

Nuclear Reactions

1. Handout: Unit Notes

2. Introduction

1. The difference between chemical and nuclear energy

1. Chemical Energy

1. Potential energy that can be converted to other forms, primarily heat and light, energy when bonds form.
2. The stronger the bond the more chemical energy that can be converted.

2. Nuclear Energy

1. Nuclear energy is not related to the formation of chemical bonds (which are due to the interactions of electrons).
2. Nuclear energy is the energy that can be converted to other forms when there is a change in the nucleus of an atom.

3. The nuclear change can be one of three basic processes:

1. Splitting of the nucleus
2. Fusing two nuclei to form a new nucleus
3. Releasing high energy electromagnetic radiation (gamma rays) to form a more stable version of the same nucleus.

4. Comparison of energy conversion

1. The amount of chemical energy typically released (or converted) in a chemical explosion is:

5 kJ for each gram of TNT

2. The amount of nuclear energy typically released by an atomic bomb is:

100,000,000 kJ for each gram of uranium or plutonium

1. Film: A collection of newsreels about early atomic tests.
2. Film: Military news reel of aftermath at Hiroshima and Nagasaki

2. Symbolic representations of atoms - isotopes

1. Atomic Symbols

1. The subscript number is called the atomic number = number of protons.
2. The superscript number is called the mass number = protons+neutrons

	Protons	Neutrons
${}^{14}_6\text{C}$	6	8
${}^{15}_7\text{N}$	<input type="text"/> Ans	<input type="text"/> Ans
${}^1_1\text{H}$	<input type="text"/> Ans	<input type="text"/> Ans

2. The number of protons defines the element. All carbon atoms have 6 protons. All nitrogen atoms have 7 protons.
3. Atoms of the same element can, however, have different masses. Each unique form of an element has a specific number of protons and neutrons.

	Protons	Neutrons
${}^{14}_6\text{C}$	6	8
${}^{13}_6\text{C}$	<input type="text"/> Ans	<input type="text"/> Ans
${}^{12}_6\text{C}$	<input type="text"/> Ans	<input type="text"/> Ans

4. Each form of carbon above would be called an isotope of carbon. Sometimes they are referred to as Carbon-14 or Carbon-12. All isotopes of carbon have the same number of protons, but their number of neutrons can differ.
5. Atomic mass is the weighted average of the isotopes of a particular element. For example ~99% of carbon is Carbon-12 and ~1% is Carbon-14. In any sample of carbon on earth you will generally find this ratio. When you use a sample of carbon it contains both isotopes, so you

need a way of determining the average atomic mass. Calculate the average atomic mass based on the abundances of the isotopes listed above. It should match the atomic mass listed on the periodic table - 12.01.

6. Atoms of course are made of one other elementary particle - the electron. Neutral atoms would exactly balance positive and negative charge. Each proton carries a charge of +1 and each electron carries a charge of -1. Any atom that is not neutral is called an ion.

	Protons	Neutrons	Electrons
${}^{14}_6\text{C}$	6	8	<input type="text"/> Ans
${}^{14}_7\text{N}^{-2}$	<input type="text"/> Ans	<input type="text"/> Ans	<input type="text"/> Ans
${}^{14}_7\text{N}^{+3}$	<input type="text"/> Ans	<input type="text"/> Ans	<input type="text"/> Ans
${}^{16}_8\text{O}^{-2}$	<input type="text"/> Ans	<input type="text"/> Ans	<input type="text"/> Ans
${}^7_3\text{Li}^{+1}$	<input type="text"/> Ans	<input type="text"/> Ans	<input type="text"/> Ans

3. Types of Radiation

1. The term "radiation" is often used to refer to different things. There are two main types of radiation: electromagnetic waves and high energy particles. When people use the term "radiation" sometimes they are referring to electromagnetic wave, sometimes high energy particles, and sometimes both.
2. Electromagnetic Radiation
 1. Electromagnetic Radiation is a type of energy that travels in waves.
 2. Types of EMR
 1. Radio waves
 2. Microwaves

3. Infrared
4. Visible light
5. Ultra Violet
6. X-Rays
7. Gamma Rays
8. Handout: Electromagnetic Waves

3. To talk of a particular kind of energy we can discuss the energy, wavelength, or frequency of the wave.

1. Wavelength is the distance from the peak of one wave to the peak of another.
2. Frequency is the the number of waves per second that a stationary observer would count while the wave is passing by.
3. Energy, frequency, and wavelength are all interrelated due to the fact that all EMR travels at the same speed. As wavelength decreases, frequency increases, and energy increases
4. Gamma rays have the highest frequency, shortest wavelength, and highest energy. These are represented by the following symbol:
5. Lower energy forms of EMR (radio, infrared, etc.) are not harmful.

3. High Energy Particles

1. Tiny subatomic particles can have high energy if they are moving at very fast speeds.
2. The most common forms of high energy particles are:
 1. Alpha Particles

1. These are represented by the following symbols: α or ${}^4_2\text{He}^{2+}$
2. As you can see from the symbol above an alpha particle is the same as the nucleus of a Helium atom (or a Helium atom with no electrons), a cluster of two protons and two neutrons.

2. Beta Particles:

1. These are represented by the following symbols: β or ${}^0_{-1}\text{e}$
2. As you can see from the symbol above a beta particle is the same as an electron.

3. Neutrons:

1. These are represented by the symbols: n or 1_0n

3. All of the particles above get their high energy when they are ejected from the nucleus of an unstable atom. That is why they are all the familiar particles - protons, neutrons, and electrons - that make up atoms.

4. Radioactivity

1. Radioactive substances emit some or all of the particles above, as well as, gamma rays, the highest energy form of the electromagnetic waves. Other forms of electromagnetic radiation (x-rays, light, radio, etc.) are not directly emitted by radioactive substances.

2. Some radioactive substances emit primarily alpha, beta, or gamma. Most emit several types of radiation as the nucleus decays and becomes more stable.

