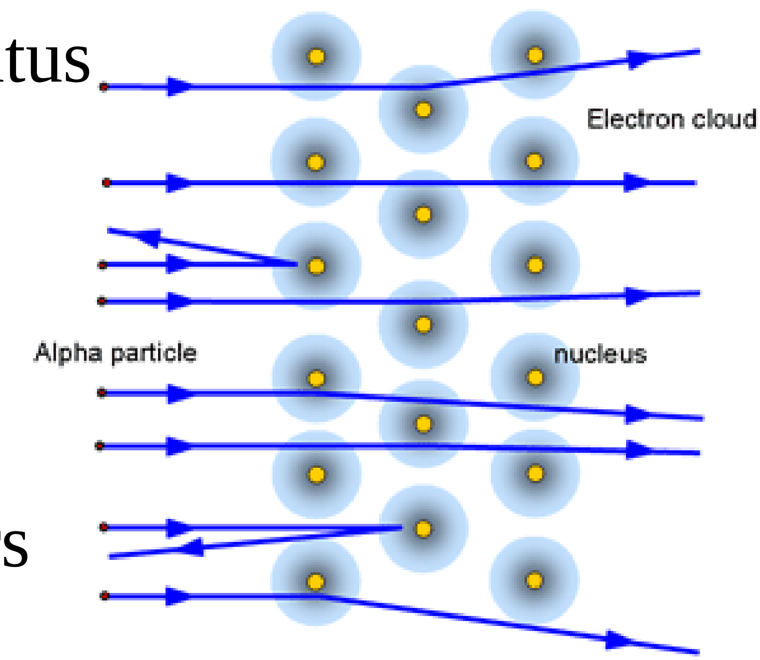
Today

- Announcements:
  - HW#9 is due April 2 at 8:00 am
  - Voting for the Spring Break Story contest is due April 2 at 8:00 am
  - HW#10 will be due April 9 at 8:00 am
- Atoms and Nuclei

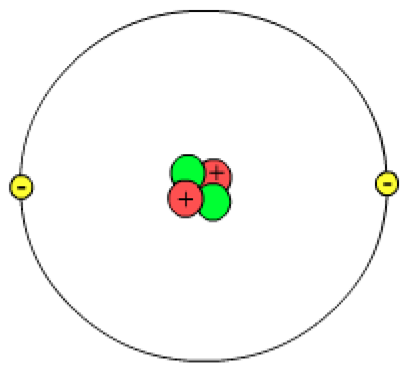
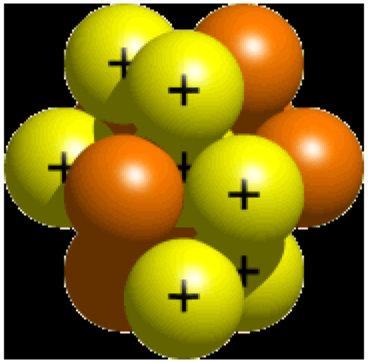
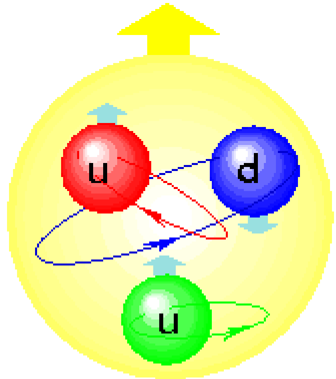
MICHIGAN STATE UNIVERSITY

History

- ca. Fourth century B.C.: Democritus proposes that matter is made of indivisible units called *atoma*.
- 1896: Henri Becquerel discovers radioactivity by chance.
- 1911: Ernest Rutherford discovers the nucleus. He found something hard and small at the center of atoms

