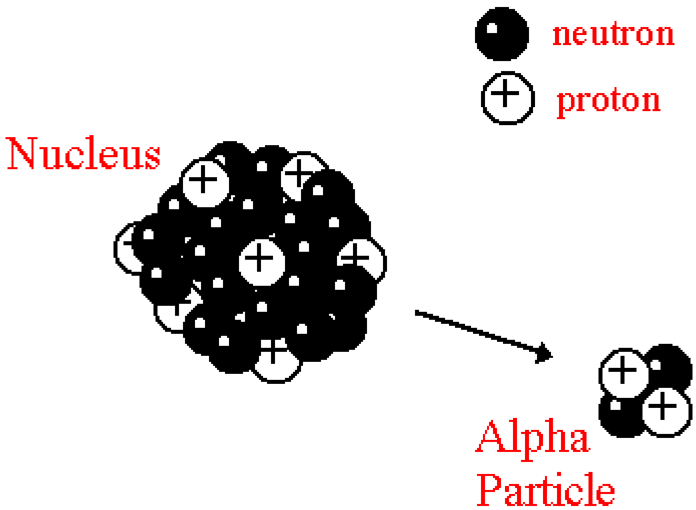
Chapter 18 Nuclear Chemistry Diary

There are about 112 atoms on the periodic table, and most are stable. But because of the many isotopes of each atom (different numbers of neutrons than "normal") most of the 1000 or so unique types of atoms are not stable. Their neutron to proton ratio is not within the range of stability.

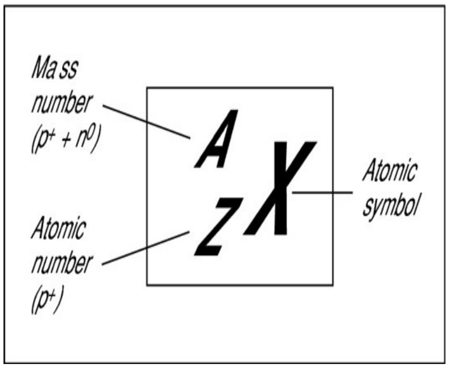


Most atoms are stable, as they have a "normal" ratio of neutrons to protons. For the smaller atoms this ratio is or is close to 1:1, but as the atoms increase in size the ratio of neutrons to protons increases, up to 1.4 or even 1.5:1 . Mercury has 121 neutrons and just 80 protons, which is a ratio of 1.5:1, but it is stable.

Unstable atoms try to become stable by giving off parts of their nucleus, *that's why this is called* Nuclear Chemistry, it's all about the nucleus. The particles and energy emitted by the nuclei to become stable is called radiation. There are many forms of radiation, and sometimes certain unstable nuclei emit more than one kind at a time, or different kinds in a series of changes they undergo to become stable. The picture above shows how an alpha particle is emitted by the nucleus of an unknown unstable isotope.

When an atom changes by emitting radioactivity (particles or energy or both), this is called natural transmutation. It is natural because it just happens without help, and the term transmutation means, changing into something else. Often unstable atoms will change from one kind of atom (or element) into a different kind of atom, because their number of protons changes.

Recall all atoms are defined by their atomic number.

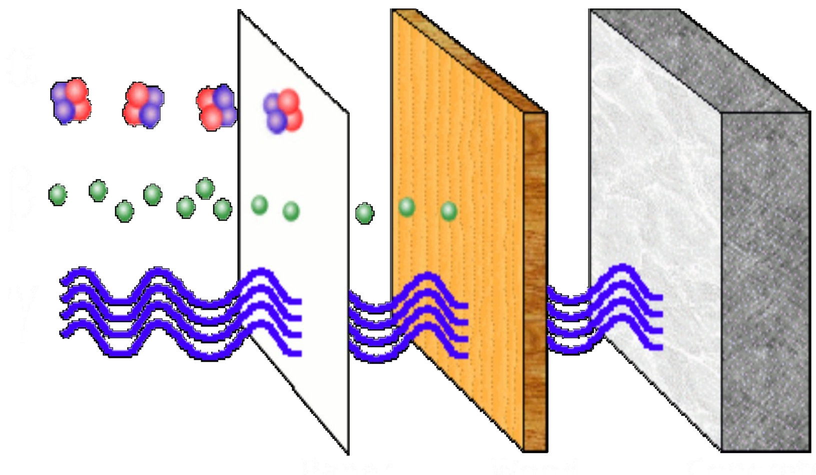


The six kinds of radiation you need to know about are listed in reference ***Table O.*** In size order from the biggest to smallest. The radiation particles are outlined in the following table.

