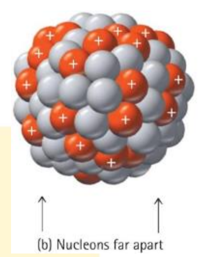
RADIOACTIVITY & HALF-LIFE

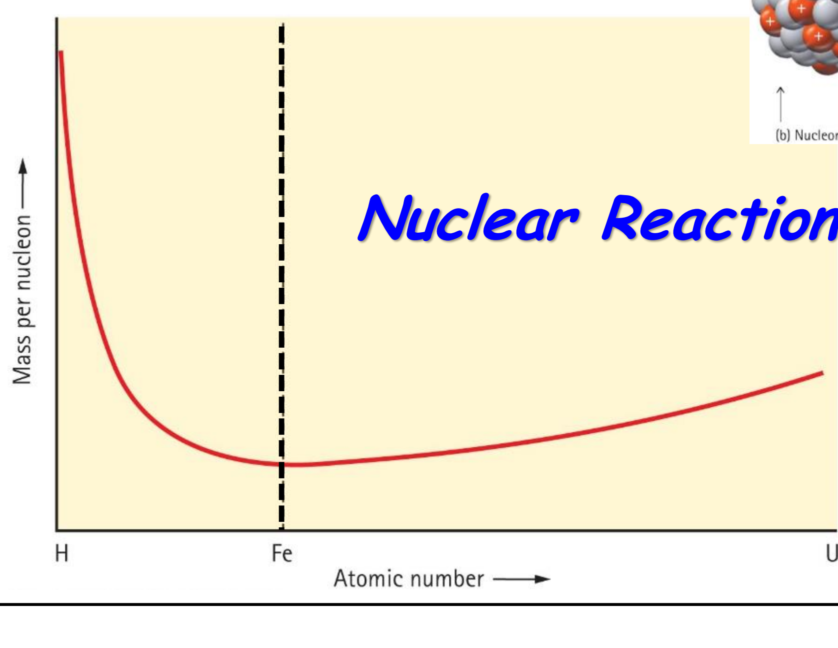
Part 3

1

Nuclear Fission



Nuclear Reaction

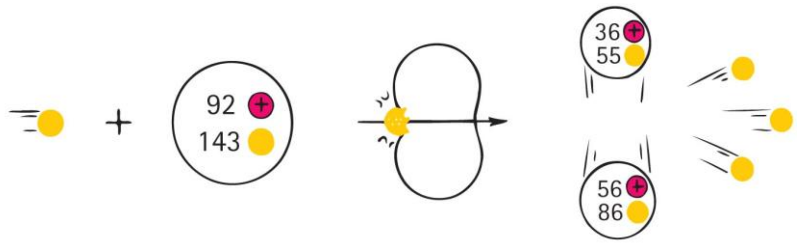


2

Nuclear Fission

Nuclear Fission:

A neutron hitting a U-235 nucleus may cause it to stretch and fly apart.



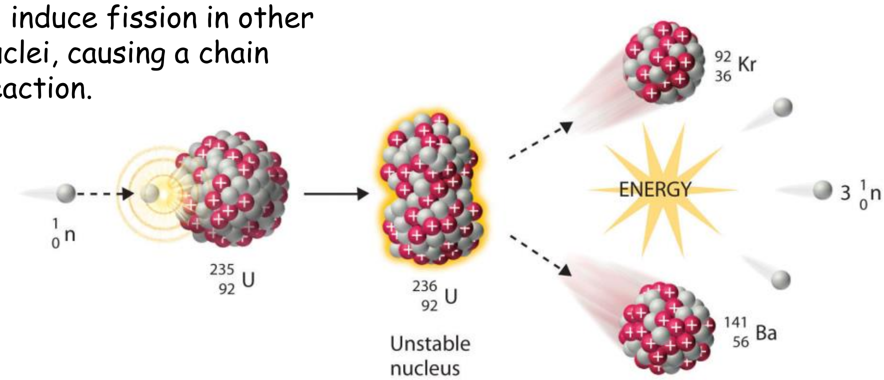
$$^{1}_{0}n + ^{235}_{92}U \rightarrow ^{91}_{36}Kr + ^{142}_{56}Ba + 3(^{1}_{0}n)$$

3

Nuclear Fission

The energy release in a fission reaction is quite large. Also, since smaller nuclei are stable with fewer neutrons, several neutrons emerge from each fission as well.