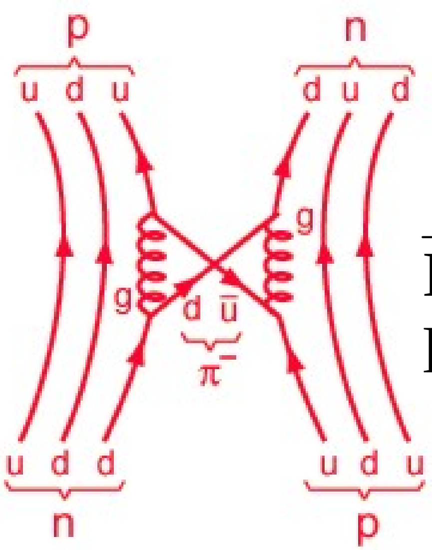


From Large to Small

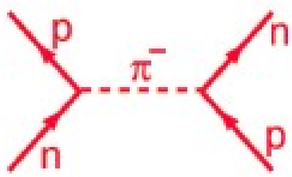
Atoms	Atomic Nucleus	A Proton
		
Made of nuclei and electrons. Size: 10^{-9} m	Made of neutrons and protons. Size: 10^{-14} m	Made of quarks. Size: 10^{-15} m A neutron has ddu quarks.

The Strong force at work

Strong force actually is mostly the result of exchange of pairs of quarks.



Looks like



The probability of an interaction decreases exponentially with the mass of the exchanges particle.

$$\Delta E \Delta t = mc^2 \Delta t \geq \frac{h}{4\pi} \rightarrow range = c\Delta t = \frac{h}{4\pi cm}$$

The Nucleus

- The nucleus contains more than 99.95% of an atom's mass, but only 1E-15 of its volume!
- The *nucleons* are held together by the *strong force*, even though the protons repel each other very strongly.

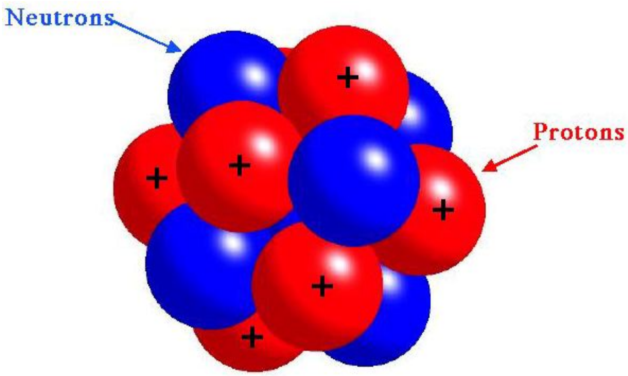
Mass Number → $^{272}_{111}\mathrm{Rg}_{161}$

Atomic Number (or Proton Number)