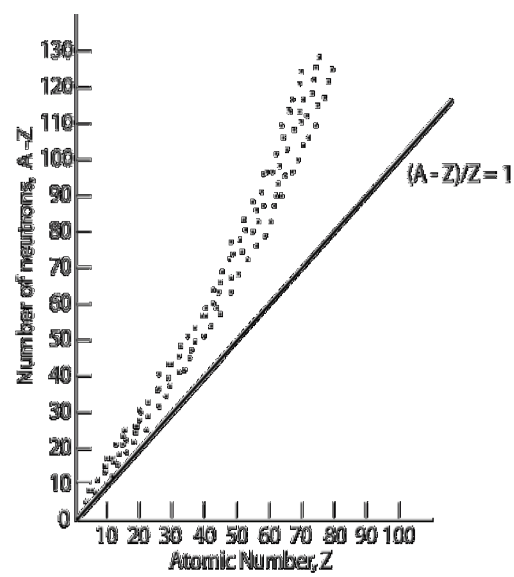
particle	relative size
alpha particles	mass = 4 amu
beta particles	mass = 0 these are electrons, the mass is zero in our class—but not "really zero"
positron particles	mass = 0 these are + charged electrons, the mass is zero in our class—but not "really zero"
neutrons & protons	both having about a mass = 1 amu
gamma radiation	no mass, just pure electromagnetic energy.

Each type of radiation has its own characteristics. Some can do more damage than others. Each one can penetrate through different objects. **Alpha** are the weakest, followed by **Beta.** The radiation with the maximum strength are the **Gamma** rays.

Alpha particles, are on top.
The green represent
beta particles,
and the waves
represent
gamma rays.



Transmutation, Natural and Artificial



In chemistry, things are what they are and stay what they are forever. In nuclear chemistry we encounter unstable atoms all the time. In their "attempts" to become more stable they will emit a variety of particles and energy to generate a more normal 1:1 ratio of protons to neutrons in their nucleus.

An exact 1:1 ratio is not necessary for stability, especially for the larger atoms, but there is what's known as the "band of stability, the stable ratios of neutrons to protons, shown here.
If a particle emits a particle and becomes some-

thing else it is said to be transmuted. This happens without any help or push by man. It is a natural process. It is random & cannot be controlled, hurried up, or slowed down.   Radio-isotopes can emit different particles and change in many ways. Some changes, or transmutations allow isotopes to become stable in one step. Often it takes many steps, through a variety of stages of instability before reaching a stable nucleus.

Humans have learned to bombard nuclei with neutrons and other particles and energy. This can cause transmutation as well. Since this is not naturally occurring it is called artificial transmutation.

Natural transmutation reactions have a single reactant followed by the arrow.

Artificial transmutation has an isotope with a neutron (or other particle) added to it BEFORE the reaction arrow. This shows it was ADDED by humans, artificially.

Radioactive Decay

(Natural Transmutation)

Radioisotopes (unstable atoms) break down or transmute in a regular time frame, each is on it's own "clock". The time it takes for one half of an isotope to transmute (or decay) into some other isotope is called its **half life**. Some half lives are milliseconds long and these radioisotopes decay quickly. Some half lives are in the billions of years. As they are undergoing this transmutation they are emitting radio-activity, which is not healthy for living things.