These neutrons can be used to induce fission in other nuclei, causing a chain reaction.

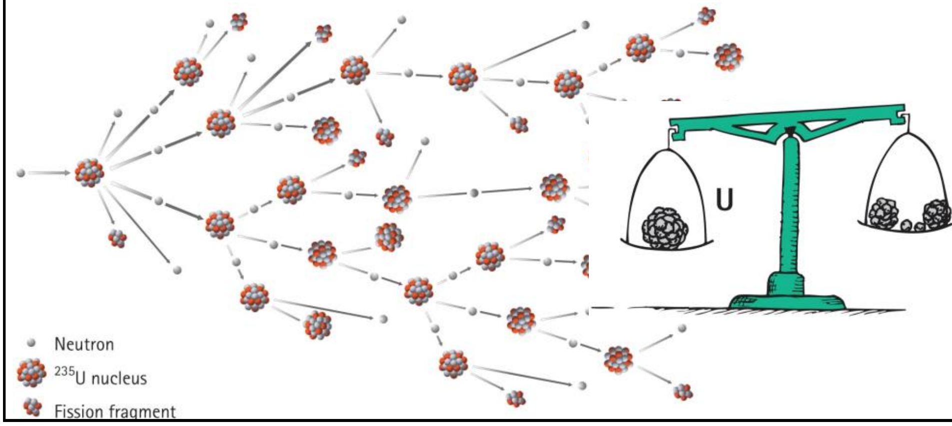


4

Nuclear Fission

Chain reaction:

is a self-sustaining reaction in which the products of one reaction event stimulate further reaction events.



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Mass–Energy Equivalence: $E = mc^2$

Albert Einstein in the early 1900s:

- discovered that mass is congealed energy.
- formulated the famous equation, *$E = mc^2$*, which is the key to understanding why and how energy is released in nuclear reactions.

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Mass–Energy Equivalence: $E = mc^2$

Relationship of equation terms:

- The more energy associated with a particle, the greater is the mass of the particle.
- The mass of a nucleon outside the nucleus is greater than the mass of the same nucleon bound in the nucleus.
- The greater mass of the nucleon is evident by the energy required to pull the nucleons apart from one another.

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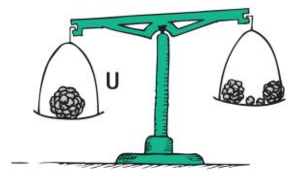
Mass–Energy Equivalence: $E = mc^2$



Relationship of equation terms:

- When nucleons lose mass in a nuclear reaction, the loss of mass, Δm, multiplied by the square of the speed of light is equal to the energy release : $E = \Delta mc^2$.
- Mass difference is related to the binding energy of the nucleus—how much is required to dissemble the nucleus.

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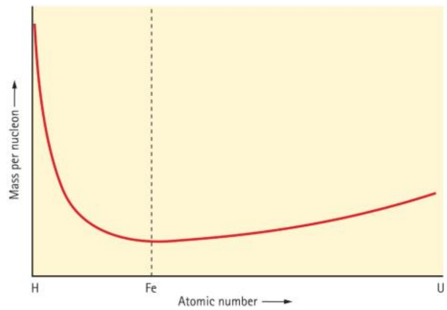
Mass-Energy Equivalence: $E = mc^2$

Dividing the mass of a nucleus by the number of nucleons in the nucleus gives the mass per nucleon.

Graph of nuclear mass per nucleon inside each nucleus versus atomic number from hydrogen to uranium:

- greatest mass per nucleon occurs for hydrogen, because it has no binding energy to pull its mass down

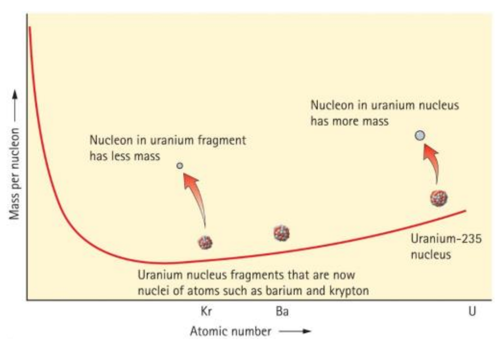


11

Mass-Energy Equivalence: $E = mc^2$

Graph of nuclear mass per nucleon versus atomic number for uranium:

- The nucleons in a uranium nucleus have more mass than the nucleons in uranium fragments.



