Nuclear Energy

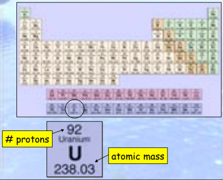
Nuclear energy - energy from the atomic nucleus. Nuclear <u>fission</u> (*i.e.* splitting of nuclei) and nuclear <u>fusion</u> (*i.e.* combining of nuclei) release enormous amounts of energy.

Nucleus - composed of: protons (+1 charge) and neutrons (0 charge)

Number of protons determines the IDENTITY of a nucleus.

Number of neutrons determines the TYPE of nucleus.

Nuclear Energy



Nuclear Energy

The atomic mass of an element is a weighted average of the masses (or mass numbers) of several types of the same element

92
Uranium
U
238.03

For example: uranium occurs naturally as a mixture of four types: uranium-234 (0.005%), uranium-235 (0.7%), uranium-238 (99.3%) and uranium-239 (0.02%)

We call these "types" - ISOTOPES. An isotope is characterized by the number of neutrons present in the nucleus; number of protons is always unchanged.

mass # = p + n

$^{235}_{92}U$

protons

Nuclear Energy

Some isotopes undergo spontaneous fission (*i.e. radioactive decay*)

They decay (or break apart) into smaller (*i.e.* lighter) nuclei plus other particles and/or radiation. While doing so, they converted to a different substance...

α	β	γ	n
low energy helium nucleus	high energy electron	high energy radiation	variable energy
$^4_2He^{+2}$	$^0_{-1}e$		^1_0n
short dist. in H_2O	medium dist. in H_2O	large dist. in H_2O	large dist. in H_2O
≤ 0.1 cm	0.1 - 1 cm	100 m	100 m

Nuclear Energy

Different *radioisotopes* decay at different rates and emit characteristic particles. When they decay, protons and neutrons stay the same on both sides of the equation...

Alpha decay: Plutonium-239 emits an alpha particle when it decays. How many neutrons and protons are there in the new particle that is formed?

$$^{239}_{94}Pu \longrightarrow {}^{A}_{p}? + {}^{4}_{2}He^{+2}$$

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Beta decay: Strontium-90 emits a beta particle when it decays. How many neutrons and protons are there in the new particle that is formed?

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$$^{90}_{38}Sr \longrightarrow {}^{90}_{39}Y + {}^{0}_{-1}e$$

Nuclear Energy

The rate at which a *radioisotope* decays is described by its characteristic *half-life*, which we represent by $t_{1/2}$.

isotope	$t_{1/2}$
uranium-238	4.5 B yr
uranium-235	700 M yr
carbon-14	5570 yr
radon-222	3.8 day
polonium-218	3 min

elapsed half-life	fraction left	% left
0	-	100
1	1/2	50
2	1/4	25
3	1/8	13
4	1/16	6
5	1/32	3
6	1/64	1.5
7	1/128	0.8
8	1/256	0.4
9	1/512	0.2
10	1/1024	0.1

Nuclear Energy

The rate at which a *radioisotope* decays is described by its characteristic *half-life*, which we represent by $t_{1/2}$.

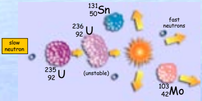
When Plutonium-239 emits an alpha particle and decays to Uranium-235, it does so at a very slow rate; its $t_{1/2} \approx$ 24,000 years. (a) If we start with 1000 g of Pu, how long will it take until 250 g remains? (b) How many years must elapse until our sample of plutonium is considered safe?

(a) 1000 * (1/2) = 500; 500 * (1/2) = 250; therefore it takes 2 half-lives or 2 * 24,000 yr = 48,000 years

(b) The sample will be safe after 10 half-lives; therefore 10 * 24,000 = 240,000 years

Nuclear Energy

Up to this point, we've been discussing spontaneous fission, *i.e.* it happens without any help from us. In nuclear reactors and in bombs, we *intentionally* cause fission…



The newly created nuclei (*i.e.* daughter-products) are also radioactive and are therefore considered to be hazardous waste

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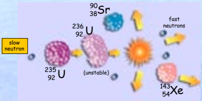

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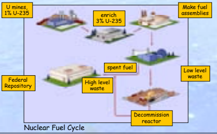
Nuclear Energy

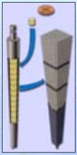
In the U.S. the 109 active nuclear reactors as of 2001, produced 770 billion kwh of electricity. All 109 reactors use uranium-235 as a fuel.



Nuclear Fuel Cycle

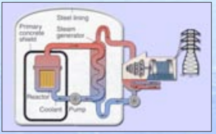
Nuclear Energy

Fuel assemblies



Nuclear Energy

A generalized schematic of a nuclear reactor is shown below.



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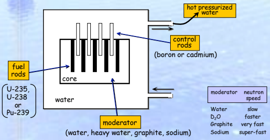

Nuclear Energy

There are a number of different types of nuclear reactors in use (≈ 440 worldwide)...

- Boiling water reactor - BWR - 37 in U.S.
- Pressurized water reactor - PWR - 72 in U.S.
- CANDU reactor - Canada & 8 other countries
- High-temperature gas-cooled reactor (*e.g.* carbon dioxide) - HTGR - used in Europe
- Graphite-water reactor - RBMK - former USSR
- Breeder reactor - France

Nuclear Energy

Where does the energy come from? Let's look at a typical nuclear reaction shown here:

$$^{235}_{92}U + ^{1}_{0}n \longrightarrow ^{90}_{38}Sr + ^{143}_{54}Xe + 3\ ^{1}_{0}n$$

According to the law of conservation of mass, mass is neither created or destroyed in any reaction; but in a nuclear reaction it can be *interchanged*. If we add up all the masses of all the pieces parts for both sides of the reaction, it seems that we have "lost" some mass, the "mass defect". A tiny bit of mass has been converted to a huge amount of energy!

$$E = mc^2$$

If we did the math, we'd find that 1 pellet of Uranium-235 has the energy of about 1 ton of coal. And this is why nuclear energy is attractive.

Nuclear Waste

Spent high-level fuel (≈ 15,000 tons in U.S.) is stored on site in deep pools of water.

Additionally:

100,000 tons low-level waste

200,000,000 tons of mining & processing wastes

Production of 1000 tons of Uranium fuel generates 100,000 tons of tailings and 3.5 M liters of liquid waste