to the total energy release in fission).

- These radioactive products are the waste products of nuclear reactors.

$$^{93}Rb \xrightarrow{6\ s} {}^{93}Sr \xrightarrow{7\ min} {}^{93}Y \xrightarrow{10\ h} {}^{93}Zr \xrightarrow{10^{6}\ y} {}^{93}Nb$$

$$^{141}Cs \xrightarrow{25\ s} {}^{141}Ba \xrightarrow{18\ min} {}^{141}La \xrightarrow{4\ h} {}^{141}Ce \xrightarrow{33\ d} {}^{141}Pr$$

Fission Cross-section



Fission Cross-section

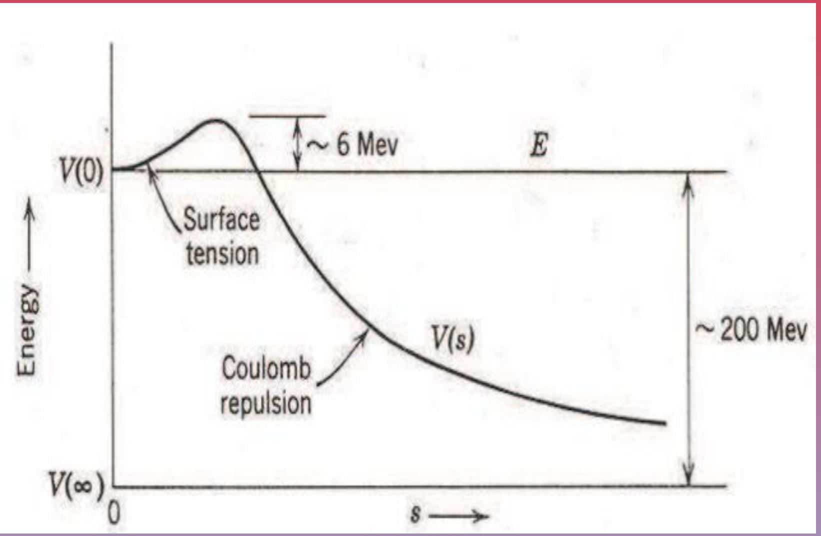
- ^{235}U will fission (n,f) at all energies of the absorbed neutron.
- ^{235}U fission cross section can grow Very large, to 500 barns sat thermal energies
- ^{238}U has a threshold for fission (n, f) at a neutron energy of 1 MeV
- There is very strong resonant capture of neutrons (n, γ) for energies in the range 10-100 eV - particularly in the case of 238U where the cross-section reaches very high values.

