Nuclear Chemistry

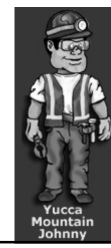
- Think of the forces that you know about already in chemistry …
- We all know about gravity and of course electrical forces can hold one atom to another
- Think about the nucleus of an atom. What is it made of? Protons and neutrons.
- How can the protons stay clumped together if they all have a + charge?
- The answer lies in the strong nuclear force. It is stronger than gravity or electrical force.
- When you split apart the nucleus you release this powerful force
- The energy required to separate nucleons (protons and neutrons) is called the binding energy

Nuclear Chemistry

- Some atoms are not stable, that is, they can spontaneously decay. We call these atoms radioactive.
- Most elements in their common form are not radioactive, however many isotopes exist of common elements that are radioactive. Even common elements like potassium and iron have radioactive isotopes. There are about 1500 different isotopes of all elements, of which only 250 are NOT radioactive.
- Polonium and higher are all radioactive
- A Geiger counter detects alpha, beta, gamma, and x-rays

Half Life

- Radioactive decay rates are constant.
- The way we look at the decay rates is in terms of half life -- the time it takes for half of a sample to decay
- See your textbook for some half-lives
- We'll talk more about radiocarbon dating later and do a lab on half lives



Atomic Structure Review

- Atomic number is the lower left-hand number
- Mass number is the upper left-hand number
- Example: Carbon-14 has 6 protons and 8 neutrons: $^{14}_{6}\mathrm{C}$
- Electron Proton Neutron

$$^{0}_{-1}\mathrm{e} \qquad ^{1}_{1}\mathrm{p} \qquad ^{1}_{0}\mathrm{n}$$

Nuclear Particles and Reactions

Alpha particle (α) emission: an alpha particle is really a helium nucleus. Because of its size it does not travel fast or far.

$$^{241}_{95}\text{Am} \rightarrow ^{237}_{93}\text{Np} + ^{4}_{2}\text{He}^{+2}$$

^{241}Am is used in smoke detectors -- it ionizes the air and a sensor can tell when smoke interrupts the flow. The alpha particles can't get out of the plastic smoke detector case.

Nuclear Particles and Reactions

Beta (β) particle emission: a beta particle is a high energy electron. 100 times more penetrating ability than alpha particles. Can be stopped by several layers of aluminum foil. (You can also use the β symbol instead of the electron)

$$^{131}_{53}\text{I} \rightarrow ^{131}_{54}\text{Xe} + ^{0}_{-1}\text{e}^{-}$$

(note that a neutron becomes a proton in the process)

Nuclear Particles and Reactions

Gamma (γ) rays: high energy electromagnetic radiation (higher than X rays!). Most dangerous type of radioactive emission. Look at how gamma (γ) rays are produced for the following decay of cobalt-60 which is used in cancer treatment.

$$^{60}_{27}\text{Co} \rightarrow ^{60}_{28}\text{Ni} + ^{0}_{-1}\text{e}^{-} + \gamma$$

(note that gamma rays are accompanied by beta emission)

Nuclear Particles and Reactions

Positron emission: A positron is a particle with the same size and mass as an electron, but with a positive charge.

$$^{207}_{84}\text{Po} \rightarrow ^{0}_{+1}\text{e} + ^{207}_{83}\text{Bi}$$

Nuclear Particles and Reactions

Electron capture: An electron is captured to turn a proton into a neutron

$$^{7}_{4}\mathrm{Be} + {}^{0}_{-1}\mathrm{e} \rightarrow {}^{7}_{3}\mathrm{Li}$$

Animation at http://www2.wwnorton.com/college/chemistry/gilbert/tutorials/ch2.htm

Radioactive Dating

- Radiocarbon dating is useful only for dating formerly living things
- While an organism is alive it takes in carbon -- most of it as carbon-12 but a small % is carbon-14 (a radioactive form of carbon).
- Carbon-14 is formed in the atmosphere by the following process (helped along by cosmic rays)

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

Radioactive Dating

- As soon as the organism dies, it stops taking in carbon. The amount of carbon 12 stays the same over time, but the amount of carbon 14 decreases as it decays.
- Carbon-14 has a half life of 5715 years. It decays by the following process:

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

- Geologists and archeologists can use the ratio of carbon-12 to carbon-14 to determine how old an object is

Half-life Calculations

Radioactive decay rate is proportional to the number of radioactive nuclei (N) in a sample. Thus: Rate = kN (k is called the decay constant)

Using a little calculus, you can turn this into:

$\ln \frac{N}{N_0} = -kt$ OR $\ln N - \ln N_0 = -kt$

Where: N = # left after a time interval and N_0 = # nuclei at time = zero

If you assume ½ sample remains we can rearrange the above equation to:

$k = \frac{0.693}{t_{1/2}}$ OR $t_{1/2} = \frac{0.693}{k}$

FYI: 0.693 = ln 2

Half-life Calculations from Lab Data

A Geiger counter or similar detection device can be used to count radioactive decays. Because the number of decays is proportional to the number of radioactive nuclei, we can say:

$$\ln \frac{R}{R_0} = -kt$$

OR

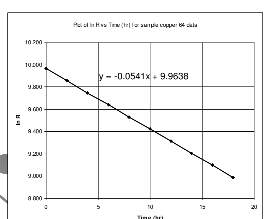
$$\ln R - \ln R_0 = -kt$$

Where: R = # counts after a time interval and R_0 = # counts at time = zero

We also need to subtract out any background radiation from our count totals.

Half-life Calculations from Lab Data

Example: Copper-64 is used in the form of copper acetate to study brain tumors. Given the count/time data below calculate k and the half-life



R	Time (hr)	ln R
21243	0	9.964
19063	2	9.856
17107	4	9.747
15351	6	9.639
13776	8	9.531
12362	10	9.422
11093	12	9.314
9955	14	9.206
8933	16	9.098
8016	18	8.989

The decay constant (k) is the –(slope). So k = 0.0541

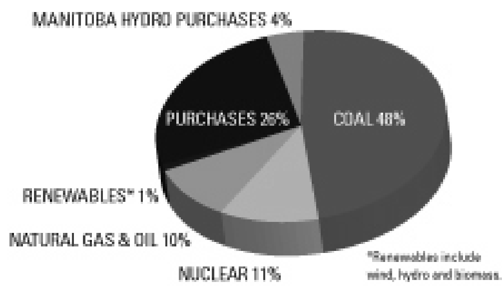
Then use: $t_{1/2} = \frac{0.693}{k}$

$$t_{1/2} = \frac{0.693}{0.0541} = 12.8 hours$$

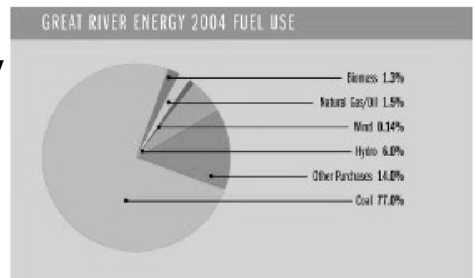
Nuclear Power

- Xcel Energy Fuel Mix Chart

Source: XCel Energy web site (http://www.xcelenergy.com)



- Great River Energy Fuel Mix Chart (some parts of MN)
  - Source: http://www.greatriverenergy.com/



