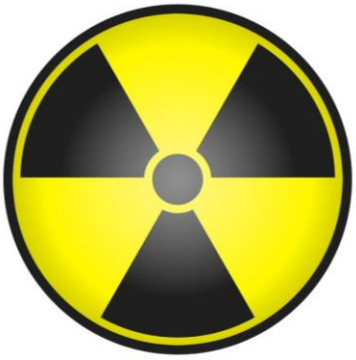
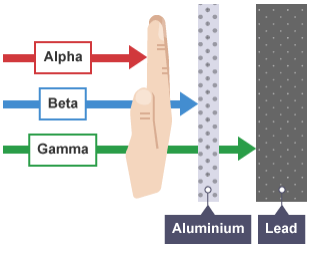


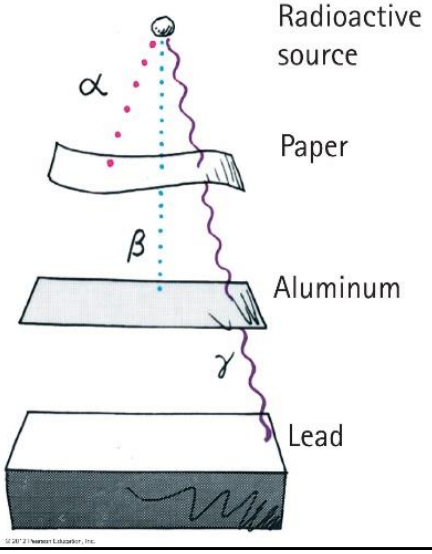
RADIOACTIVITY & HALF-LIFE

Part 3

1

Radioactivity: Alpha, Beta and gamma rays



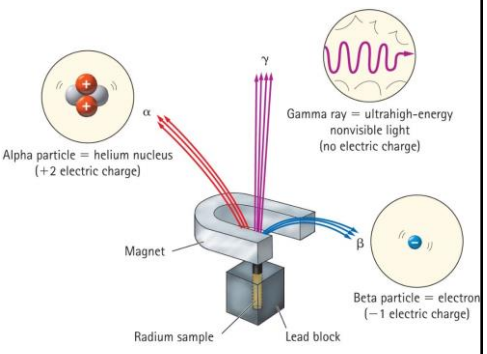


2

Radioactivity

Types of radiation:

- alpha (α)
  carries positive electrical charge
- beta (β)
  carries negative electrical charge
- gamma (γ)
  carries no charge



3

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.

$^{59}_{27}Co + n \rightarrow {}^{60}_{27}Co \rightarrow {}^{60}_{28}Ni + e^{-} + \nu_e$

4

Nuclear Medicine

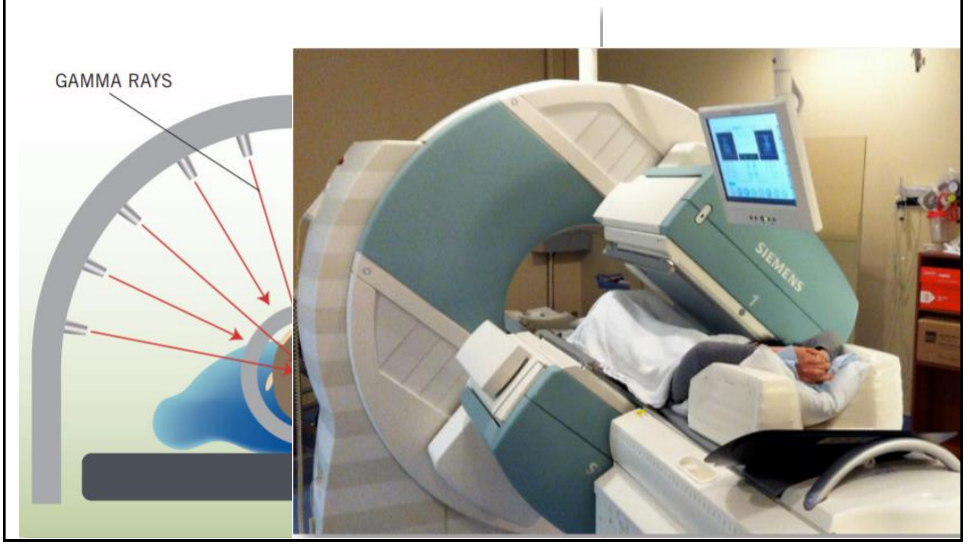
- The term *nuclear medicine* refers to the use of radionuclides for medical purposes.
- Iodine-131 is used to measure thyroid activity.
- The gas xenon-133 is used to diagnose respiratory problems.
  - Iron-59 is used to diagnose anemia.
  - Breast cancer can be treated using the isotope iridium-192.