Energy in Fission

- The excitation energy is

$E_{ex} = [m\,(^{236}U^*) - m\,(^{236}U)]\,c^2$
$= 931.50$ MeV/u $= 6.5$ MeV

- The activation energy =6.2 MeV

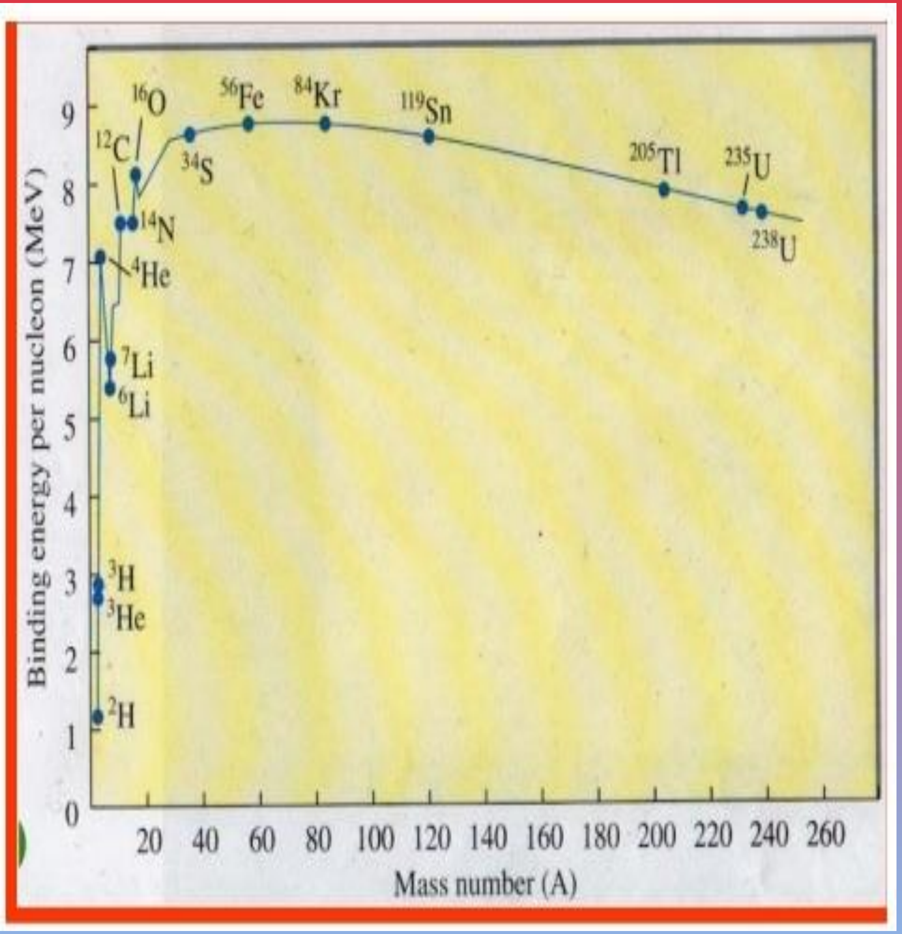


Energy in Fission

- Binding energy for a nucleus ${}^{A}_{Z}X$ is $Q\ (Z,N)=[Zm_p + Nm_n - m({}^{A}_{Z}X)]c^2$

- Typical Fission events Release 200 MeV

- For ^{235}U: ~235 MeV



Controlled Fission Reactions

- Nuclear power plants work by controlling the rate of the nuclear reactions and that control is maintained through several safety measures.
- The materials in a nuclear reactor core and the uranium enrichment level make a nuclear explosion impossible, even if all safety measures failed.
- On the other hand, nuclear weapons are engineered to produce a reaction that is so fast and intense it cannot be controlled after it has started. When properly designed, this uncontrolled reaction can lead to an explosive energy release.

Controlled Fission Reactions

Neutron Multiplication factor(k)

- The effective neutron multiplication factor, k, is the average number of neutrons from one fission that causes fission:
- k=(Number of Neutrons in one generation)/(Number of neutrons in preceding generation)

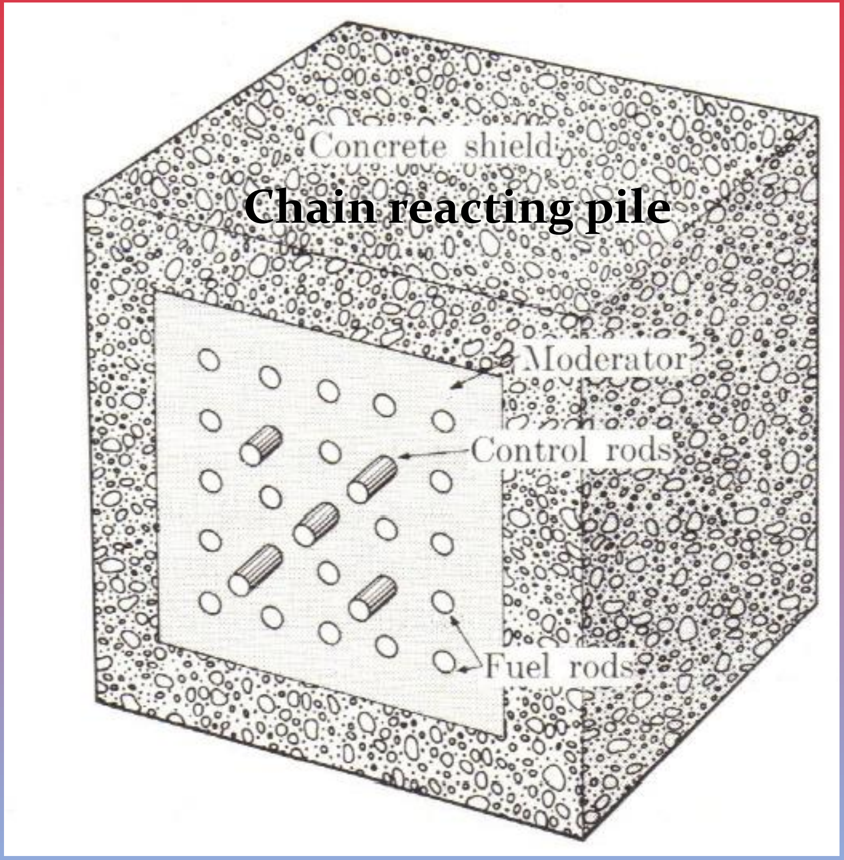
- The remaining neutrons either are absorbed in non-fission reactions or leave the system

without being absorbed.