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Agricultural Applications of Radionuclides

- Gamma radiation is used to sterilize male insects instead of killing them with pesticides.
- Cobalt-60 emits gamma rays when it decays and is often used in agriculture.
- Gamma-irradiation of food is used to kill microorganisms.

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Nuclear Medicine

- The term *nuclear medicine* refers to the use of radionuclides for medical purposes.
- Iodine-131 is used to measure thyroid activity.
- The gas xenon-133 is used to diagnose respiratory problems.
- Iron-59 is used to diagnose anemia.
- Breast cancer can be treated using the isotope iridium-192.

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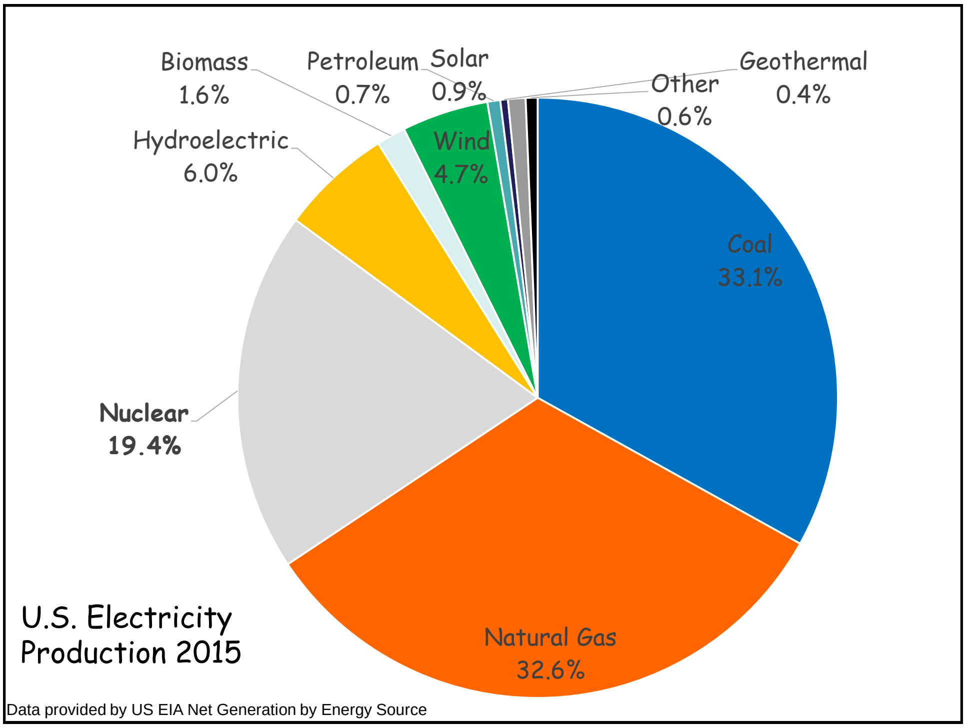
Biomass
1.6%
Petroleum
0.7%
Solar
0.9%
Other
0.6%
Geothermal
0.4%
Hydroelectric
6.0%
Wind
4.7%
Coal
33.1%
Nuclear
19.4%
U.S. Electricity
Production 2015
Natural Gas
32.6%
Data provided by US EIA Net Generation by Energy Source