5

CT- PET

6

Nuclear Medicine



7

Chemistry Link to the Environment: Dating Objects

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

The uptake of carbon-14 in the CO_2 stops when the plant dies.

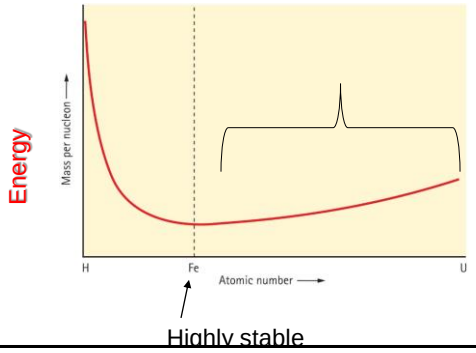
As the carbon-14 decays, the amount of radioactive carbon decreases.

In a process called carbon dating, scientists use the half-life of carbon-14 (5730 yr) to calculate the length of time since the plant died.

8

Transmutation

- Transmutation is the changing of one chemical element into another. This can take place in nature or it can be induce in the laboratory



***Natural transmutation*:**

Artificial Transmutation:

9

Transmutation

***Natural transmutation*:**

Alpha emission from a nucleus:

- *mass number decreases by 4*
- *atomic number decreases by 2*
- resulting atom belongs to an element two places back in periodic table

Naturally

$$^{238}_{92}U \rightarrow {}^{234}_{90}Th + {}^{4}_{2}He$$

10

Alpha Particle Emission

- Radium-226 decays by alpha emission. Identify *X*

$$^{226}_{88}\text{Ra} \longrightarrow {}^{A}_{Z}X + {}^{4}_{2}\text{He}$$

1. First, balance the number of protons:

$$88 = Z + 2, \text{ so } Z = 86 \text{ (Rn)}$$

2. Balance the number of protons plus neutrons:

$$226 = A + 4, \text{ so } A = 222$$

$$^{226}_{88}\text{Ra} \longrightarrow {}^{222}_{86}\text{Rn} + {}^{4}_{2}\text{He}$$

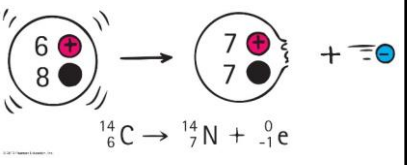
11

Transmutation

Natural transmutation:

Beta emission from a nucleus:

- no change in mass number—no loss in nucleons
- *atomic number increases by 1*
- resulting atom belongs to an element one place forward in periodic table



Gamma emission from a nucleus:

- no change in mass number
- no change in atomic number

12

Natural transmutation: Beta Particle Emission

- Some radioactive nuclides decay by beta emission.
- Radium-228 loses a beta particle to yield actinium-228.

$$^{228}_{88}\text{Ra} \longrightarrow {}^{228}_{89}\text{Ac} + {}^{0}_{-1}\text{e}$$

13

Natural transmutation: Gamma Ray Emission

- For example, uranium-233 decays by releasing both alpha particles and gamma rays.

$$^{233}_{92}\text{U} \longrightarrow {}^{229}_{90}\text{Th} + {}^{4}_{2}\text{He} + {}^{0}_{0}\gamma$$

- Note that a gamma ray has a mass and a charge of zero, so it has no net effect on the nuclear reaction.

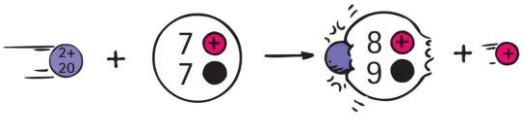
14

Transmutation

Artificial Transmutation:

Ernest Rutherford's cloud-chamber experiment in 1919 succeeded in transmuting a chemical element. After bombardment of nitrogen gas with alpha particles from a radioactive piece of ore, he found traces of oxygen and hydrogen.