Controlled Fission Reactions

Neutron Multiplication factor(k)

- The value of k determines how a nuclear chain reaction proceeds.
- $k \geq 1$ ▶ Chain reaction
- $k < 1$ ▶ subcritical
- $k = 1$ ▶ critical system
- $k > 1$ ▶ supercritical
- For steady release of energy (steady- state operation) we need k =**1**



Controlled Fission Reactions

Four –factors formula

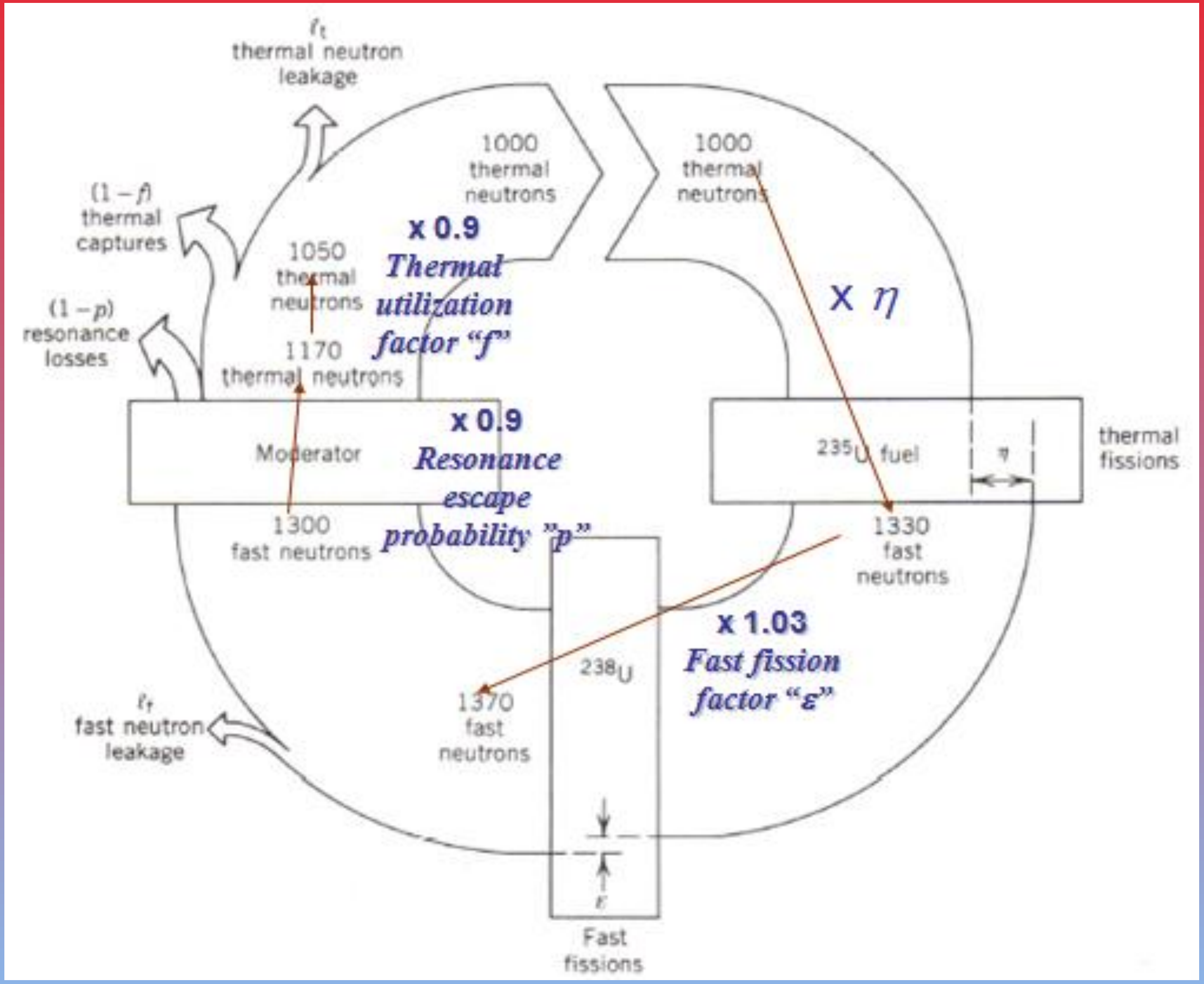
- Neutron multiplication factor in an infinite medium k_∞