3. When and how this radiation is released will be discussed later.

4. Lab: Cloud Chambers - visualizing radiation

3. Measuring Radiation and Health Effects

There are several units for measuring radiation. Below are some of the most common ones:

1. Measuring radioactivity

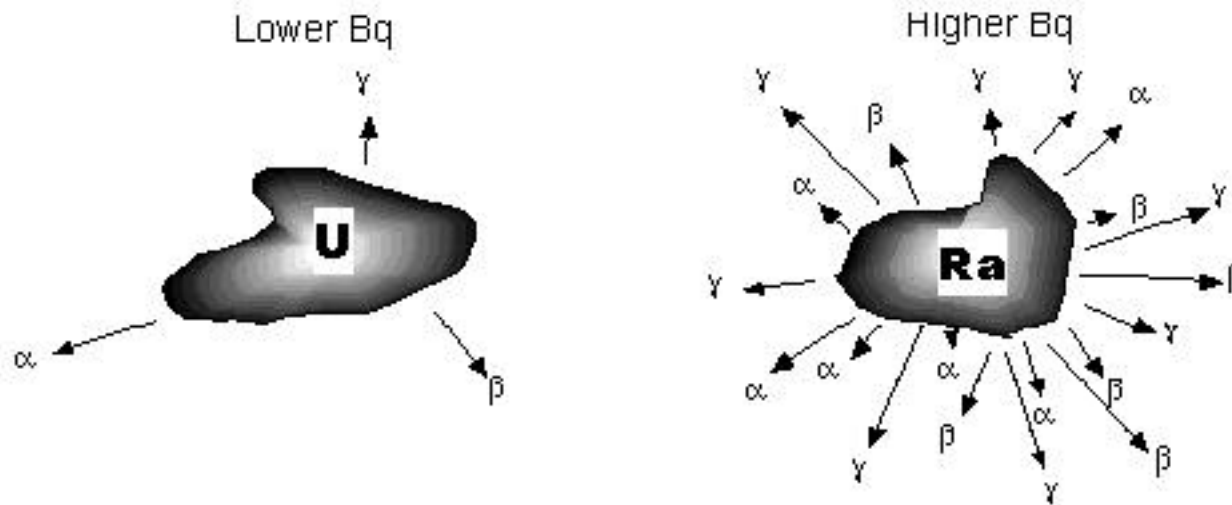
1. We can monitor and count every time a substance emits a radioactive particle or a gamma ray.

2. If a substance emits more radiation per minute than another substance we consider it to be more radio active than another substance.

3. The common unit for measuring this radioactivity is the Becquerel (Bq) and the SI unit is the Curie (Ci).

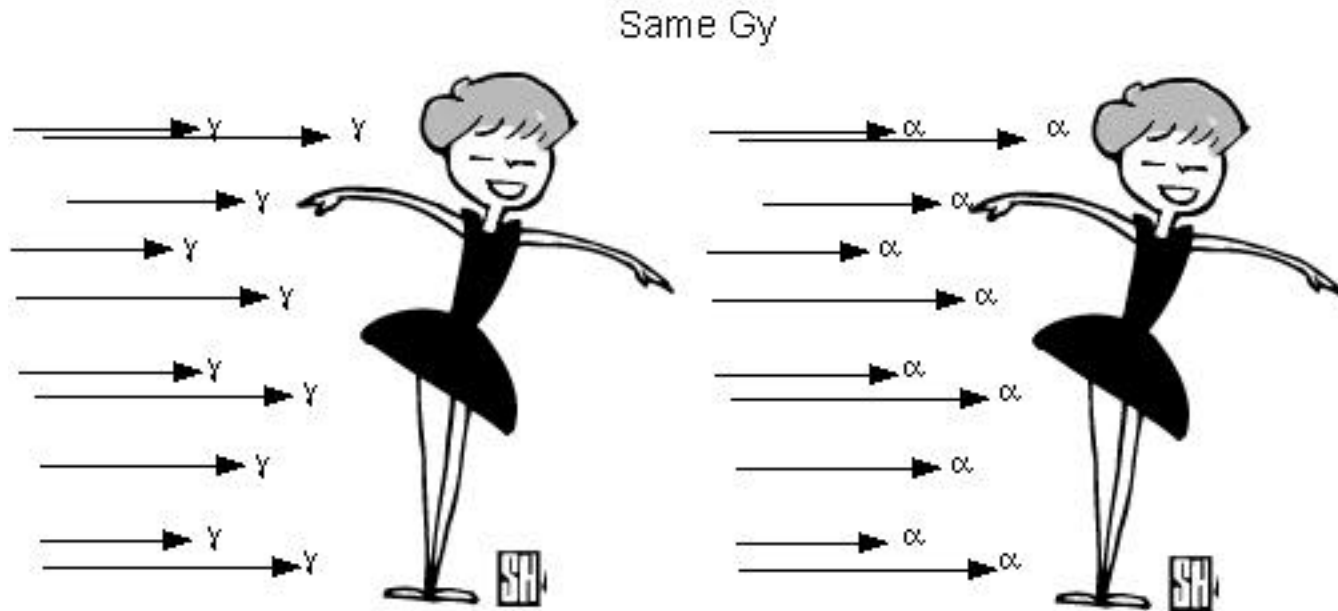
4. For example, a typical gram of radium emits 1,000,000 times more radiation than 1 gram of uranium

Amount of Radiation Given off Measured in Bq or Ci



5. A Bq = 1 particle of radiation released per second. A Ci = 37 billion particles of radiation released per second.
6. The Ci (Curie) is related to Marie Curie who did her first work with radium. 1 Ci = number of particles of radiation released per second by 1 gram of radium.
2. Measuring energy absorption
 1. Each particle of radiation (the gamma ray included) carries a certain amount of energy. Sometimes you might want to know how much energy is being absorbed by surrounding objects instead of how many particles of radiation are being emitted.
 2. The measurement of energy absorbed is also given in two different units. The common unit is the radiation absorbed dose (rad) and the SI unit is the Gray (Gy).
 3. Depending on the type of radiation absorbed (alpha, beta, gamma, or neutrons) the amount of energy absorbed could be different. Alpha particles and gamma rays can have very similar energies. For example, a person exposed to the same number of alpha particles or gamma rays may absorb the same amount of radiation.