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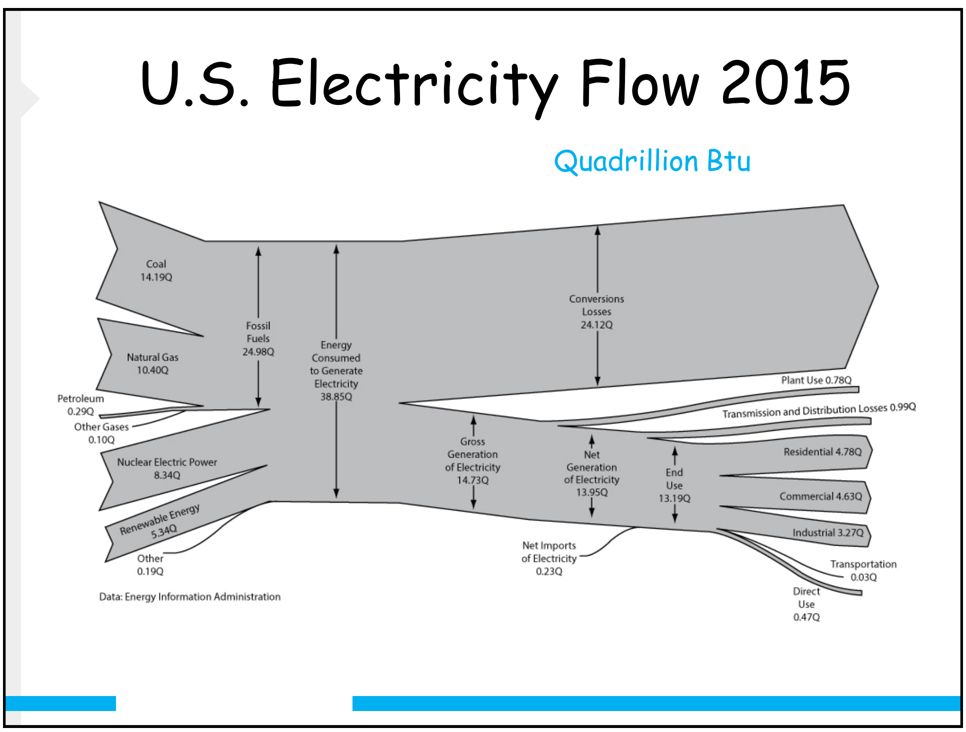
U.S. Electricity Flow 2015
Quadrillion Btu
Coal
14.19Q
Natural Gas
10.40Q
Petroleum
0.29Q
Other Gases
0.10Q
Nuclear Electric Power
8.34Q
Renewable Energy
5.34Q
Other
0.19Q
Fossil
Fuels
24.98Q
Energy
Consumed
to Generate
Electricity
38.85Q
Conversions
Losses
24.12Q
Plant Use 0.78Q
Transmission and Distribution Losses 0.99Q
Gross
Generation
of Electricity
14.73Q
Net
Generation
of Electricity
13.95Q
End
Use
13.19Q
Residential 4.78Q
Commercial 4.63Q
Industrial 3.27Q
Transportation
0.03Q
Direct
Use
0.47Q
Net Imports
of Electricity
0.23Q
Data: Energy Information Administration

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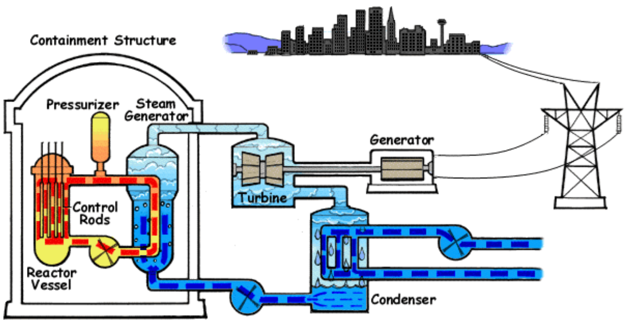
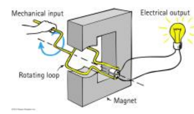
Nuclear Fission; Nuclear Power Plant