Element

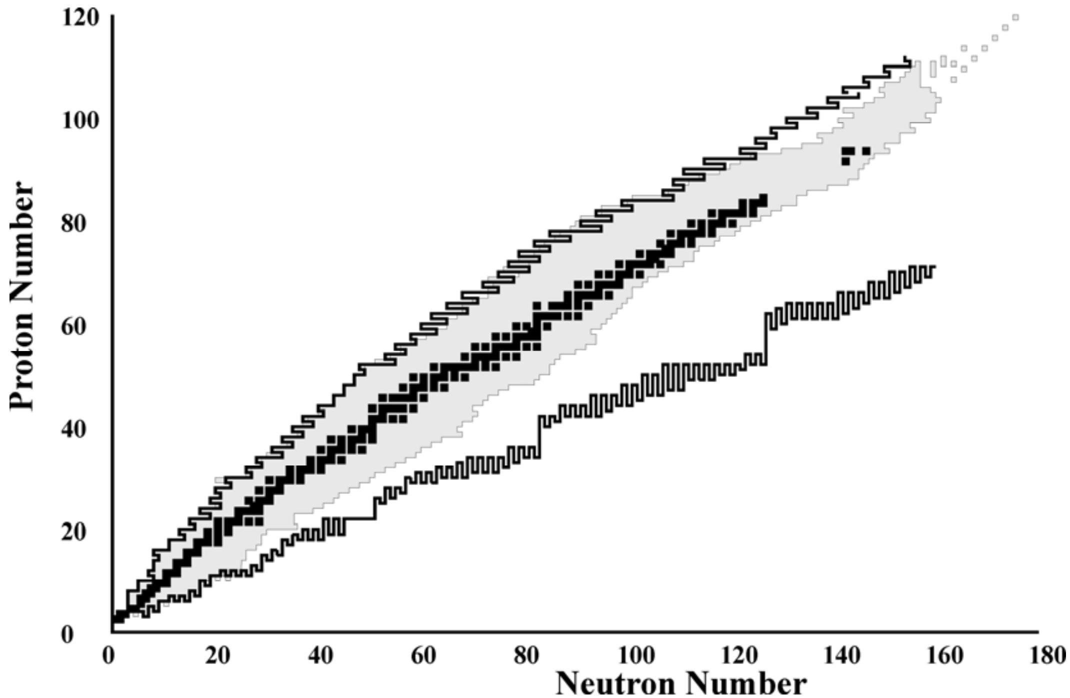
Neutron Number

Atomic Nuclei and Elements



The number of protons determine the element (oxygen). The number of neutrons+protons determines the atomic mass (16 as shown). This nucleus is ^{16}O.

The Chart of the Nuclides: A Map of All Known and Possible Nuclei



Radioactivity

- A radioactive nucleus is unstable:
  - Alpha Decay

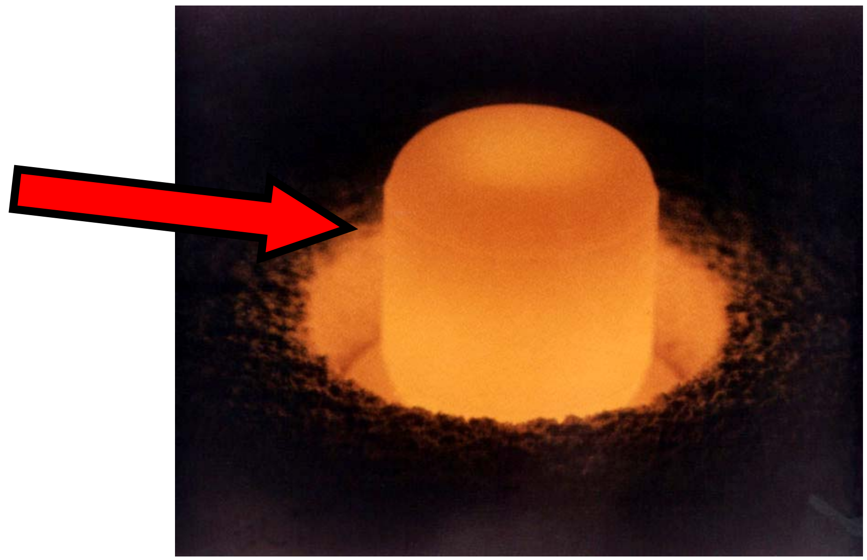
    $^{238}\text{Pu} \rightarrow {}^{234}\text{U} + {}^{4}\text{He}$
  - Beta Decay

    $^{131}\text{I} \rightarrow {}^{131}\text{Xe} + e^{-} + \bar{\nu}$
  - Gamma Decay

    $^{152}\text{Dy}^{*} \rightarrow {}^{152}\text{Dy} + \gamma$
  - Fission

    $^{248}\text{Cm} \rightarrow {}^{144}\text{Ce} + {}^{102}\text{Sr} + 2\,{}^{1}\text{n}$ (spontaneous)