Amount of Energy Absorbed in Gy from Alpha Particles and Gamma Rays



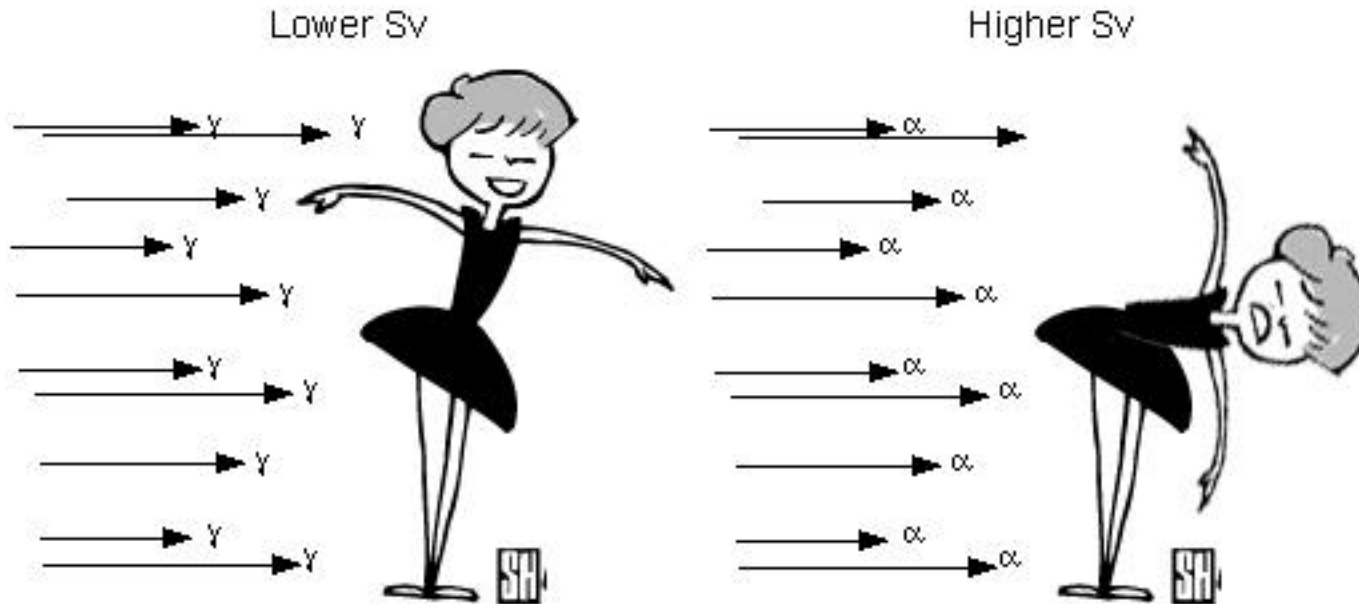
4. In the example above the gamma rays each carry the same energy as the alpha particles. This is not always true, but may be true. Therefore, in the case above the same number of particles absorbed equals the same amount of energy absorbed.
5. Rads and Gys are related in the following way: $1 \text{ Gy} = 100 \text{ rad}$.

3. Measuring Biological Effects

1. Although the amount of energy absorbed may be equivalent, the biological effect of different particles can be very different. That is why we need a different measurement of "dosage", one that will make it easier to compare different exposures to radiation.
2. The units used for measuring biological dosage come in two varieties as well. The common unit is the roentgen equivalent man (rem) and the SI unit is the Sievert (Sv).
3. Depending on the type of radioactive particle (or ray) that is absorbed, varying amounts of biological damage can be done.
4. For example, alpha particles tend to concentrate all their energy in one small region

while the energy absorbed from a gamma ray may be spread out over a larger volume. This means that absorbing an equal number of alpha particles can be much more dangerous than absorbing the same number of gamma rays.

Biological Effects in Sv from Alpha Particles and Gamma Rays



5. As you can see the same number of alpha particles, carrying the same amount of energy can do much more biological damage. Because we most care about how much radiation will affect us, this is the most common type of measurement used.

6. While the Sv is the SI unit, the most commonly used unit is the rem. 1 Sv = 100 rem.

4. Background Radiation

1. Radiation exists all around you. Humans have evolved with this normal amount of natural radiation, so our bodies have some built in repair mechanisms which allow us to deal with these normal levels of radiation. This normal level of radiation is called "Background Radiation".

2. Below is a table of the typical sources of background radiation an average person receives each year:

Background Radiation Sources	
Natural Sources:	
- Radon	200 mrem
- Cosmic Rays	28 mrem
- Rocks and Soil	28 mrem
- Internal Sources: natural found in the human body	40 mrem
Human created sources:	
- Medical X-Rays	40 mrem
- Nuclear Medicine	14 mrem
- Consumer Products	10 mrem
- Other	3 mrem
Total -->	363 mrem

*Radon is a naturally occurring radioactive element.

-Cosmic rays are high energy particles or rays that hit the Earth's atmosphere causing many other high energy particles to be produced.

- Rocks and soil (as well as building materials) contain naturally occurring radioactive elements like uranium, thorium, and radium.

- Internally, one major source is potassium-40 a naturally occurring radioactive isotope of potassium.

**Many smoke detectors contain small amounts of radioactive material.

- Sitting in front of computer monitors and TVs also raise your dosage very slightly. TV adds about 10 mrem per year for the average person.

3. To get a sense of how specific activities affect our exposure see the table below:

Typical activities and their exposure:	
- Chest X-Ray	8.0 mrem
- Cross country round trip airplane ride	5.0 mrem
- Watch TV for an hour	0.15 mrem
- Live outside a nuclear power plant for a year	0.10 mrem

5. Health Effects

1. There is a debate about how much small amounts of radiation can affect our health. Some people feel that any radiation above the natural background is too much while others argue that our bodies were designed to tolerate a certain level of radiation, so very low exposures have no effect.
2. So background radiation is about 360 mrem or 0.36 rem. Below is some of what we know happens at higher doses:

Acute effect of whole-body irradiation*	
Dose in rem	Effect
0 - 0.360	Little to none. This is normal background radiation.
5-20	Possible late effect; possible chromosomal aberrations
20 - 100	Temporary reduction in leukocytes (white blood cells); after 50 rem temporary sterility in men
100-200	Mild radiation sickness within a few hours: vomiting, diarrhea, fatigue; reduction in resistance to infection; possible bone growth retardation in children
200 - 300	Serious radiation sickness; effects as in 100 - 200 above and also bone marrow syndrome (loss of blood producing tissue), hemorrhage; 10 - 35% will die within 30 days
300 - 400	Serious radiation sickness as above; also marrow and intestine destruction; permanent sterility in women; 50 - 70% will die within 30 days
400 - 1000	Acute illness, early death; 60 - 95% will die within 30 days
1000 - 5000	Acute illness, early death in days; 100% will die within 10 days
Over 5000	Acute illness; death in hours to days; central nervous system syndrome; 100% will die within 2 days.

*from "Nuclear Arms Race" by Paul P. Craig and John A. Jungerman

3. These doses are extremely high and not something you are likely to ever encounter. Only people close to a nuclear explosion or a major nuclear accident would ever experience such high doses of radiation. Keep in mind that background radiation is only 0.36 rem.