Since then, synthetic elements have been produced from atomic numbers 93 to 115, all with short half-lives.



$^{4}_{2}He + {}^{14}_{7}N \rightarrow {}^{17}_{8}O + {}^{1}_{1}H$

15

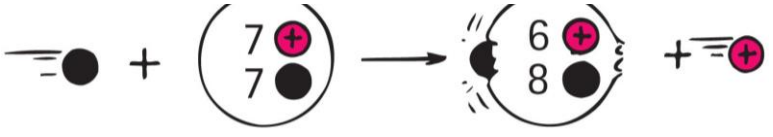
Transmutation

Artificial Transmutation of elements:

the changing of one chemical element to another occurring in artificially in labs

—artificial transmutation

artificially



$^{1}_{0}n + {}^{14}_{7}N \rightarrow {}^{14}_{6}C + {}^{1}_{1}H$

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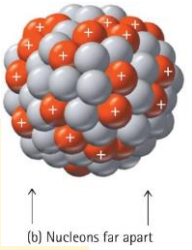
Natural transmutation

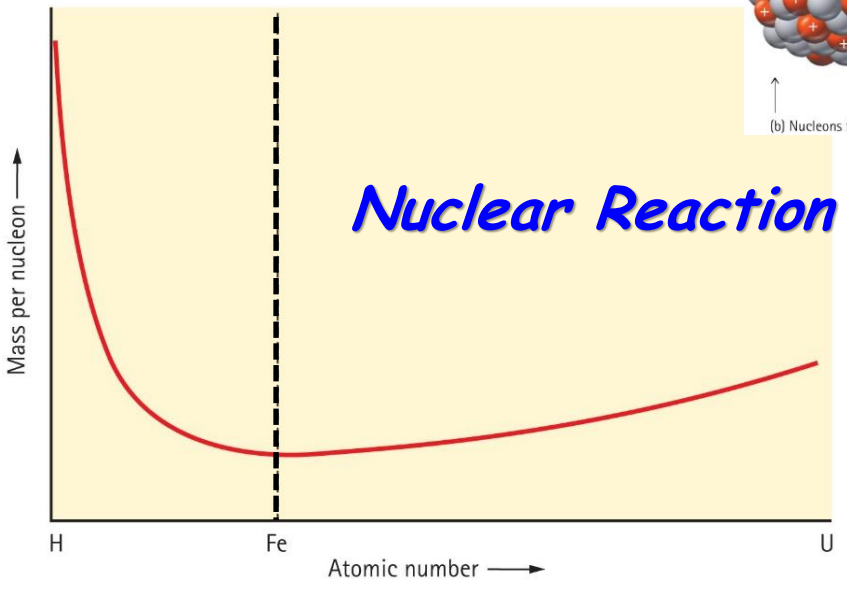
In class question

What does the radioactive decay of uranium to lead have to do with the gas in the child's balloon?

17

Nuclear Fission





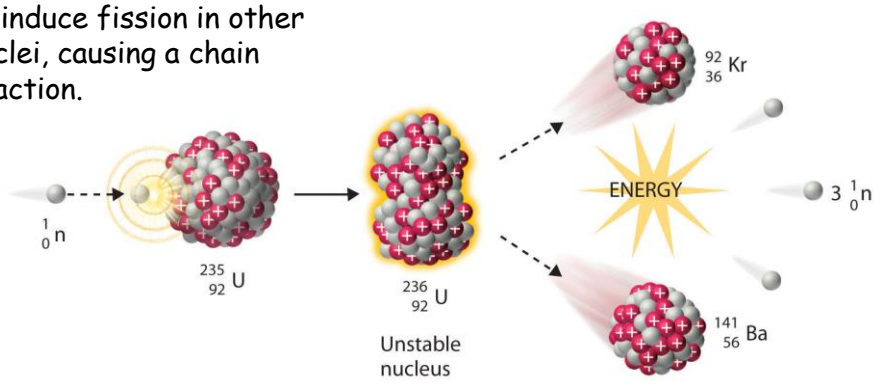
Nuclear Reaction

18

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.