Nuclear Power

2006 Xcel Energy-owned Generating Facilities

2006 Xcel Energy-owned Generating Facilities

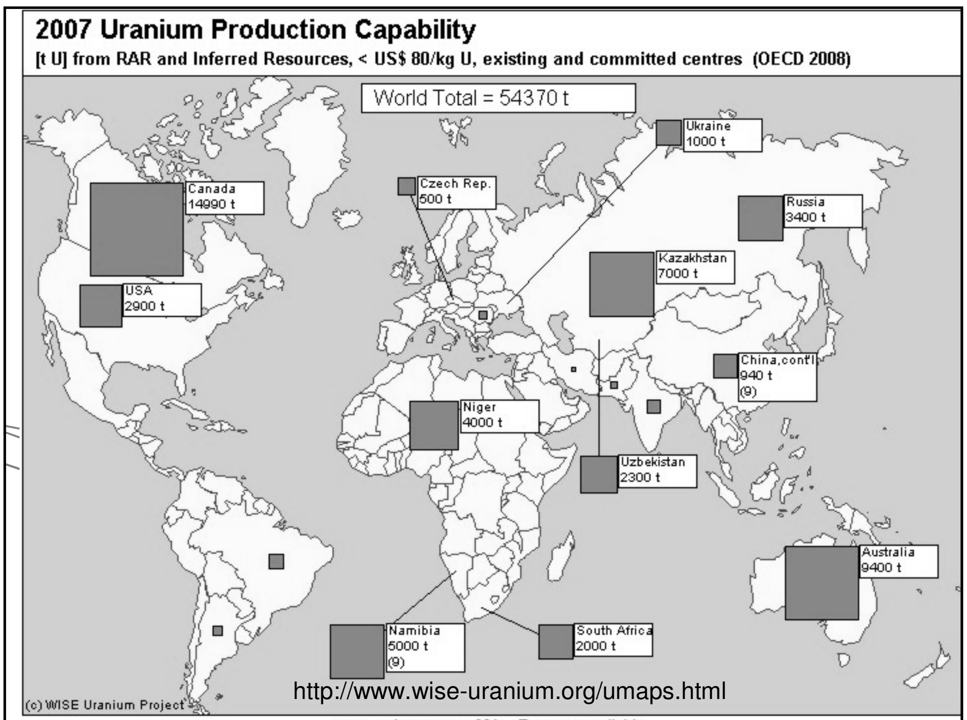
Unit Type	Number of Generating Facilities	Number of Generating Units	Generating Capacity (MW)
Coal	17	35	8,207
Natural Gas	26	61	4,913
Nuclear	2	3	1,617
Hydro	28	83	508
Oil	9	24	460
Refuse-derived Fuel	3	6	67
Wind	1	37	27*

*Xcel Energy purchased 1,296 megawatts of wind power in 2006.

Source: XCel Energy web site (http://www.xcelenergy.com)

Nuclear Power

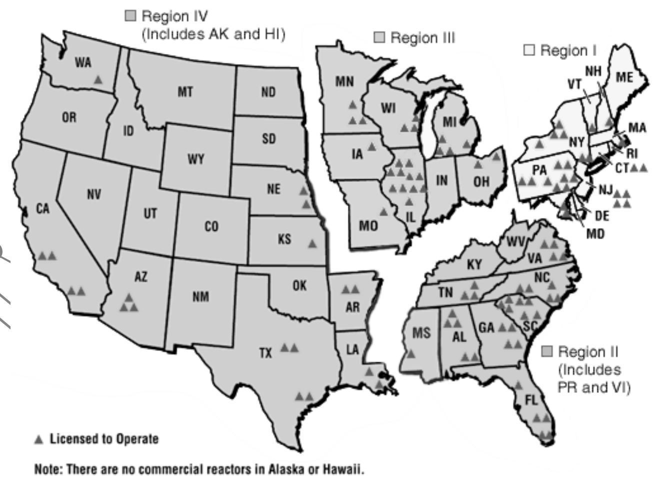
- Uranium Mines/Milling Sites in the USA
- Image from http://www.nrc.gov/info-finder/materials/uranium/



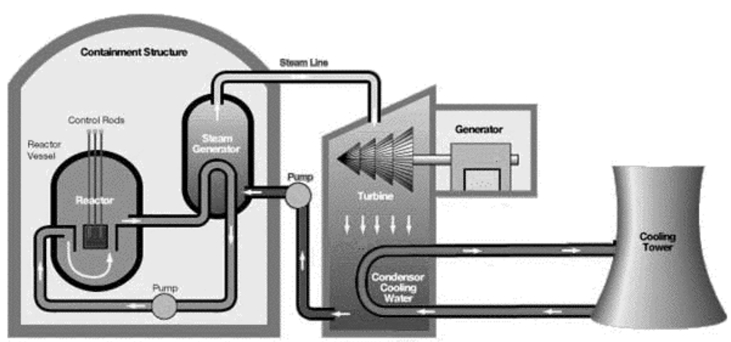
http://www.wise-uranium.org/umaps.html

Nuclear Power

- Operating Nuclear Reactors in the USA
- Image from http://www.nrc.gov/info-finder/reactor/



Nuclear power is produced in reactors. These include various components principally, nuclear fuel, moderators, coolants, steam generators, turbines, condensers, cooling towers and of course a containment structure.