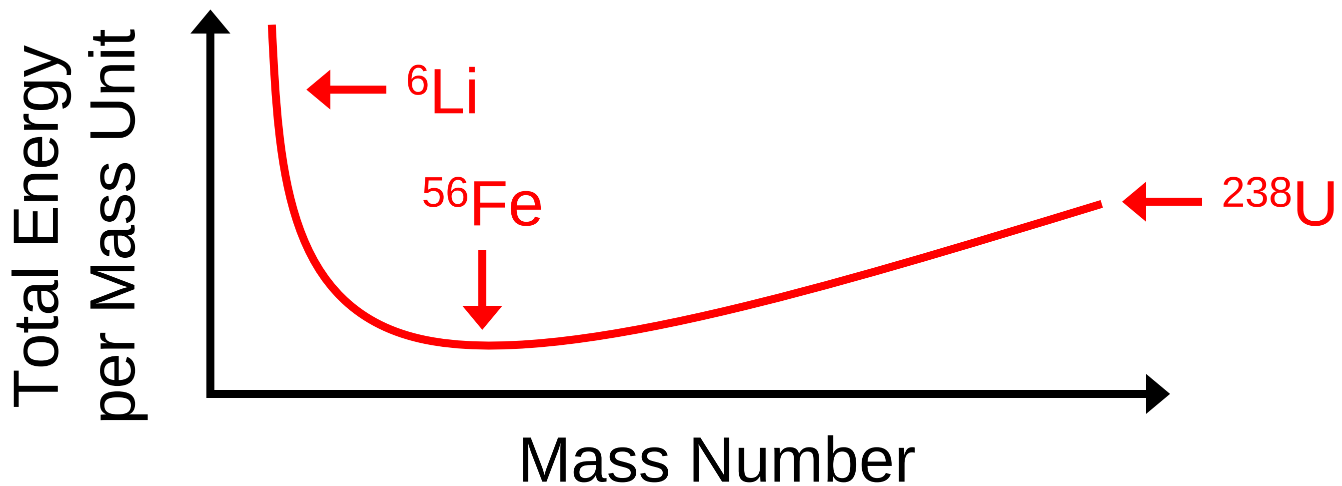
    $^{1}\text{n} + {}^{235}\text{U} \rightarrow {}^{141}\text{Ba} + {}^{92}\text{Kr} + 3\,{}^{1}\text{n}$ (induced)



^{238}Pu heated by its own radioactivity.

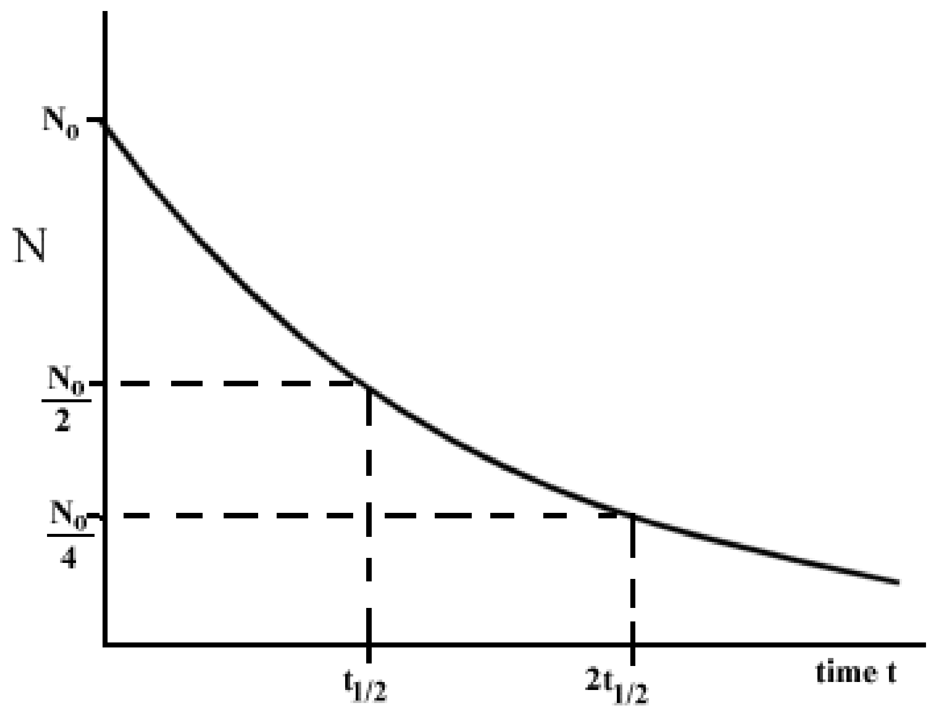
Why are some nuclei unstable?