$$k_\infty = \eta f p \varepsilon \text{ (Four-factor formula)}$$

- η- reproduction factor - the number of fission neutrons produced per absorption in the fuel
- f - the thermal utilization factor - probability that a neutron that gets absorbed does so in the fuel material
- p - the resonance escape probability - fraction of fission neutrons that manage to slow down from fission to thermal energies without being absorbed
- ε- the fast fission factor = (Total Number of fission neutrons)/(Number of fission neutrons from just thermal fission)

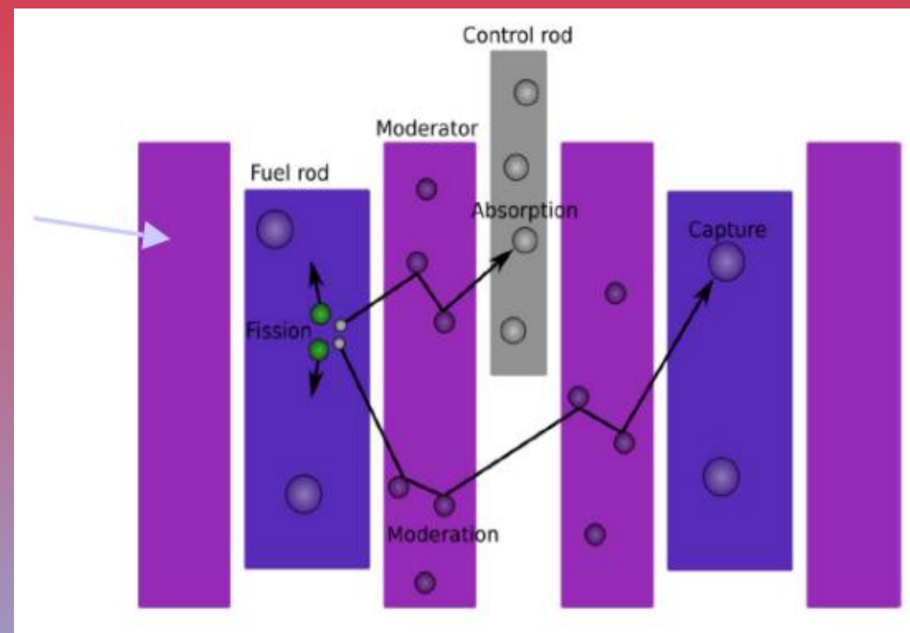
Controlled Fission Reactions

Four –factors formula



Fuel Use in the Reactor

In nature there are only 3 isotopes - ^{235}U, ^{238}U and ^{232}Th – which can be used as nuclear fuel (^{235}U) or reproduction of fuel (as $^{238}U \rightarrow 239Pu$; $^{232}Th \rightarrow ^{233}U$). Naturally occurring uranium consists 99.3% of ^{238}U and only 0.7% of ^{235}U i.e. for 1 nucleus of ^{235}U there are 140 nuclei of ^{238}U.



$$n + {}^{238}_{92}U \longrightarrow {}^{239}_{92}U \xrightarrow[\beta^-,23min]{} {}^{239}_{93}Np \xrightarrow[\beta^-,2,3days]{} {}^{239}_{94}Pu$$