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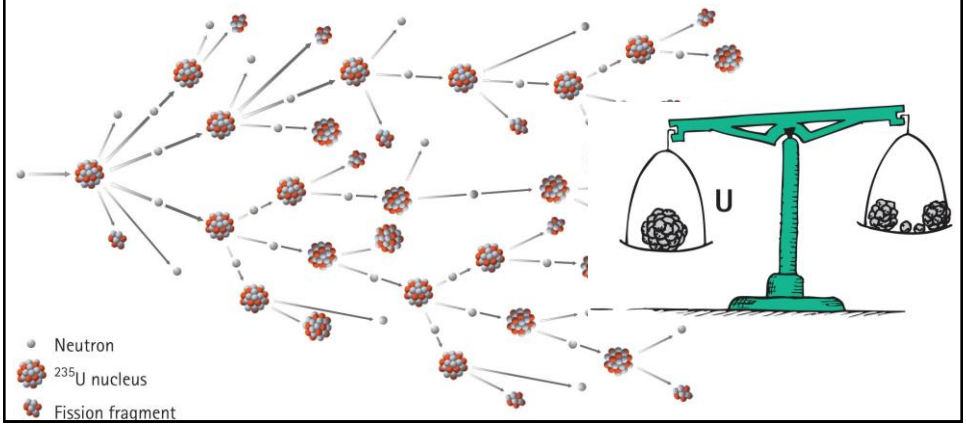
Nuclear Fission

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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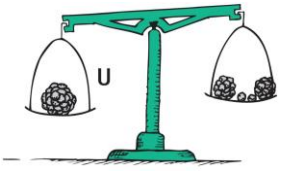
Mass–Energy Equivalence: $E = mc^2$



Relationship of equation terms:

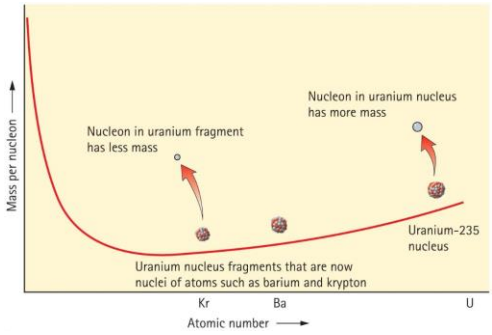
- When nucleons lose mass in a nuclear reaction, the loss of mass, Δm, multiplied by the square of the speed of light is equal to the energy release : $E = \Delta mc^2$.
- Mass difference is related to the binding energy of the nucleus—how much is required to dissemble the nucleus.

22

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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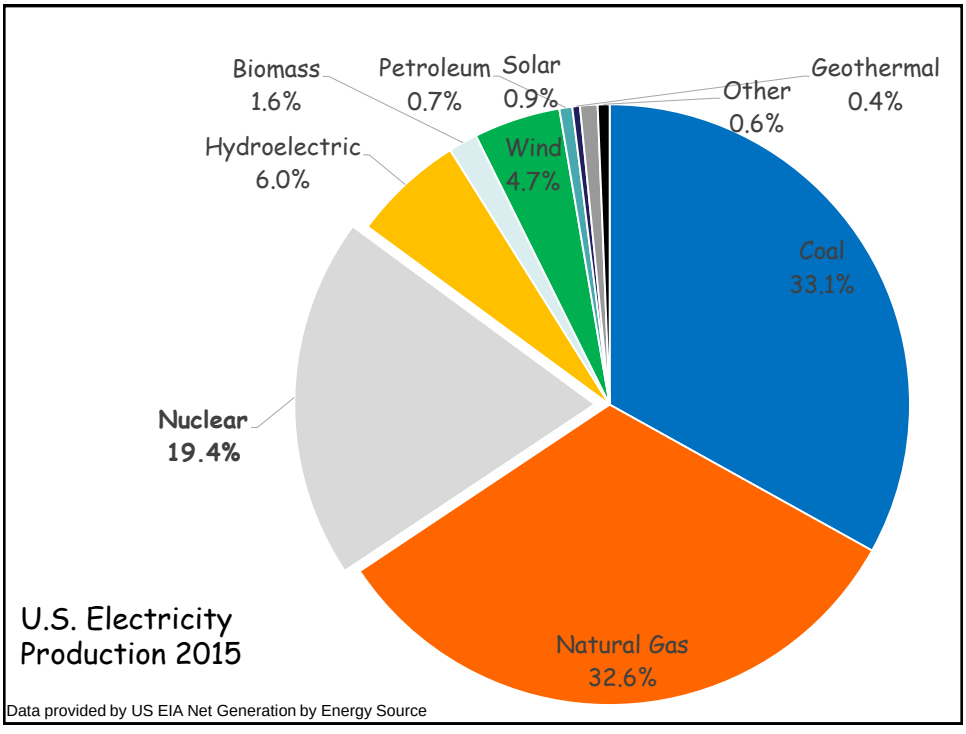