- Two fundamental tendencies in nature:
  - Move toward higher entropy
  - Move toward lower potential energy
- For most nuclear processes the change in entropy is ~0. Therefore, energy dominates.



Half-Life

Radioactive decay is governed by the rules of quantum mechanics. If we start with N_0 atoms, after one **half-life** then half will have decayed (on average). In the next half-life, half of those remaining will have decayed, and so on.



Law of Radioactive Decay

- Nuclei decay according to the Law of Radioactive decay:

$$N = N_0 e^{-\lambda t}$$

Amount Now → N

Original Amount → N_0

A Constant → λ

Time → t

- A more useful form is this:

$$\text{Observed Ratio} = \frac{N}{N_0} = \left(\frac{1}{2}\right)^{(t/t_{1/2})}$$

$t_{1/2}$ is the Half-Life

Sample Problem

Suppose we find a sample of material that has 43.5% of the expected original amount. The half-life of the material is 23.0 days. What is the best estimate for the age of the sample?

$$\frac{N}{N_0} = \left(\frac{1}{2}\right)^{(t/t_{1/2})} \Rightarrow \frac{N}{N_0} = 0.435 = \left(\frac{1}{2}\right)^{(t/23.0\ \mathrm{d})}$$

$$\ln 0.435 = \ln\left[(1/2)^{\left(\frac{t}{23.0\ \mathrm{d}}\right)}\right] = \left(\frac{t}{23.0\ d}\right)\ln(1/2)$$

$$\Rightarrow t = \frac{(23.0\ \mathrm{d})(\ln 0.435)}{\ln(1/2)} = 27.6\ \mathrm{d}$$

Radioisotope Dating

- ^{14}C is an isotope of carbon that is produced continually by the interaction of cosmic rays with ^{14}N in the atmosphere:

$$^{1}n + {}^{14}N \rightarrow {}^{14}C + {}^{1}H$$

- An organism establishes an "equilibrium" with ^{14}C by breathing in $^{14}CO_2$.
- After death, no new ^{14}C is absorbed, so it decays away with a half-life of 5730 years.

Examples of Radioactive Dating

- ^{14}C (half-life = 5730 y) is used to date archeological objects. Normal living material has a certain amount of ^{14}C, which is produced in the atmosphere.
- ^{40}K (half-life = 1.25 Gy) is used to date rocks. It decays 10% of the time to ^{40}Ar which is not naturally found in most rocks.
- ^{238}U (half-life = 4.5 Gy) is used to date the Earth, the Sun, and other stars. This is one of the ways we estimate that the Earth is 4.5 Gy old.

Average Dose per Year

We are constantly exposed to small amounts of radiation. As long as the damage is not too great our natural repair mechanisms fix the damage:

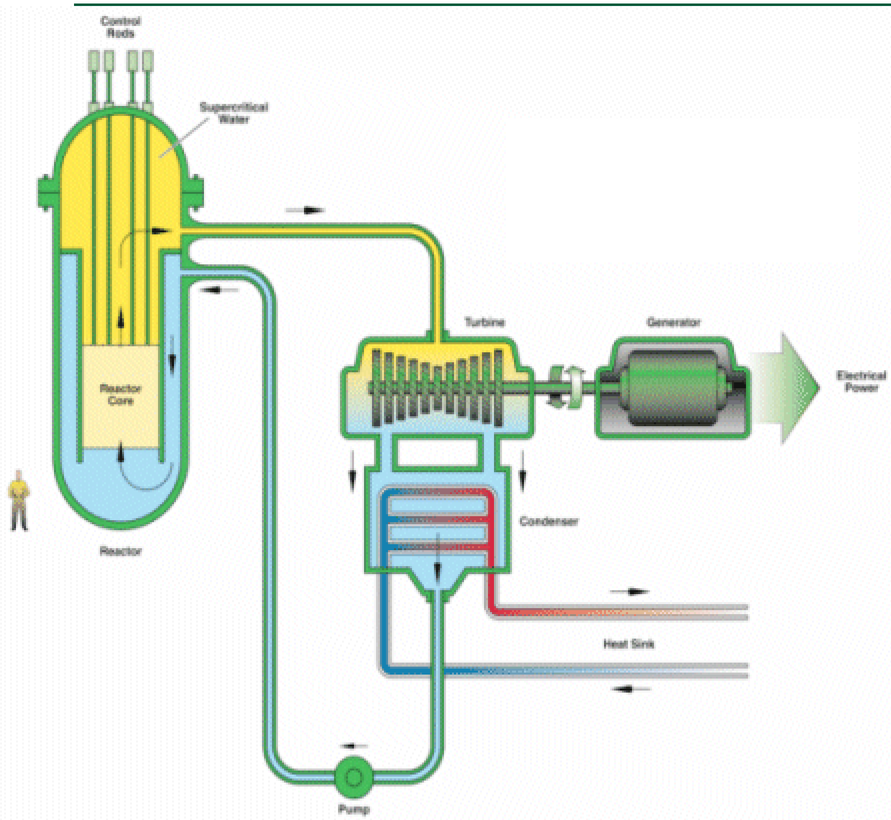
Source	Dose (mrem/year)
Radon	200
Medical/Dental X-Rays	40
Internal Sources	40
Other Natural Sources	60
Consumer Products	~11

Average Dose per Year (continued)

Source	Dose (mrem/year)
Nuclear Medicine	~15
Fallout from weapons testing	~2
Nuclear Power	~0.4
Coal Power	~1.2
Total (U.S. Average)	~360