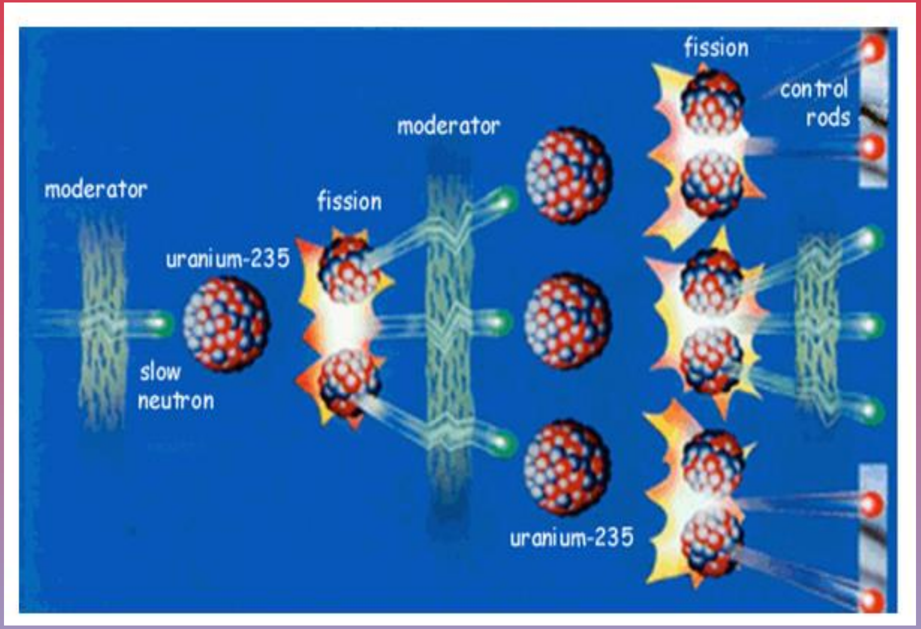
$$n + {}^{232}_{90}Th \longrightarrow {}^{233}_{90}Th \xrightarrow[\beta^-,22min]{} {}^{233}_{91}Pa \xrightarrow[\beta^-,27days]{} {}^{233}_{92}U$$

Moderator

In nuclear reactors there are neutron moderators, which reduce the velocity of fast neutrons, thereby turning them into thermal neutrons.

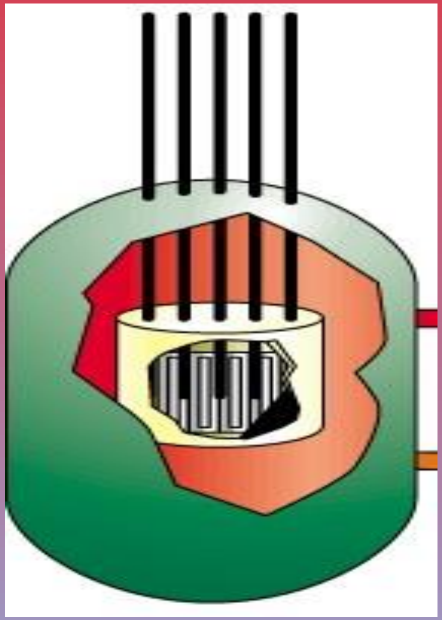
The following substances are commonly used as moderators.

- graphite,
- H_2O, D_2O
- He
- Be (high temperature liquid metal).
- Na (773 to 873 K used in breeder reactor)
- $BeF_2 + ZrF_4$ (for GCR)



Absorber

- A control rod is a rod made of chemical elements capable of absorbing many neutrons without fissioning themselves. They are used in nuclear reactors to control the rate of fission of uranium and plutonium.
- Usually, Cadmium, Boron, Carbon, Cobalt, Silver, Hafnium, Gadolinium and Europium are common elements used in control rods.



Technology of Nuclear Power Plants

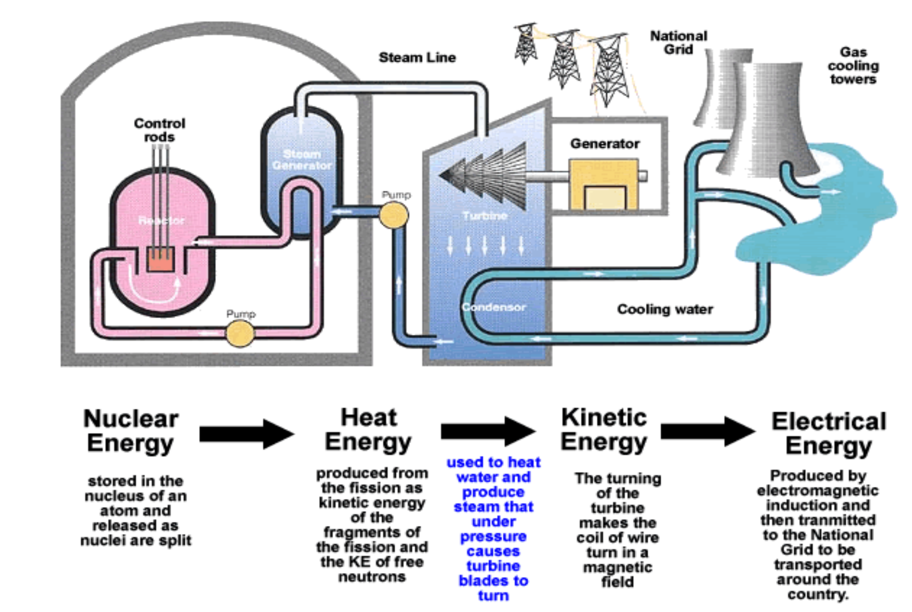
Nuclear Power Plant

- In a nuclear power plant use is made of the fission reaction. Most power plants produce electricity by first boiling water to produce steam. The steam is used to spin a turbine. The shaft of the turbine spins the generator (a large coil of wire) between two magnets. The spinning coil of wire generates electricity by electromagnetic induction.