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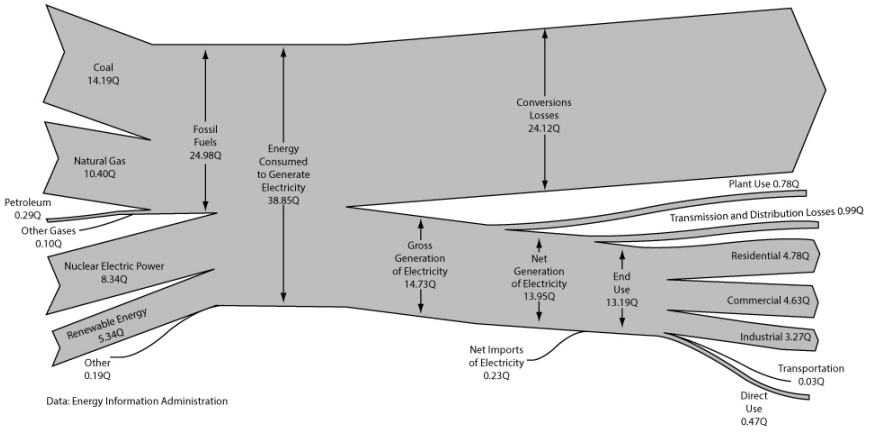
U.S. Electricity Flow 2015

Quadrillion Btu



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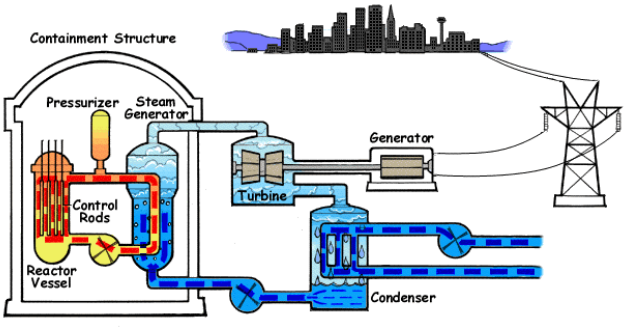
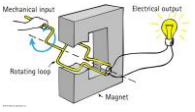
Nuclear Fission; Nuclear Power Plant

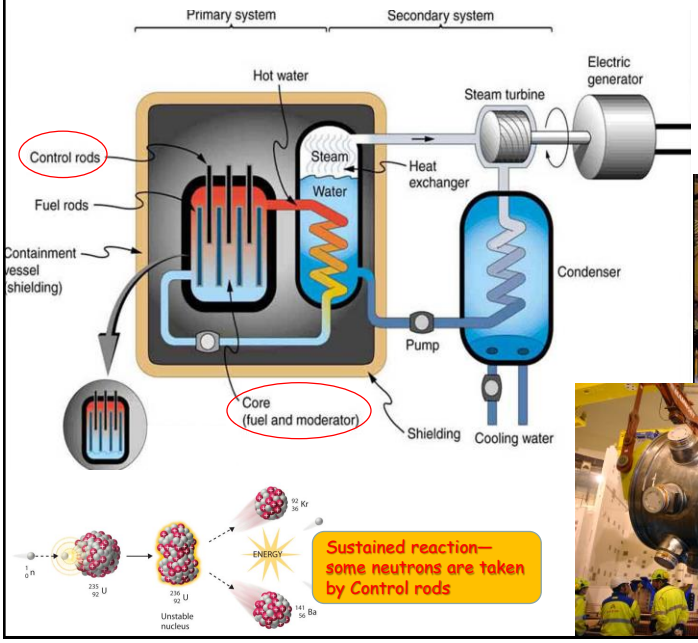


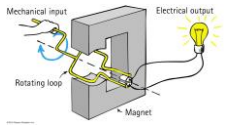


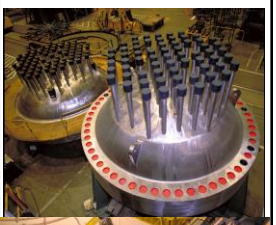
Rancho Seco
Nuclear Generating Station
SMUD