Typical pressurized water reactor

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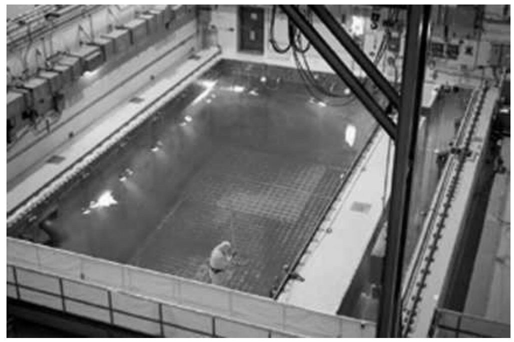
Chapter 2. Nuclear Energy Production



Nuclear plant fuel pool

Nuclear plant containment building

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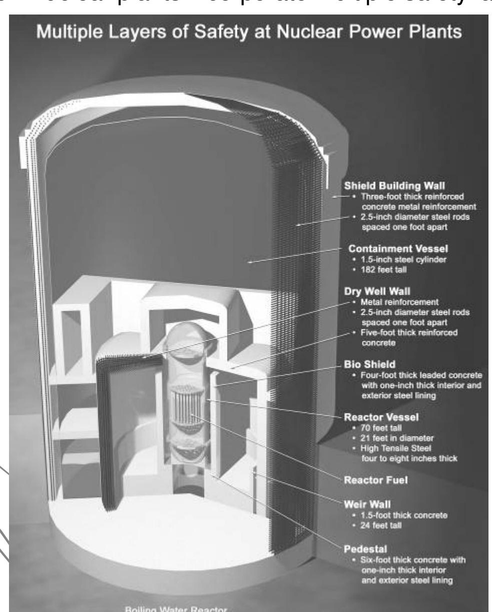
New nuclear plants incorporate multiple safety layers.



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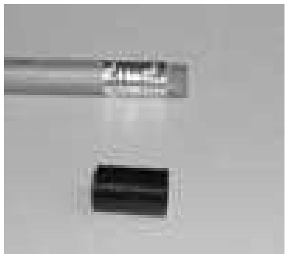
Uranium provides the energy source for nuclear reactors. 1 ton of uranium has the equivalent energy of 20,000 tons of coal!



Typical fuel pellet

Fuel assembly in a representative boiling water reactor (about 4.3 meters [14 feet]) tall and each weighing about 317.5 kilograms (700 pounds). NFI type 9x9 Fuel.

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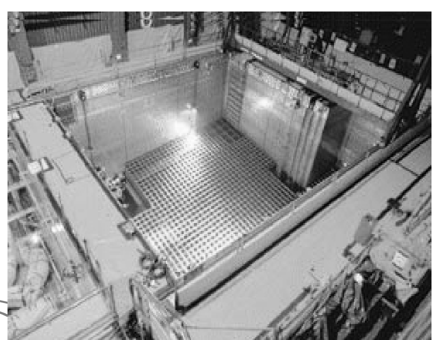
Commercial spent fuel storage



Spent fuel pool storage at reactors

Above-ground fuel storage containers

Note: The blue glow is called Cerenkov radiation. It only happens when highly radioactive fuel rods are immersed in water. They cause the water molecules to get excited and emit blue light when they drop back to their normal state.