Nuclear Power Plant

- The whole arrangement can be divided into following main stages.

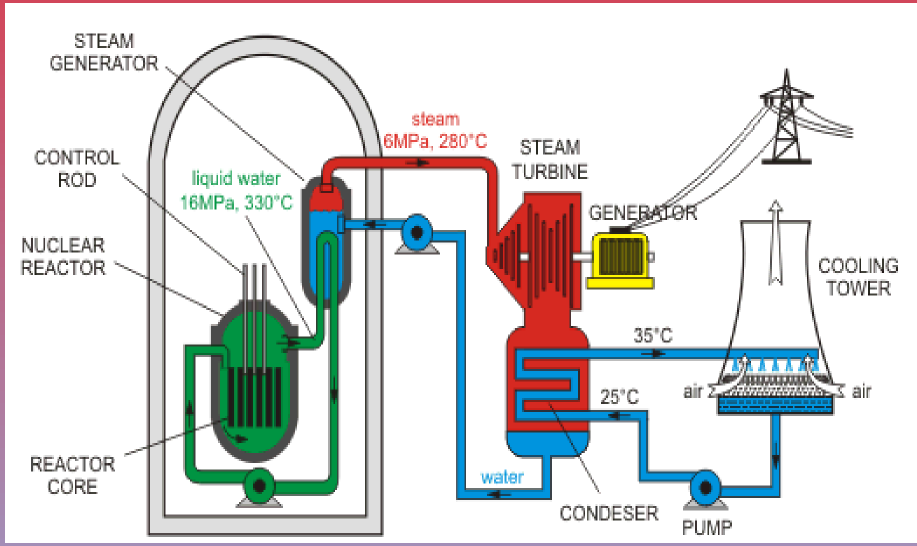
- (i)Nuclear Reactor
- (ii) Heat Exchanger
- (iii)Steam Turbine
- (iv) Alternator



Nuclear Reactor

Essential Components and types of a Nuclear Reactor

- **The core** of the reactor contains all of the nuclear fuel and generates all of the heat.
- **The coolant** is the material that passes through the core, transferring the heat from the fuel to a turbine.
- **The turbine** transfers the heat from the coolant to electricity, just like in a fossil-fuel plant.
- **The containment** is the structure that separates the reactor from the environment.
- **Cooling towers** are needed by some plants to dump the excess heat that cannot be converted to energy due to the laws of thermodynamics.