27

Nuclear Reactor







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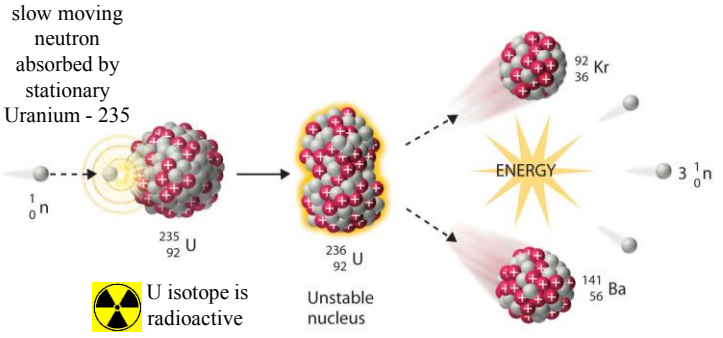
Fission of Uranium – 235

slow moving neutron absorbed by stationary Uranium - 235



U isotope is radioactive

- 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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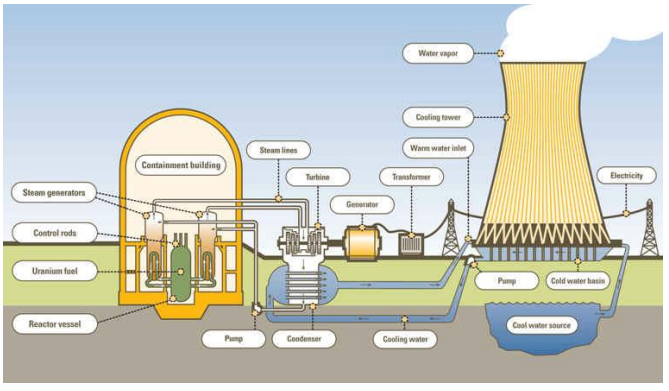
Nuclear Power Plants

- 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

30

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

31

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**

32

Fukushima Power Plant Before March 11, 2011

33

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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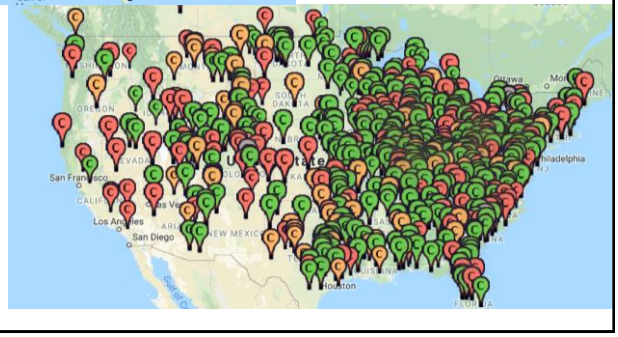
Nuclear Plants vs Coal Plants