1. Homework: Types of Radiation and It's Effects sheet

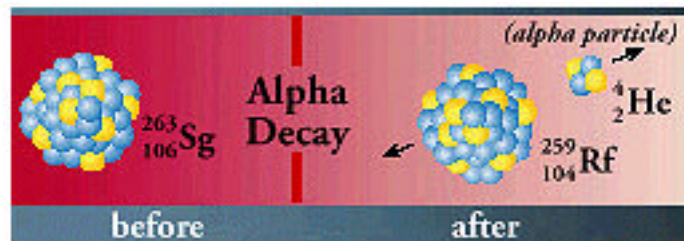
2. Homework: read Radiation and Risk

4. Radioactive Decay

1. Some isotopes are very stable, never spontaneously changing at all. However, some isotopes can spontaneously go through a transformation which causes them to emit radiation and usually change from one nuclear structure to another, transmuting the atom from one element to another.
2. Certain isotopes are radioactive because their nuclei are unstable. There has to be a balance between neutrons and protons in the nucleus. The larger the difference the more unstable the nucleus becomes. Also, as nuclei get larger they also become unstable, so that all elements with an atomic number greater than 89 are naturally radioactive.
3. When the nucleus breaks down in some way to become more stable, we call this a "decay". When atoms decay they give off radiation. Here we will explore several of the most common ways an atom can decay.

4. Alpha Decay

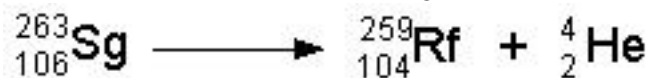
1. If a nucleus ejects a glob of two protons and two neutrons, then it has just emitted an alpha particle. See the illustration below:



(Used with permission. Original source:

<http://www2.slac.stanford.edu/vvc/theory/nuclearstability.html>)

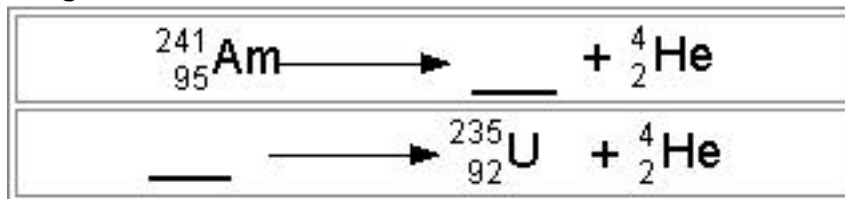
2. The symbolic representation of the above decay would be:



or



3. Because alpha particles are so big compared with other emitted radioactive particles they can't penetrate very far into matter, but they do a great deal of damage where they are absorbed. Alpha particles can only travel a few centimeters through air and can be blocked by a piece of paper. However, if you ingested or inhaled even a microscopic dust grain of plutonium then there is a very high chance cancerous growth will occur wherever this grain of plutonium (an alpha emitter) gets lodged in your system.
4. Practice. Try filling in the blanks below. Click on each one to see the answer:



5. Beta Decay

1. If a nucleus ejects an electron, then it has just emitted a beta particle. You might ask how a nucleus can eject an electron because electrons are not in the nucleus. However, this happens through the transformation of a neutron into a proton. If a neutron becomes a proton, then an electron (beta particle) is ejected at high speed. Also, a neutrino is ejected as well, but neutrinos almost never interact with matter, so we don't worry about their biological effects. See the illustration below:



(Used with permission. Original source:
<http://www2.slac.stanford.edu/vvc/theory/nuclearstability.html>)

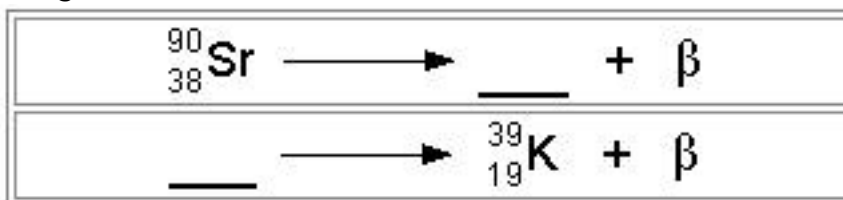
2. The symbolic representation of the above decay would be:



or

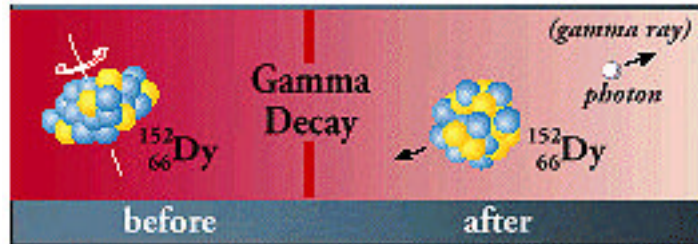


3. Beta particles are much smaller and can easily go through a piece of paper. They can travel several meters through air and can be stopped by a thin sheet of lead.
4. Practice. Try filling in the blanks below. Click on each one to see the answer:



6. Gamma Decay

1. Sometimes a nucleus is in an excited state, and to become stable it only needs to emit some energy. When pure energy is emitted with no material change in the nucleus, a photon of gamma radiation is emitted. See the illustration below:



(Used with permission. Original source:
<http://www2.slac.stanford.edu/vvc/theory/nuclearstability.html>)

2. The symbolic representation of the above decay would be:



3. Gamma rays have no mass at all and can penetrate matter extremely well. They can travel through many kilometers of air, but are blocked by thick sheets of lead.

7. An excellent summary of all these concepts can be found at:

<http://www.darvill.clara.net/nucrad/types.htm>

1. Homework: Radioactive Decay Sheet

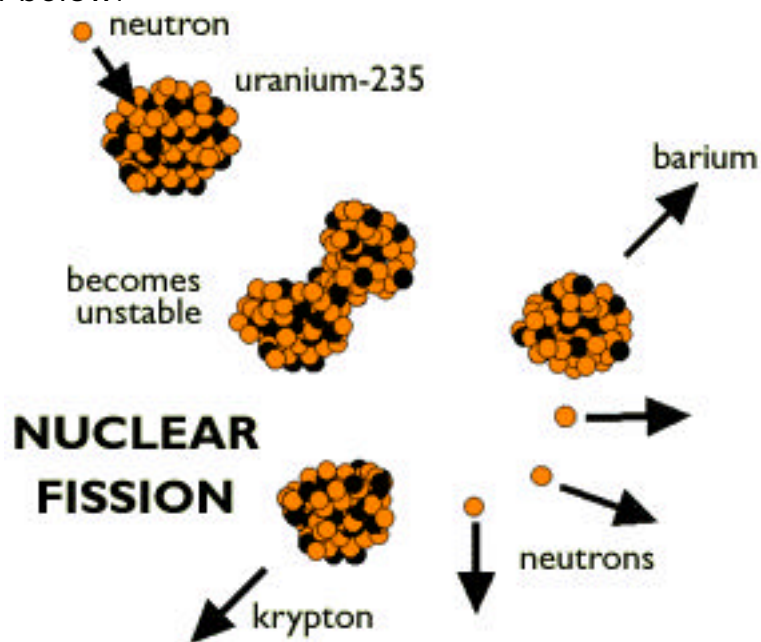
5. Fission and Fusion

1. In addition to decaying, a nucleus can be transformed in two other important ways: fission and fusion. The isotope iron-55 is the most stable nucleus. Atoms with higher mass will tend to go through fission and give off energy while atoms with mass lower than iron-55 can go through fusion to become more stable and give off energy.