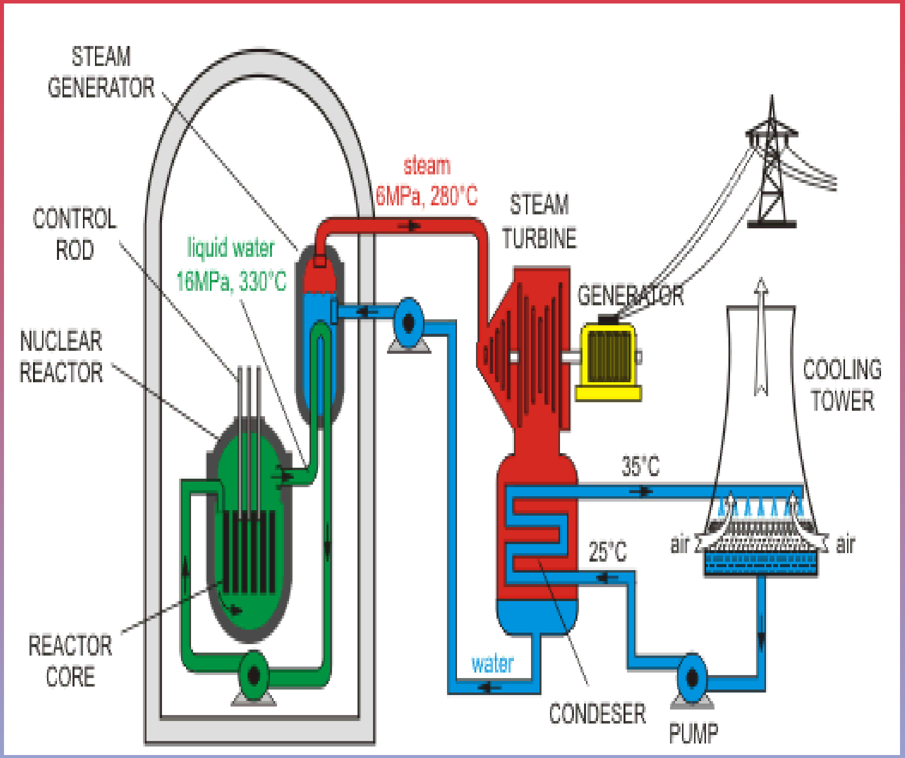
Types of Nuclear Reactors

There are very many different types of nuclear reactors with different fuels, coolants, fuel cycles, purposes.

- **Pressurized Water Reactor**
- **Boiling Water Reactor**
- **Sodium Cooled Fast Reactor**
- **Canada Deuterium-Uranium Reactors (CANDU)**
- **Liquid Fluoride Thorium Reactor**
- **High Temperature Gas Cooled Reactor**

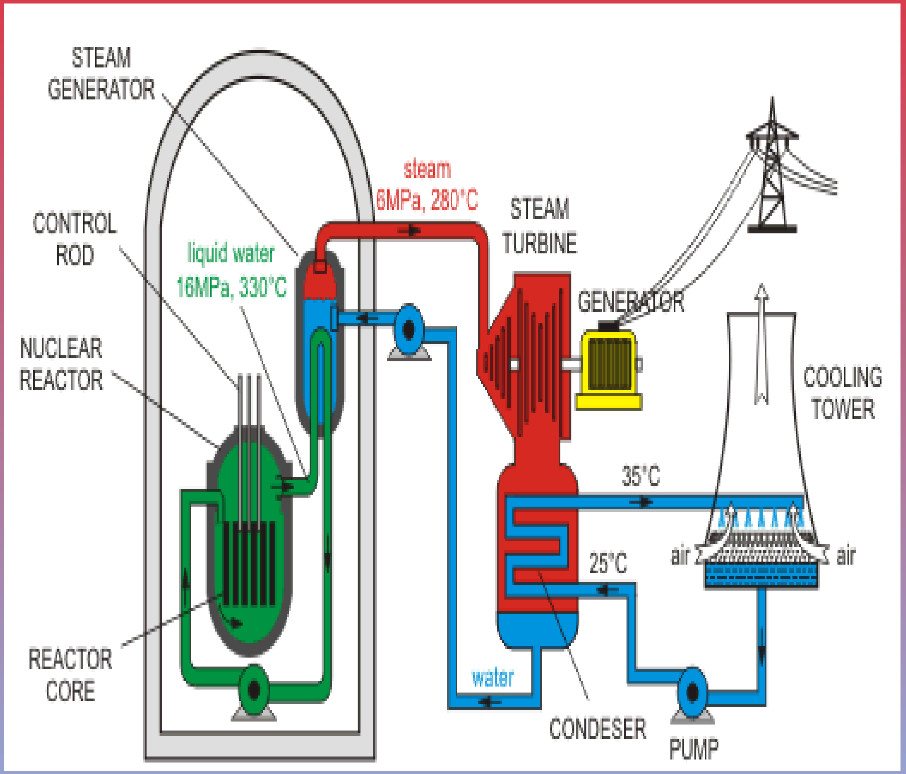
How Nuclear Power Plant Works

- First, uranium fuel is loaded up into the reactor.
- Control rods made of materials such as cadmium and boron can be raised or lowered into the reactor to soak up neutrons and slow down or speed up the chain reaction.
- Water is pumped through the reactor to collect the heat energy that the chain reaction produces.



How Nuclear Power Plant Works

- Inside the heat exchanger, the water from the reactor gives up its energy to cooler water flowing in another closed loop, turning it into steam.
- The steam from the heat exchanger is piped to a turbine. As the steam blows past the turbine's vanes, they spin around at high speed.
- The spinning turbine is connected to an electricity generator and makes that spin too.
- The generator produces electricity that flows out to the power grid.