Nuclear PP



Coal PP

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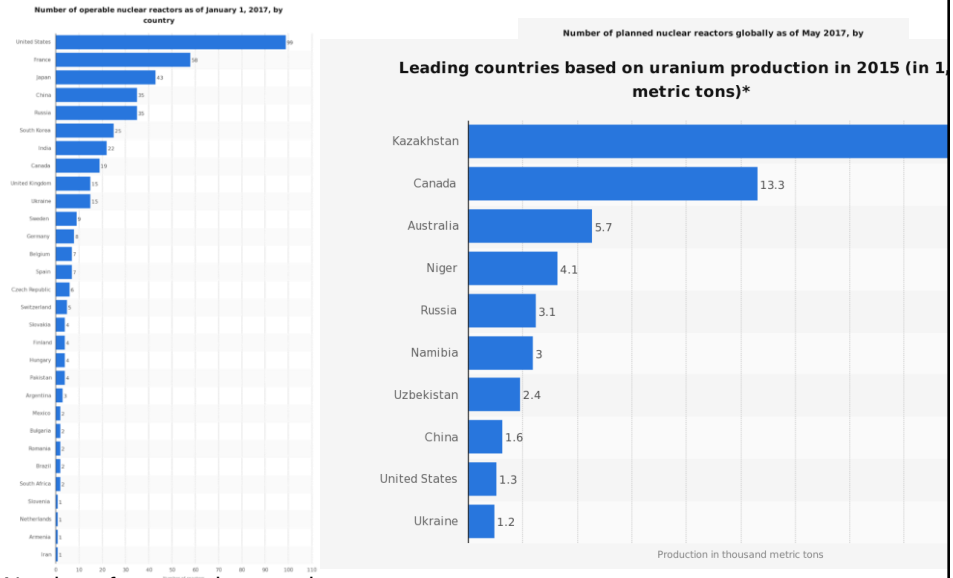
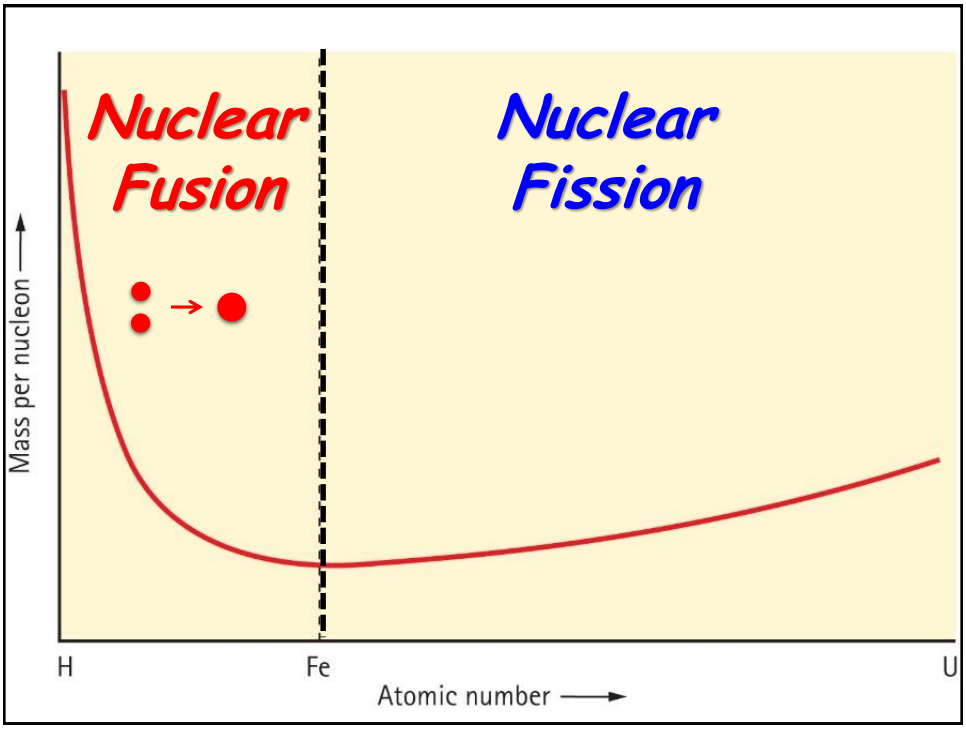
Nuclear Fission; Nuclear Reactors



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

36



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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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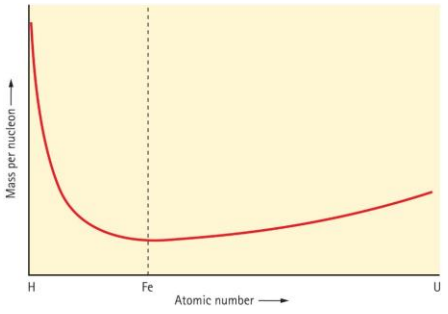
Mass–Energy Equivalence: $E = mc^2$

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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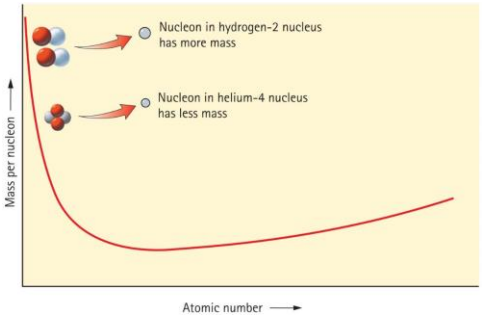
Nuclear Fusion

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.