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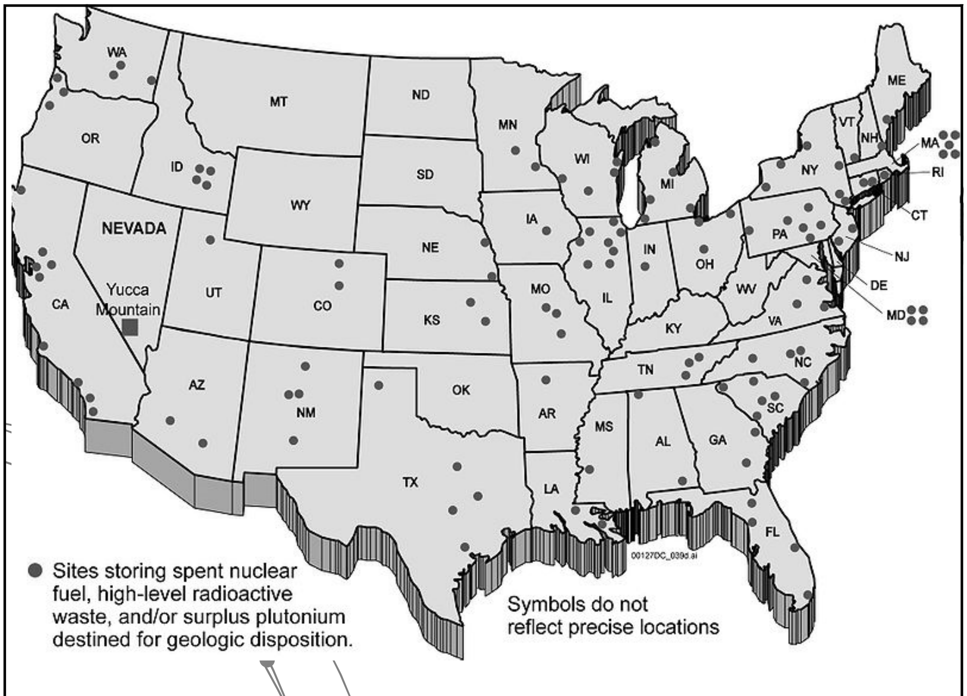
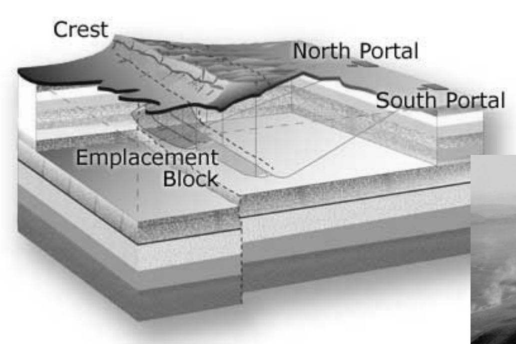


http://en.wikipedia.org/wiki/File:Nuclear_waste_locations_USA.jpg

Permanent Storage Facility?



The proposed Yucca Mountain Nuclear Waste Repository near Las Vegas, Nevada

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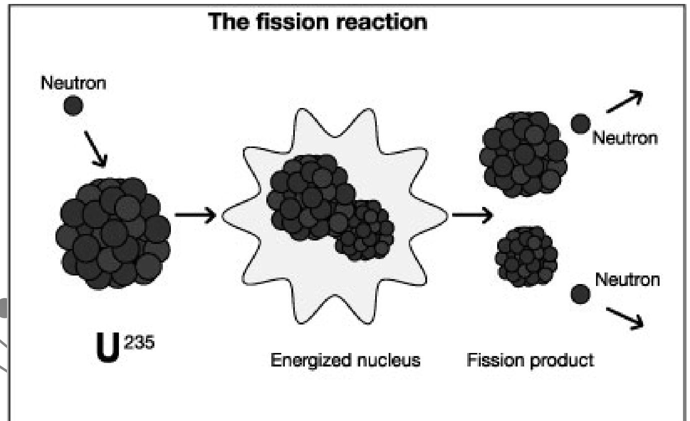
Nuclear fission produces heat when neutrons are used to bombard heavy atoms such as Uranium.



Typical fission reaction

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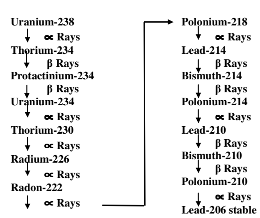
As atoms decay, they give up radiation and produce various unstable elements on their way to producing a stable element. Uranium-238 goes through 14 transformations on its way to becoming Lead-206.



The uranium decay chain

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