Rancho Seco
Nuclear Generating Station
SMUD

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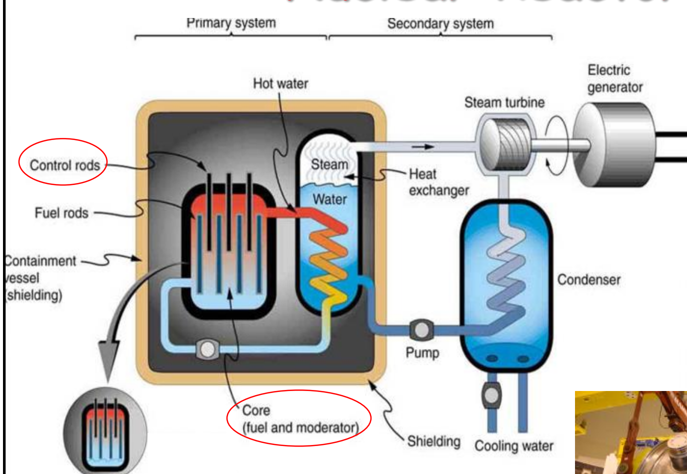
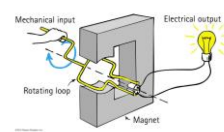
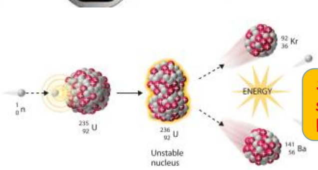
Nuclear Reactor







Sustained reaction—
some neutrons are taken
by Control rods

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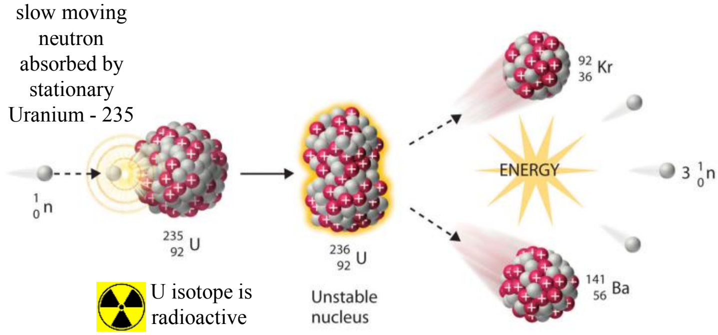
Fission of Uranium – 235



- There is a large gain in KE, from 0.03 eV to 200 million eV – a factor of over 1 billion.
- The energy density for Uranium 235 is 81 million kJ/g; the energy density for gasoline is 50 kJ/g.
- Per gram, uranium produces more than 1 million times more energy than gasoline does

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Nuclear Power Plants

- US nuclear power plants use U 235 as fuel
- There are two other factors to consider: the **financial cost** and **public safety**
- in terms of finances, the cost of nuclear power electricity must be comparable to the cost for other methods
- in terms of safety, something must be done with the radioactive end products that fission produces

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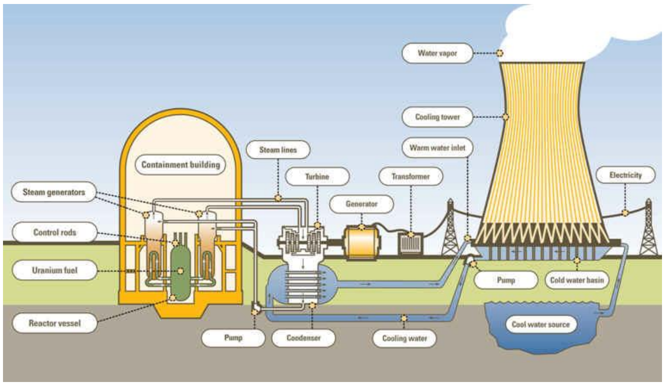
Radioactive Waste



- Radioactive isotopes produced in fission are referred to as the radioactive waste
- The radioactive waste must be stored in a safe place until it is no longer dangerous
- currently, radioactive waste is kept on site and is kept safe by the containment structure
- but this is a temporary solution

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Chernobyl Accident (1986)

- This reactor was located in Ukraine and used slightly enriched uranium with a graphite (carbon) moderator instead of a water moderator
- Cooling system in core failed which resulted in high temperature and pressure in the core and led to an explosion (a chemical explosion) that damaged the core but also shut down fission
- However, the radioactive waste kept heating the core and ignited the graphite moderator leading to a 10 day fire
- the smoke from the fire contained radioactive waste and dispersed into the atmosphere.