Advantages of Nuclear Power

- Nuclear electricity is reliable and relatively cheap (with an average generating cost of 2.9 cents per kW/h) once the reactor is in place and operating.
- A lot of energy is generated from a single power plant
- Nuclear power plants contribute no greenhouse gasses and few atmospheric pollutants

Disadvantages of Nuclear Power

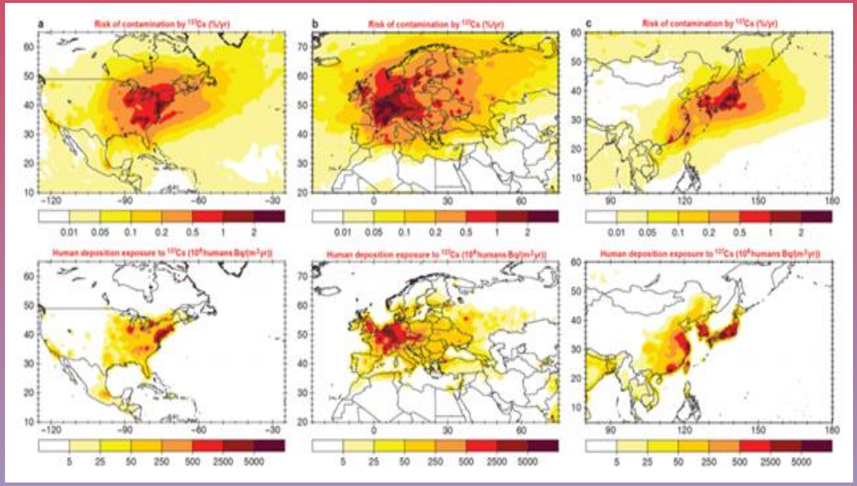
- Uranium is ultimately a nonrenewable resource.
- Nuclear power plants are extremely costly to build.
- The slight possibility that nuclear power plants can have catastrophic failures.
- Large environmental impact during the mining and processing stages of uranium are numerous.
- Nuclear waste (Spent nuclear fuel) is extremely hazardous and must be stored safely for thousands of years.

Conclusions

- Nuclear power is a clean, safe, affordable way to meet future power demands in the all around the world.
- It emits virtually no greenhouse gases (GHG), making it a clean power source that can help address global warming.
- Nuclear power plants can produce an uninterrupted flow of electricity for extended periods.
- To establish a nuclear power plant, we have to take more cautious for the following important issues.

Conclusions

- Environmental Impacts
- Waste Management's:
- Sustainability
- Accidents



Conclusions

Location	Country	INES	Date	Total	^{131}I	^{137}Cs
Fukushima	Japan	7	11 March 2011	>630	190–380	12–37
Chernobyl	USSR	7	26 April 1986	>12 000	1760	85
Mayak	USSR	6	29 September 1957	74–1850	n.d.a	n.d.a
Chalk River	Canada	5	12 December 1952	>0.3	n.d.a.	n.d.a.
Windscale	UK	5	10 October 1957	1.6	0.7	0.02
Simi Valley	USA	5–6	26 July 1959	> 200[a]	b	n.d.a.
Belojarsk	USSR	5	1977	n.d.a.	n.d.a.	n.d.a.
Three Mile Island	USA	5	28 March 1979	1.6[c]	<0.0007	n.d.a.
Chernobyl	USSR	5	1 September 1982	n.d.a.	n.d.a.	n.d.a.
Idaho Falls	USA	4	29 November 1955	d	d	d
Idaho Falls	USA	4	3 January 1961	n.d.a.	n.d.a.	n.d.a.
Monroe	USA	4	5 October 1966	d	d	d
Lucens	Switzerland	4–5	21 January 1969	d	d	d
Windscale	UK	4	1973	n.d.a.	n.d.a.	n.d.a.
Leningrad	USSR	4–5	6 February 1974	e	n.d.a.	n.d.a.
Leningrad	USSR	4–5	October 1974	55	n.d.a.	n.d.a.
Jaslovské Bohunice	CSSR	4	22 February 1977	n.d.a.	n.d.a.	n.d.a.
Saint-Laurent	France	4	13 March 1980	n.d.a.	n.d.a.	n.d.a.
Buenos Aires	Argentina	4	23 September 1983	n.d.a.	b	n.d.a.
Tokaimura	Japan	4	30 September 1999	n.d.a.	n.d.a.	n.d.a.

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Thanks a lot

For your Attention!