2. Fission

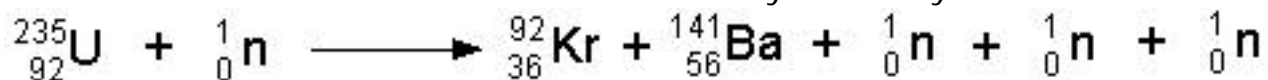
1. If an unstable nucleus breaks into two smaller pieces, it can form two new atoms. This is known as fission.
2. When this occurs some energy is also released. This is the source of energy that powers nuclear power plants and the first nuclear bomb.

3. See the illustration below:



(Used with permission. Original found at:
<http://www.sciencenet.org.uk/database/Physics/Atomic/p00435c.html>)

4. The above illustration could be written symbolically as:



(note: The two nuclei that form can vary. They are not necessarily the isotopes listed above.)

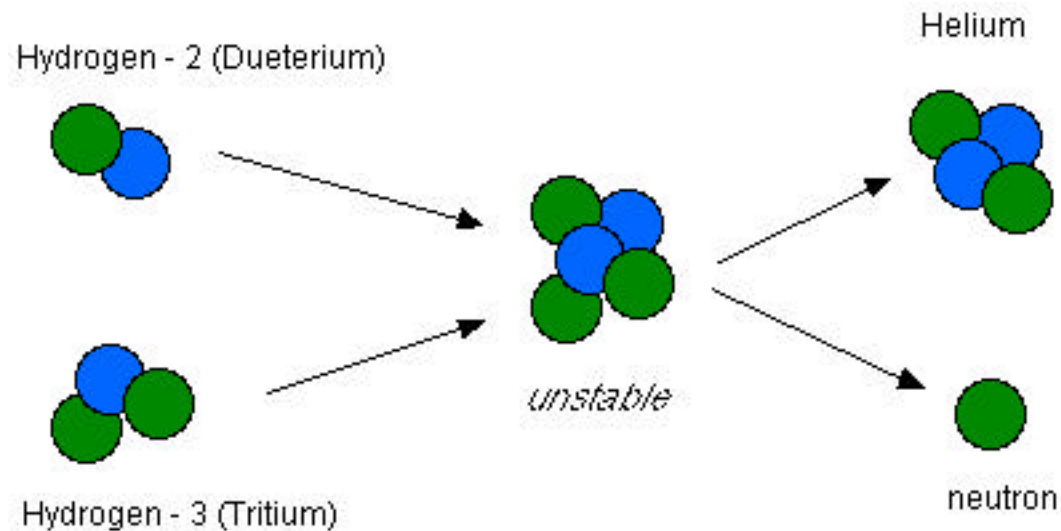
5. Check out an animation of this at:

<http://www.atomicarchive.com/Fission/Fission1.shtml>

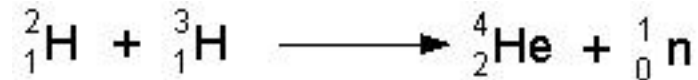
6. Only a few isotopes spontaneously fission. Uranium - 235 and Plutonium - 239 are the ones most commonly used for this purpose.

3. Fusion

1. If two nuclei collide with enough force then they may fuse together forming a larger single nucleus. This is known as fusion.
2. When this occurs some energy is also released. This is the source of energy that powers the sun (as well as other stars) and hydrogen bombs.
3. See the illustration below:



4. The above illustration could be written symbolically as:



5. Check out an animation of this at: <http://www.atomicarchive.com/Fusion/Fusion1.shtml>

4. Energy Released

1. Einstein's famous equation states that: $E = mc^2$

E = energy

m = mass

c = speed of light = $3.0 \times 10^8 \frac{m}{s}$

- This means that mass can be converted into pure energy. The amount of energy is determined by multiplying the mass times the speed of light squared.
- Consider the following table:

Mass of reactants:	
Mass of ${}^2_1\text{H}$	3.344548×10^{-27} kg
Mass of ${}^3_1\text{H}$	5.008347×10^{-27} kg
Total -->	8.352895×10^{-27} kg
Mass of products:	
Mass of ${}^4_2\text{He}$	6.64658×10^{-27} kg
Mass of ${}^1_0\text{n}$	1.674954×10^{-27} kg
Total -->	8.321534×10^{-27} kg

$$\text{Missing Mass} = 8.352895 \times 10^{-27} \text{ kg} - 8.321534 \times 10^{-27} \text{ kg} = 0.031361 \times 10^{-27} \text{ kg}$$

- Somehow the products weigh less than the reactants! Einstein said that this missing matter was converted to energy according to his famous equation: $E = mc^2$

$$E = mc^2 = 0.031361 \times 10^{-27} \text{ kg} \cdot \left(3.0 \times 10^8 \frac{\text{m}}{\text{s}} \right)^2$$

$$E = 2.8 \times 10^{-12} \frac{\text{kg} \cdot \text{m}^2}{\text{s}^2} = 2.8 \times 10^{-12} \text{ J}$$

5. That is a tiny amount of energy, but that is only for one reaction. In 1 kg of starting material there could be 1.2×10^{26} nuclear reactions.

$$1.2 \times 10^{26} \cdot 2.8 \times 10^{-12} \text{ J} = 6.7 \times 10^{14} \text{ J of energy released}$$

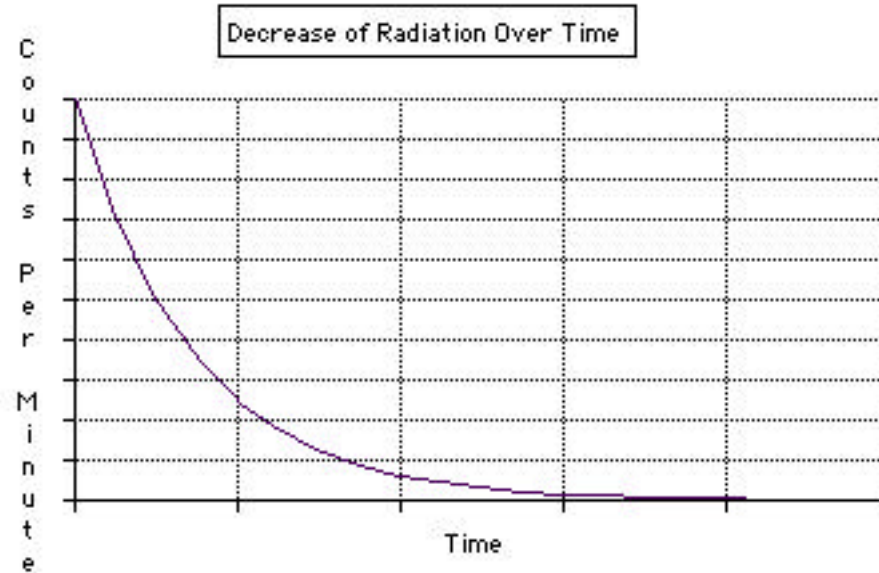
That is equivalent to the energy released in about 10 Million tons of TNT!