- There were 31 deaths within a few weeks (operators and rescue workers) and it is estimated that there could be up to **16,000 excess cases of cancer in the next 50 years (a more conservative analysis yields 4,000 excess cancers in the next 50 years**

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Fukushima Power Plant Before March 11, 2011

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Fukushima Power Plant After March 11, 2011

- All four main reactors had chemical explosions
- Units 3 and 4 are major problems
- Both contain spent fuel that is still radioactive
- Unit 3 has less spent fuel but has not been reinforced against structural damage
- Unit 4 has has had some reinforcement but it contains more radioactive waste **AND** the waste is open to the atmosphere

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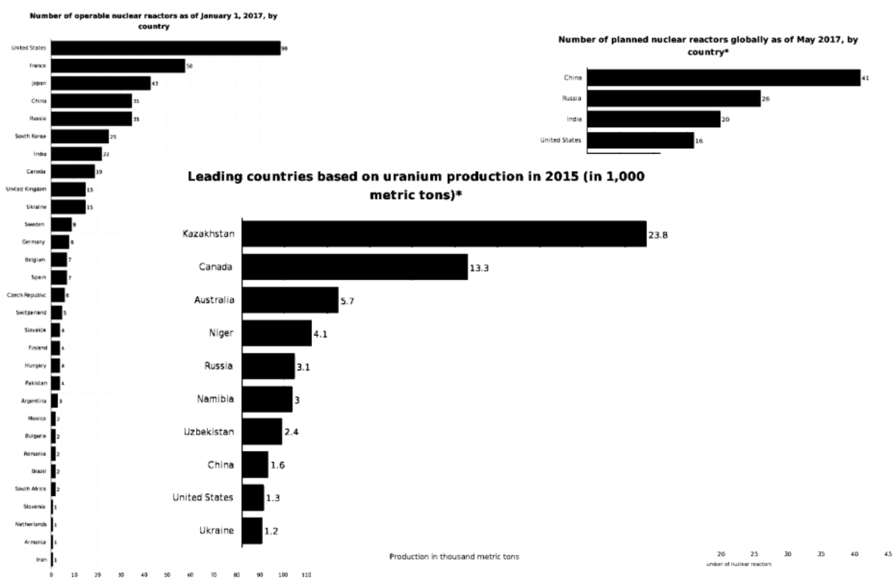
Nuclear Plants vs Coal Plants

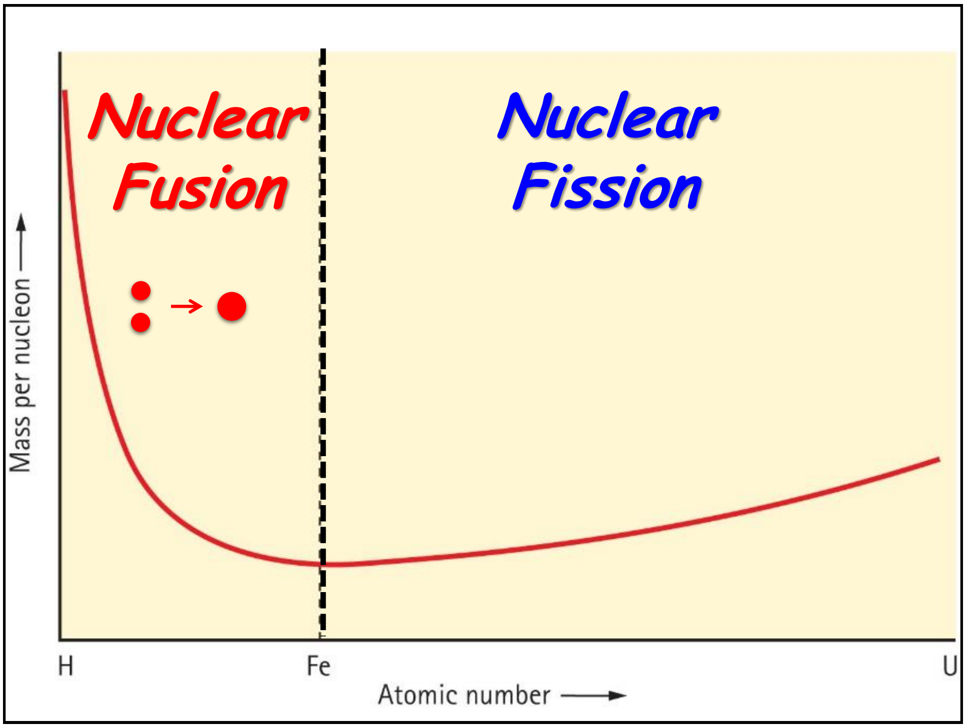
Nuclear PP

Coal PP

Nuclear Fission; Nuclear Reactors



Number of reactors in operation, worldwide, 2017-02-04 (IAEA 2016)



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Nuclear Fusion

Nuclear fusion:

is the combination of nuclei of light atoms to form heavier nuclei with the release of much energy.