Smoking one pack per day	+1200
Smoking two packs per day	+2400

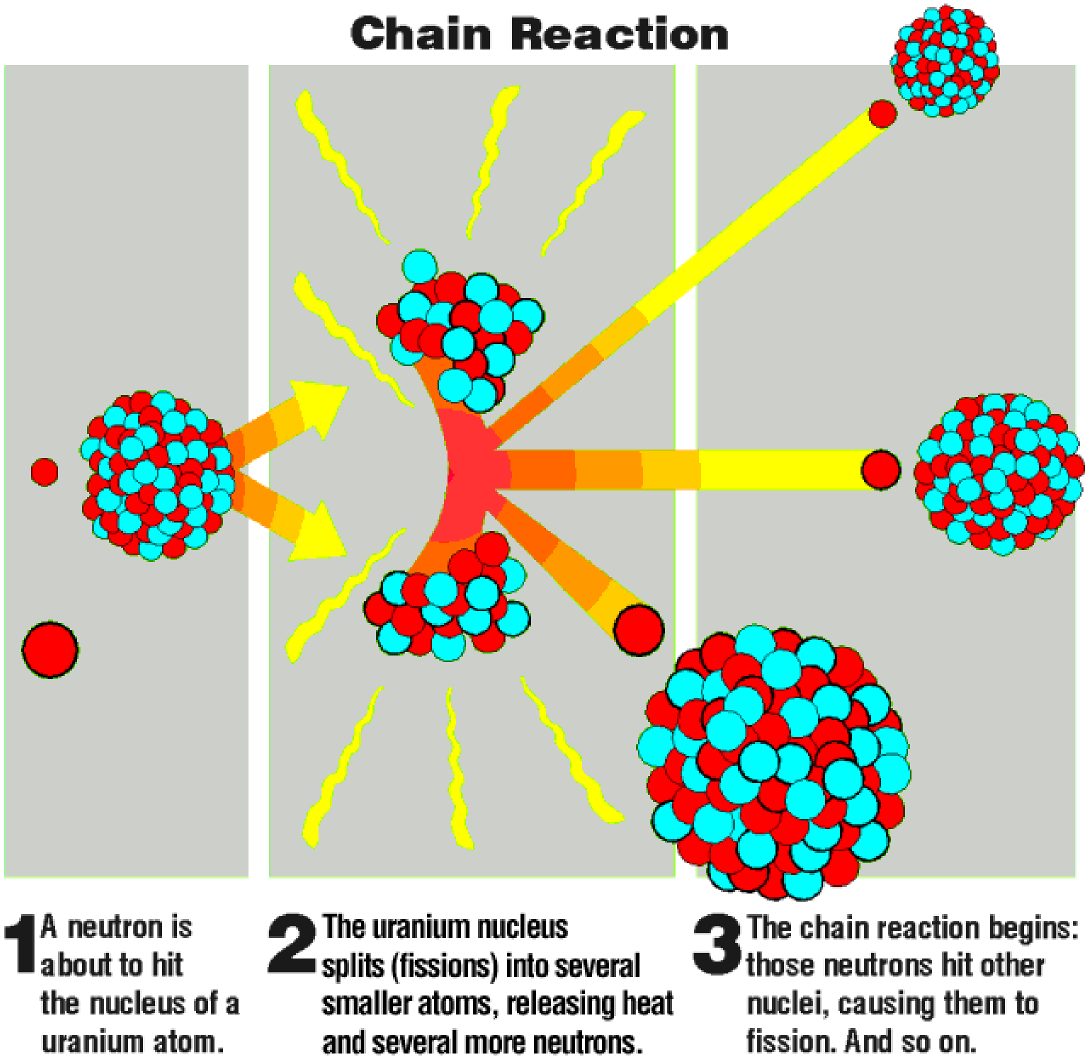
Nuclear Power



- A nuclear reactor is a fancy way of generating heat to produce steam. The rest works like a traditional power plant.
- All nuclear plants produce *fissile* material as part of their operation. This had led to concerns about *proliferation* of this material, which could be used for a dirty bomb or possibly to make a nuclear weapon.

- Nuclear plants produce radioactive wastes which must be stored safely, possibly for tens of thousands of years.
- Nuclear plants do not produce greenhouse gases.