1 kilogram of nuclear fuel could theoretically yield as much energy as 10 million tons of TNT!

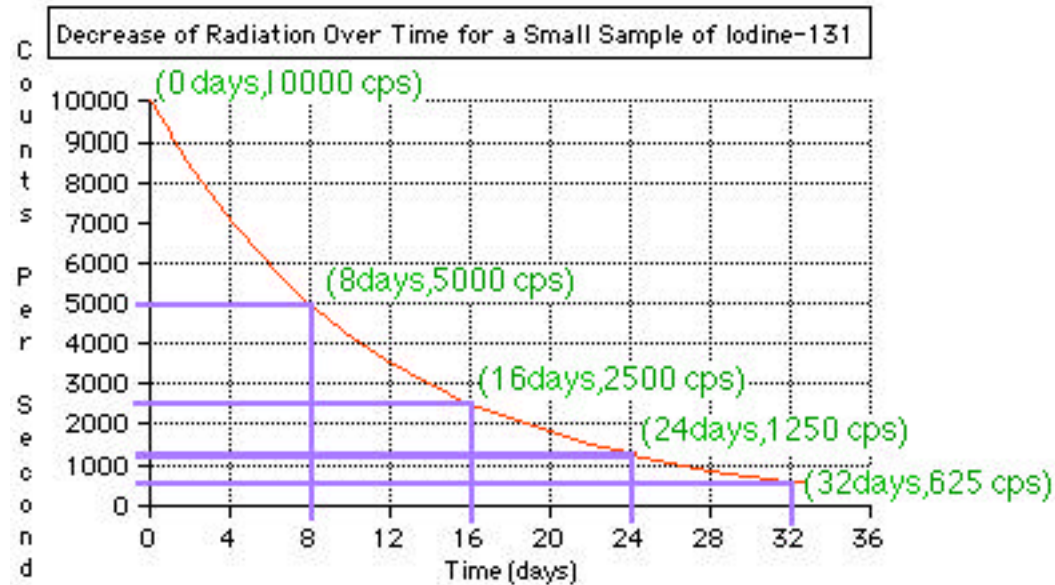
6. As you can see, nuclear reactions can produce an enormous amount of energy. Both fission and fusion produce energy in this way. A bomb releases the energy all at once while a nuclear power plant releases the energy slowly over very long periods of time. Currently we don't have any way to control a fusion reaction. All nuclear power plants in operation today use fission to produce energy.
7. Fusion reactions similar to the one described above are the source of power for the Sun and other stars. Notice how the lighter hydrogen nuclei fuse to form a heavier helium nucleus. Inside the sun heavier and heavier atoms are then fused together to form more and more elements. That is where all of the elements heavier than helium have come from - inside a sun. You are made from atoms that were once at the center of some star which exploded sending out all the elements it created through nuclear fusion in its core. You are made from old stars!

6. Half-life

1. Radioactive materials by their very nature, decay via various methods to form other elements, ultimately to form stable non-radioactive isotopes.
2. If you monitor a radioactive substance with a Geiger counter, you will hear "clicks" every time the device detects a particle of radiation. Over time, if you graphed the number of clicks per second you would see a graph resembling something like you see below:



3. Depending on how quickly an element decays, the time needed to make the above graph could take anywhere from a fraction of a second to billions of years.
4. To see a visual depiction of how this graph is formed go to:
http://www.colorado.edu/physics/2000/isotopes/radioactive_decay3.html
5. One way to describe how fast a radioactive substance decays is to determine how long it will take half of the currently present atoms to decay. Let's look at a particular example - Iodine-131 which is used to diagnose problems with the thyroid gland.



By looking at the graph you can see that half of the Iodine-131 has decayed every 8 days. We then say that Iodine-131 has a "half-life" of 8 days.

If you started with 80 grams of radioactive Iodine-131, how long would it take until you had less than 5 grams left?

6. The shorter the half-life the more unstable the atoms of that isotope are, and the faster they will decay.

1. Demo: Observing Radioactive Decay
2. Homework: Half-Life practice sheet

7. Uses for Radioactive Materials

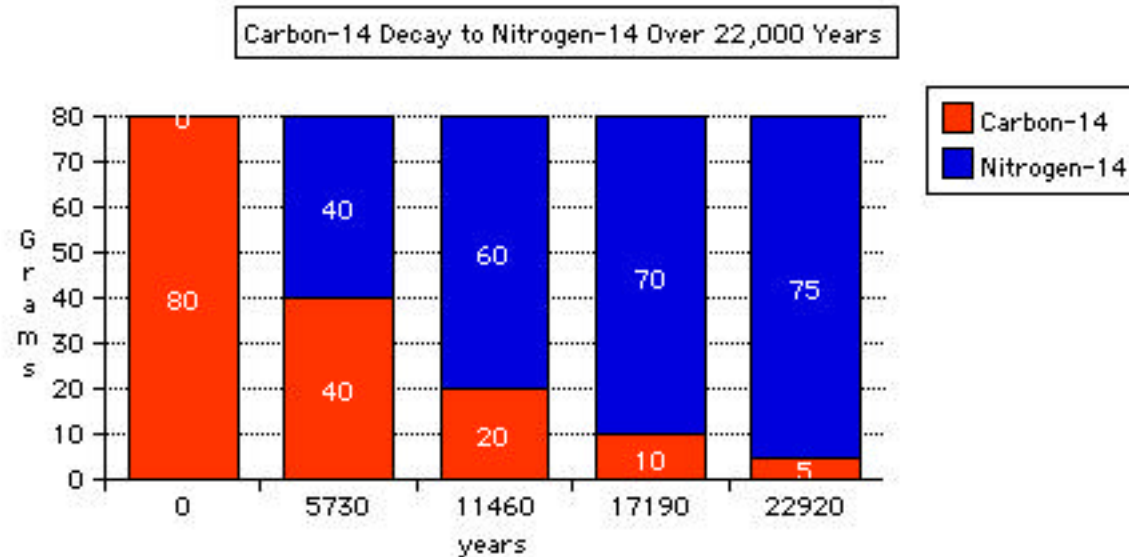
1. Radioactive Dating

1. You can use the fact that radioactive isotopes have a constant half-life to determine the age of something containing radioactive material.
2. Let's take Carbon-14 for example with a half-life of 5730 years. This naturally occurring isotope decays via the emission of a beta particle as shown below:



Half-life = 5730 years

3. If we know how many Carbon-14 atoms we start with, then we can measure how many are left. If half of the original amount of Carbon-14 has decayed then, 5730 years have passed. See the illustration below:



4. Radioactive Carbon-14 is constantly created in our atmosphere by cosmic rays. Over long periods of time ratio of Carbon-14 to Carbon-12 has remained relatively constant.
5. All living things constantly take in carbon, either as carbon dioxide (in the case of plants), or as food in the form of vegetation or meat. Therefore, while something is alive it will have the same ratio of Carbon-14 to Carbon-12 in its body as the surrounding environment. However, as soon as something dies it stops replenishing its system with carbon so the amount of Carbon-14 becomes fixed at death. At this point, as the organic matter ages, the amount of Carbon-14 present is less and less as it decays to Nitrogen-14.
6. As you can see from the graph above after about 20000 years the % of Carbon-14 that

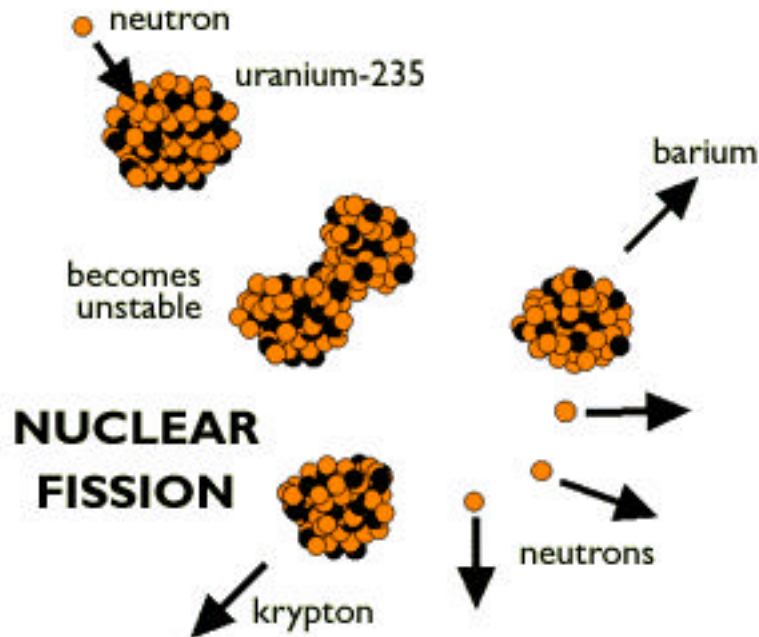
remains is quite small, so carbon dating can only be used to date organic material that is younger than 20-30 thousand years old.

7. Other isotopes are used to date rock and other materials that may be far older.

1. Computer Lab: Half-life Practice

2. Nuclear Power

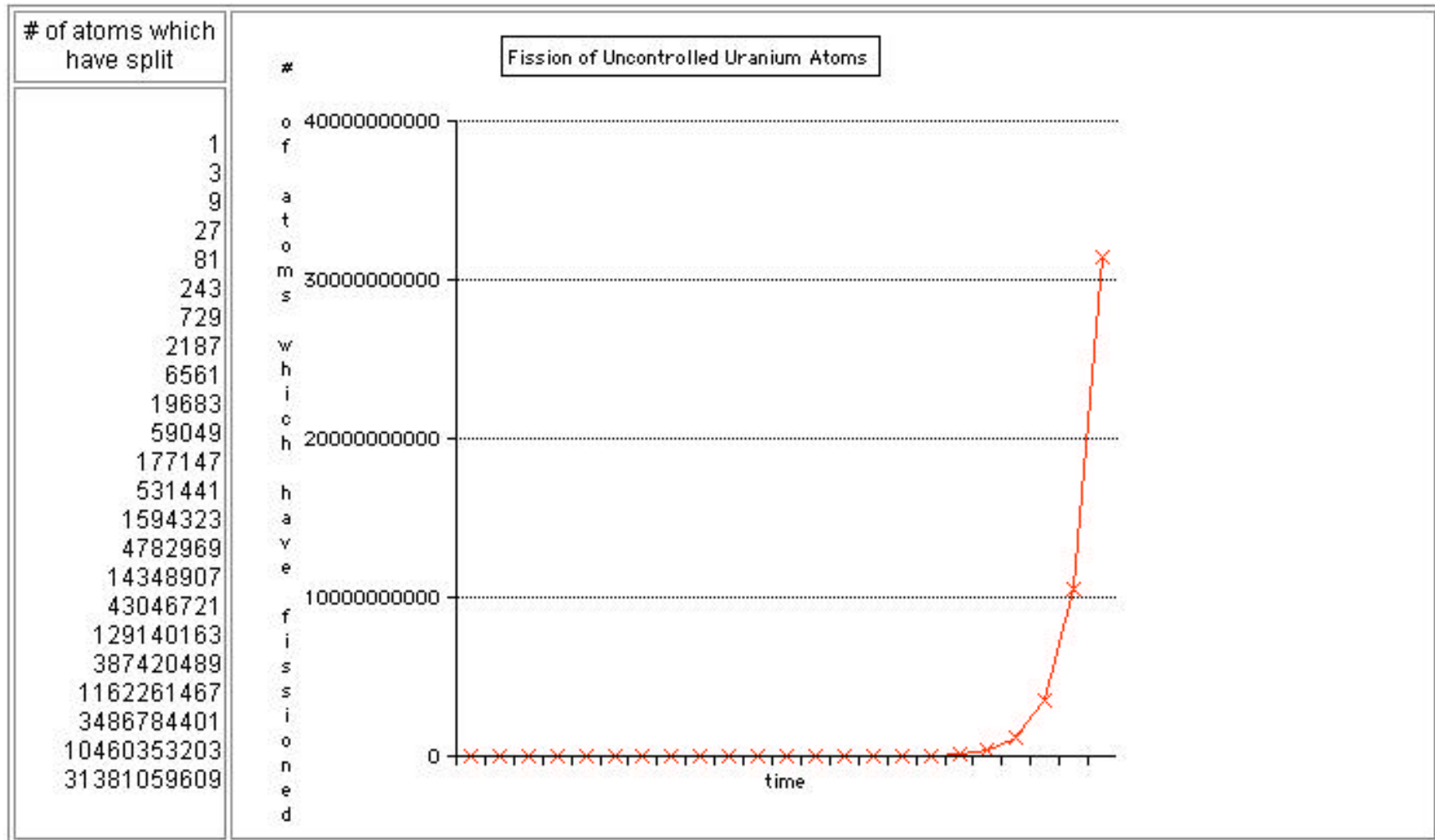
1. All electricity is generated by spinning a big wheel that has magnets near large coils of wire (or vice versa).
2. Something has to be used to turn the turbine. Often steam is used as depicted above. Power plants that use coal, oil, or gas to generate electricity just use those fuels to heat water so that steam can turn a turbine. In nuclear power plants, the heat generated by fissioning Uranium or Plutonium boils water which creates the steam needed to rotate the turbines.
3. Recall the previous illustration of the fissioning of Uranium:



(Used with permission. Original found at:

<http://www.sciencenet.org.uk/database/Physics/Atomic/p00435c.html>)

4. Notice that for every one uranium atom that splits three neutrons are produced (along with some energy). If every neutron causes another atom to fission the amount of energy released would soon grow out of control (what happens in a nuclear explosion). The graph below shows how quickly the number of atoms splitting would grow if unchecked.



5. So, some of the neutrons which are emitted must be absorbed before they can cause another uranium atom to fission. Control rods are inserted between rods of uranium fuel. These rods capture some of the neutrons and prevent the fission reaction from going out of control.
6. Below is an image of the type of reactors common in the US:

(original source: <http://www.nrc.gov/reading-rm/basic-ref/students/animated-pwr.html>)

7. Safety Issues

1. There are several different designs for nuclear power plants. The variations are mostly in what material surrounds the nuclear fuel and how the fuel is packaged.
2. Most of the nuclear power plants in use today in the US are of the design depicted above. These plants are very old and no new plants have been constructed since the early seventies. This is primarily due to the safety concerns people have had regarding a major catastrophe at one of the plants.
3. If for some reason the fission reaction goes out of control, it is possible to have a large release of radioactive material. It is impossible to have a nuclear explosion like that of an atomic bomb, but a major accident at a nuclear power plant would be devastating to the surrounding area. Fortunately, there are MANY safety systems and backups for the backup systems to prevent this. The only major release of radiation occurred in 1986, at the Chernobyl nuclear power plant in Kiev (the former Soviet Union). And this happened only because the people operating the plant disregarded virtually every safety regulation and disconnected the safety systems to run a test. Even the design of the plant is much more dangerous than any power plant in operation here in the US.
4. Some people fear that just living near a nuclear power plant can expose them or their children to high amounts of radiation, but this is not true. Living right next to a power plant would add only about 1 mrem (of the 360 mrem present in the normal background radiation) per year of radiation.
5. Today there are plant designs that are inherently much safer than those already in operation. However, concern over the dangers of nuclear power have prevented any of

these plants from being built.

8. Waste disposal issues

1. Many proponents of nuclear power say that it is "clean" power. What they mean is that the air pollution caused by the burning of coal, oil, or gas, is not created in nuclear power plants.
2. While this is true, the main environmental issue with nuclear power plants is the highly radioactive waste they produce. To date, we still have no solution as to how this waste can be safely stored. Currently, all the nuclear waste that is produced is kept in relatively unsecured storage facilities at the power plant. They have no place to put it.
3. Several of the isotopes present in the waste have very long half-lives requiring that the waste be stored for 10,000 - 100,000 years before they have decayed to a safer low level.
4. The only real option being considered today is underground storage of the waste under Yucca mountain in Nevada. After decades of study, there is still controversy over whether this site is suitable to safely contain the nuclear waste over the time periods necessary.

1. Homework: read science news article about radio active release from coal plants
2. Homework: Read the Pro/Con article about nuclear power and make a list of the pros and cons you find. Then write a paragraph explaining your own thoughts on the use of nuclear power.

3. Nuclear Bombs

1. There are two main types of nuclear bombs: atom bombs and hydrogen bombs.
2. In either type of bomb, a nuclear chain reaction occurs because the nuclear material has reached critical mass.
3. Critical mass occurs when the chain reaction of fissioning or fusing atoms is self-sustaining.
4. Reaching critical mass

1. There are two ways to have nuclear material reach critical mass: through high density of atoms or through just having large numbers of atoms.
2. To make things simple let's experiment with some atoms going through the fission process. Click on the image below to explore reaching critical mass.

5. Atom Bombs

1. Atom bombs are made from either Uranium-235 or Plutonium-239 which fission spontaneously.
2. Critical mass can be reached by putting enough Uranium-235 in one place so that enough neutrons which are emitted continue the chain reaction, causing more atoms to fission. This type of nuclear weapon is very simple. If you have enough Uranium-235 in one place it will explode with a force of thousands of tons of dynamite.
3. Below is a picture of the bomb dropped on Hiroshima, Japan during the second world war.
4. Inside the bomb are two pieces of Uranium. At the moment of explosion the two pieces are brought together causing there to be enough fissioning uranium atoms to cause an out of control chain reaction.
5. This one bomb released an explosion equivalent to 25,000 pounds of TNT. It killed between 80,000 to 140,000 people, while injuring 100,000 more very seriously.
6. Another way to make an atom bomb is to surround a sphere of Plutonium-239 with normal explosives so that they will squeeze the plutonium atoms into a mass of very dense atoms, causing critical mass and a sustained chain reaction that quickly gets out of control.
7. The nuclear bomb dropped on Nagasaki three days later is depicted below is a plutonium bomb:

6. Hydrogen Bombs

1. Hydrogen bombs use fusion instead of fission to generate their explosions.
2. While uranium and plutonium spontaneously fission to produce energy, hydrogen atoms resist very strongly the urge to fuse.
3. The nuclei of hydrogen atoms is positive. Like charges repel, so it is very difficult to get the nuclei of atoms to fuse.
4. The only way to do it is to slam the atoms together with enough force to make them fuse. Temperatures of over 50 million degrees are necessary to make this happen. Of course, the sun has no problem maintaining these temperatures in its core, but achieving those high temperatures here on Earth is very difficult.
5. In order to get the hydrogen atoms to fuse together, a fission type atom bomb must be exploded first, generating the intense heat and pressure necessary to fuse the hydrogen atoms.
6. This is the reason all nuclear power plants use the fission process. Fission happens spontaneously without the need for extreme temperatures and pressures. People are working on making a fusion type reactor, but a working controlled fusion reactor is many decades away.

1. Film: Fission Bomb Blasts

2. Film: Hydrogen Bomb Blast

3. Homework: Nuclear bombs and reactors

4. Other uses

see <http://www.darvill.clara.net/nucrad/uses.htm>

1. Homework: read the radioactive boy scout.