40

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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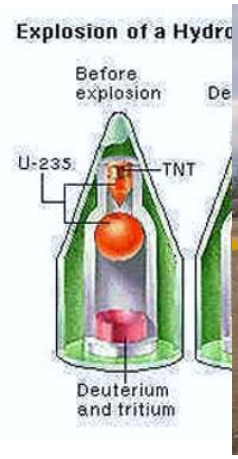
Nuclear Fusion

Thermonuclear weapon: Fission + Fusion



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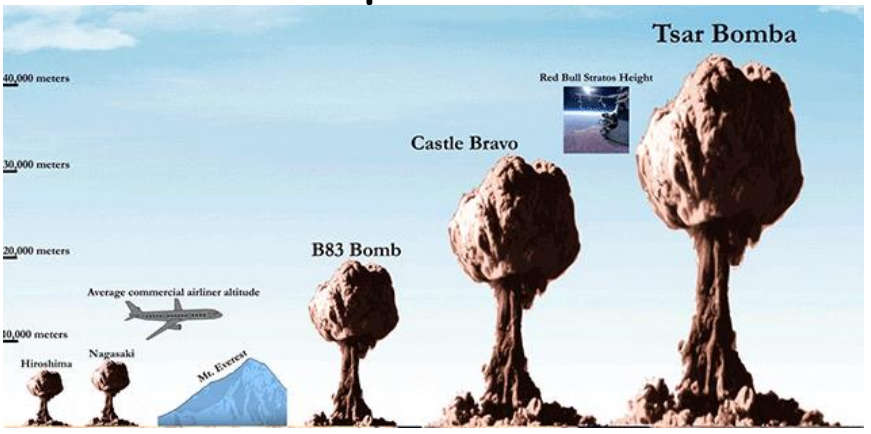
Nuclear Fusion

Thermonuclear weapon:



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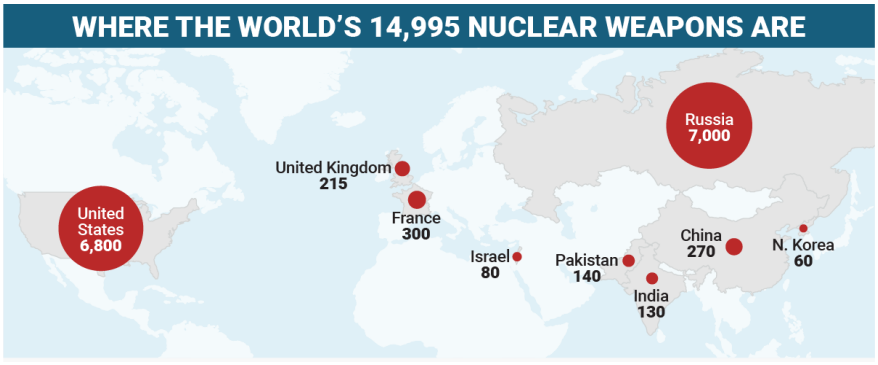
Nuclear Fusion

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:

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

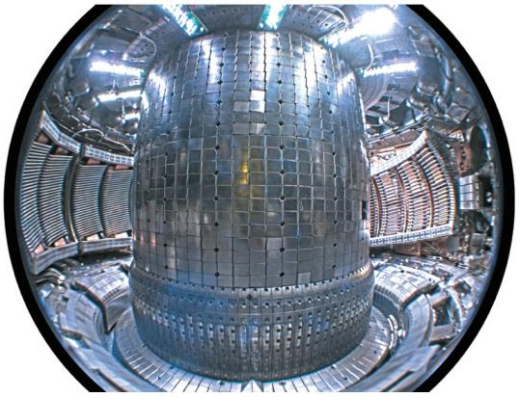
$$ {}_{1}^{2}\mathrm{H} + {}_{1}^{1}\mathrm{H} \longrightarrow {}_{2}^{3}\mathrm{He} + \text{energy} $$

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

46

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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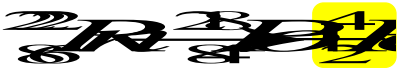
Chapter Summary

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



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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.
- Artificial 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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