Any nuclear transformation that moves nuclei toward iron releases energy.

Iron is the “nuclear sink” for energy production.

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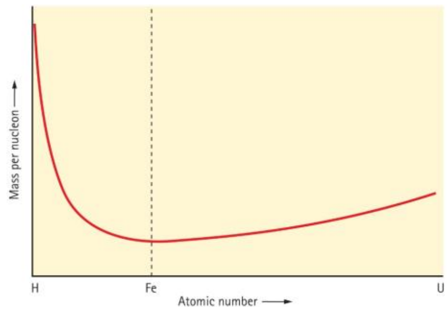
Mass-Energy Equivalence: $E = mc^2$

Dividing the mass of a nucleus by the number of nucleons in the nucleus gives the mass per nucleon.

Graph of nuclear mass per nucleon inside each nucleus versus atomic number from hydrogen to uranium:

- greatest mass per nucleon occurs for hydrogen, because it has no binding energy to pull its mass down



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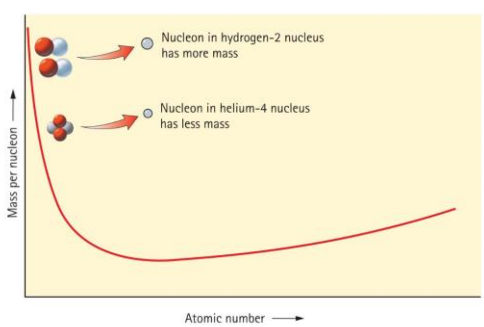
Nuclear Fusion

A graph of mass per nucleon versus atomic number from hydrogen to iron

- shows how the average mass per nucleon decreases from hydrogen to iron.



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Nuclear Fusion

Thermonuclear fusion:

- Nuclear fusion is produced by high temperature resulting in more tightly bound nuclei.
- Mass decreases as energy is released.
- This is analogous to chemical combustion requiring a high temperature, where the end result is energy release and a tightly bound molecule.
- A solution is still being sought for reactions to occur under controlled conditions to provide an enormous amount of sustained energy.

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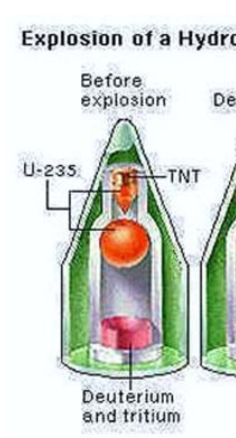
Nuclear Fusion

Thermonuclear **weapon**: Fission + Fusion



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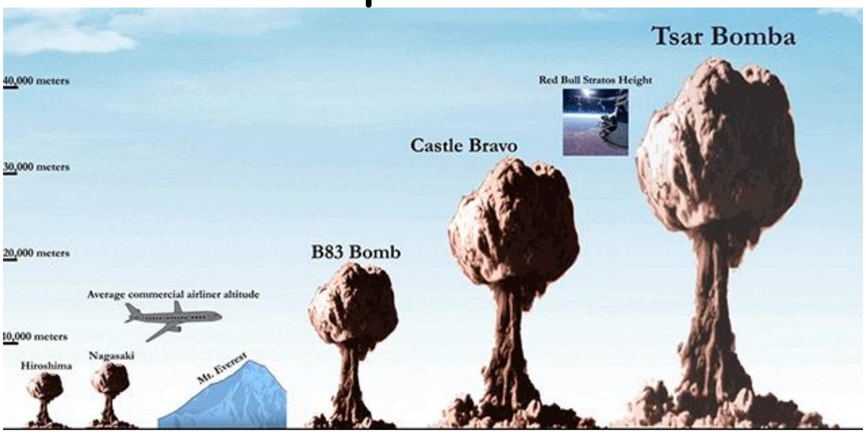
Nuclear Fusion

Thermonuclear weapon:



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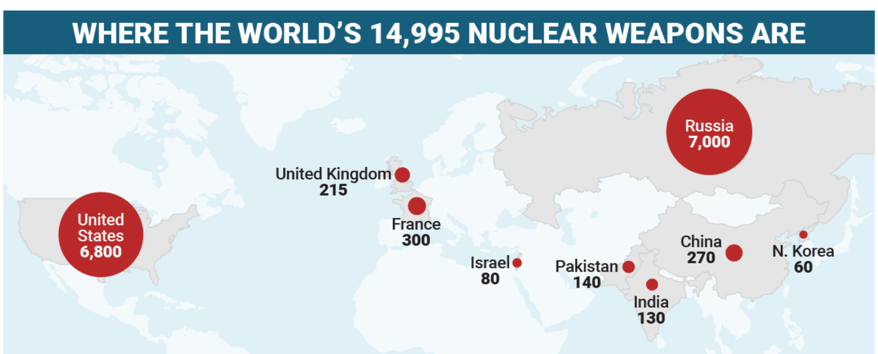
Nuclear Fusion

Thermonuclear weapon:



Source: The Washington Post

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Nuclear Fusion

- ***Nuclear fusion*** is the combining of two lighter nuclei into a heavier nucleus.
- It is more difficult to start a fusion reaction than a fission reaction, but it releases more energy.
- Nuclear fusion is a cleaner process than fission because very little radioactive waste is produced.
- The Sun is a giant fusion reactor, operating at temperatures of millions of degrees Celsius.

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Fusion in the Sun (and Other Stars)

- The Sun is about 73% hydrogen, 26% helium, and 1% all other elements.
- Three common fusion reactions that occur in the Sun are as follows:

$$^{1}_{1}H + ^{1}_{1}H \longrightarrow ^{2}_{1}H + ^{0}_{+1}e + \text{energy}$$

$$^{2}_{1}H + ^{1}_{1}H \longrightarrow ^{3}_{2}He + \text{energy}$$

$$^{3}_{2}He + ^{1}_{1}H \longrightarrow ^{4}_{2}He + ^{0}_{+1}e + \text{energy}$$

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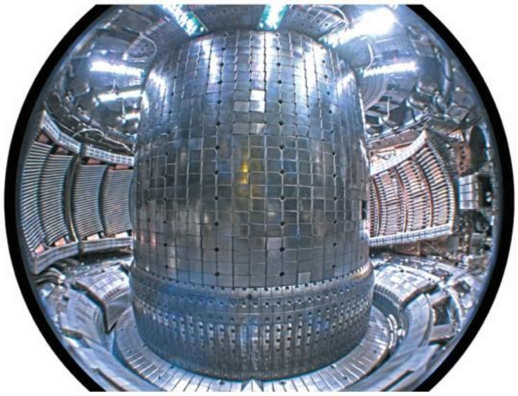
Fusion Reactor

- A fusion reactor is a large "magnetic bottle" that contains the nuclei that have been heated to a temperature of millions of degrees for fusion.



Tokamak (Токамáк)
By Igor Tamm

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Nuclear Fusion
CHECK YOUR NEIGHBOR

When energy is released by the process of fission or fusion, the total mass of the material after the event is

A. less.
B. the same.
C. more.
D. none of the above.

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Chapter Summary

There are three types of radioactivity:

1. ***Alpha particles*** (α) are identical to helium nuclei, containing two protons and two neutrons.
2. ***Beta particles*** (β) are identical to electrons.
3. ***Gamma rays*** (γ) are high-energy photons.

Examples

$$^{222}_{86}Rn \rightarrow {}^{218}_{84}Po + {}^{4}_{2}He$$

$$^{14}_{6}C \rightarrow {}^{14}_{7}N + {}^{0}_{-1}e$$

$$^{222}_{86}Rn^{*} \rightarrow {}^{222}_{86}Rn + {}^{0}_{0}\gamma$$

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Chapter Summary, Continued

- The time required for 50% of the radioactive nuclei in a sample to decay is constant and is called the ***half-life***. After each half-life, only 50% of the radioactive nuclei remain.
- New nuclides are produced by ***transmutation***.
- The splitting of a heavy nucleus into two lighter nuclei is ***nuclear fission***.
- The combining of two lighter nuclei into one nucleus is ***nuclear fusion***.

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