Chain Reaction

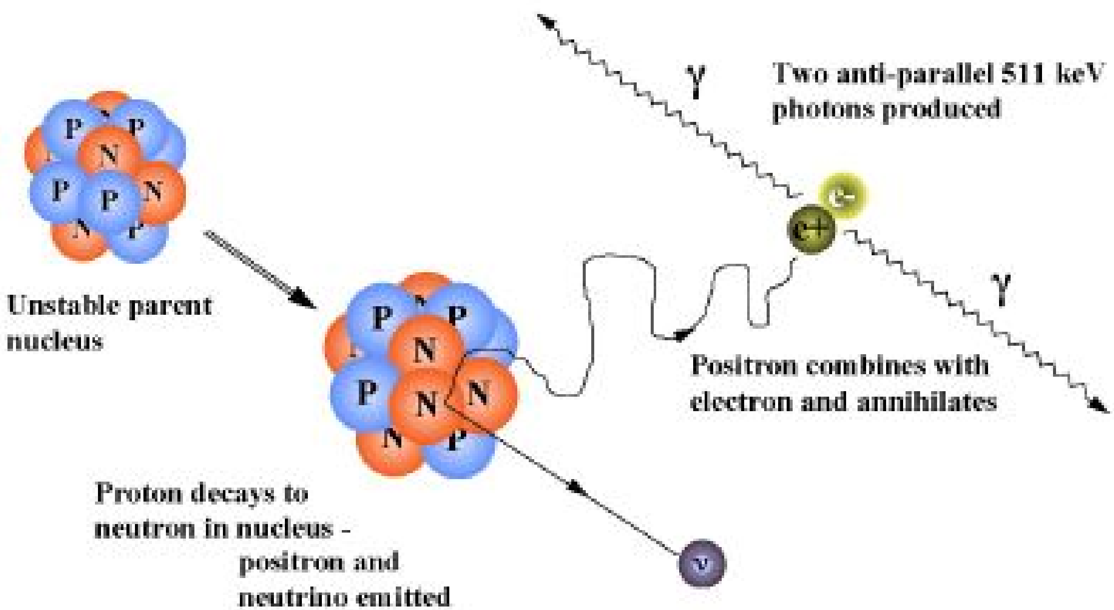


- This process repeats continuously.
- Nuclear Reactor: Stays at "criticality."
- Nuclear Weapon: Reaction goes "supercritical."

RISK – Average Loss of Life Expectancy (days)

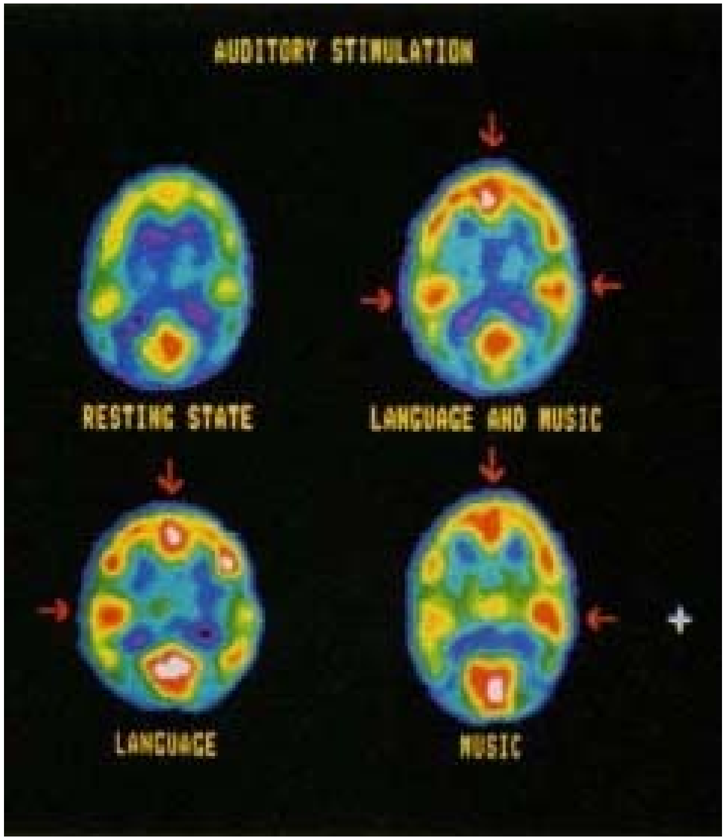
Being male 2800
Being unmarried 2000
Smoking cigarettes (1 pack/day) 1600
Coal Mining 1100
Cancer 980
30 lb overweight 900; 15 lb overweight 450
Driving a car (risk of accidents) 200
Alcohol 130
Homicide 90
Drowning 40
Diet drinks, one per day for life 2
Power generated by all nuclear 1.5 (Union Concerned Scientists)
Hurricanes and tornadoes 1
Airline crashes 1

How Positron Emission Tomography Works



PET Scanner

Nuclear Medicine



Example of use
Roger Ressmeyer/Corbis

- *Radiolabelled* compounds can be injected into the body for diagnostic purposes.
- Similarly, compounds can be attached to tumors to kill them (but leaves them in place).
- X-rays, CT scans, PET scans.