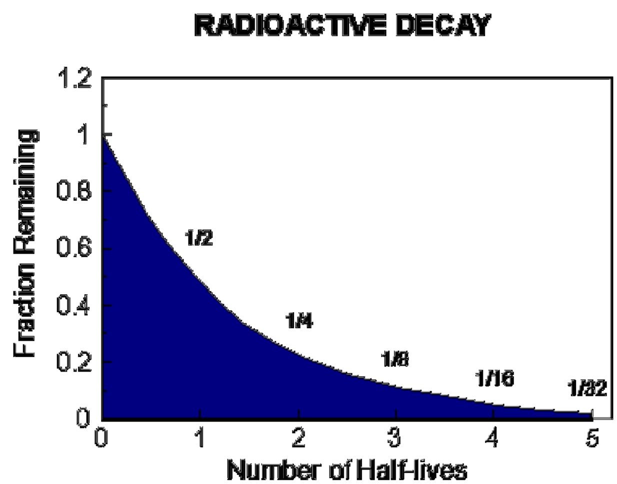


Table N and Table O

The column headers on table N include nuclide, half life, decay mode and nuclide name. The first column header is the symbol of the radioactive (unstable) isotope of a particular atom. The symbol is the chemical symbol from the periodic table, the number is the mass of that unstable atom. The last column just shows you how to "say" the symbol out loud. For example, the first isotope, ^{198}Au is said out loud: gold-198. Underneath the 198 could be the atomic number, or the number of protons/electrons in gold. All gold atoms have 79 protons and 79 electrons. Not all gold is radioactive. Since the mass of this isotope is 198 and there are 79 protons, that means that this isotope has 198-79= 119 neutrons.

The second column listed is half life. A half life is the amount of time it takes for one half the mass of a radioactive isotope to decay, to breakdown, into something more stable. When an isotope decays, it quite literally breaks part of its nucleus off and emits it as a radioactive particle, often along with energy. The loss of particles leads to a more stable nucleus, which is what the isotopes "wants", or is attempting to gain.

Some times an isotope will decay directly into some other element and it reaches nuclear stability. Often a decay will lead to another unstable nucleus, which will also decay in a multi-step process towards gaining a stable nucleus.

This decay is a random process, you cannot predict that "this" atom will decay and "that" one won't. Half will decay in a half life. The length of time a half life takes is dependent upon the isotope. They all have their own process and it takes what ever time it takes. We are given many half life time frames (from milliseconds to billions of years) in Table N.

The decay mode shows the individual particles that the nucleus of an isotope gives off. Not all unstable nuclei will undergo alpha particle decay. Some will give off beta particles, some positron particles, some neutrons or protons or even gamma energy decay. Some go through multiple decays to reach stability. Table N shows us how these 25 isotopes decay.

We can use the decay mode to determine what new atom the radioactive isotope will transmute into (become) by giving off these decay particles.

When isotopes give off particles and transmute into new atoms, this process has several ways of being named. You could say…

- The radioisotope will decay into some other atom.
- The radioisotope will transmute into another atom.
- The radioisotope will under go natural transmutation (unaided, not caused by a scientist).
- Some isotopes undergo alpha decay, others undergo positron or beta decay.

- *All of these statements "mean" the same thing.*

Table O decay particles and their symbols explained:

Alpha Particle: 4 is four amu total mass, 2 is 2 protons included in the 4 amu
(2 neutrons make up the rest of the amu mass)
He stands for helium, an alpha particle is identical to a He nucleus
(or a helium atom minus its electrons)

Beta Particle: 0 for no mass, -1 for a negative one charge, e for electron.
Beta particles are electrons (they have a very small mass)

Gamma Radiation: no mass, no charge, pure energy and not healthy for humans

Neutron: 1 amu mass, no charge, n for neutron

Proton: 1 amu mass on top, +1 charge since it is a proton, H for the hydrogen nucleus which is the whole nucleus of a (non-radioactive) hydrogen atom. Less than 1% of all hydrogen on Earth is radioactive. Deuterium has 1 p^+ with a mass of 2 amu, Tritium has 2 p^+ and has a mass of 3 amu. "Normal" or non-radioactive hydrogen has no neutrons at all.

Positron Particle: 0 for no mass, +1 for a positive one charge, and e for electron. Strange things happen in nuclear chemistry. Positron particles are strange (for us). They have no mass, like an electron, they have the e for a symbol like an electron, but they are positively charged, which is opposite of electrons. These are also called anti-electrons because they are the opposite of electrons. (technically they have the tiny mass of an electron)

Fission vs. Fusion Reactions

There are two different kinds of nuclear reactions, fission and fusion. Fission is the splitting of atoms to release the energy, while fusion is the compression of 2 small atoms into a bigger atom, also releasing energy.

Fission reactions have a larger, or heavier nucleus breaking into smaller, daughter nuclei, and releasing energy. This was how the first nuclear bombs worked. An example is:

$$^{235}U + n^o \text{ ----> } {}^{134}Xe + {}^{100}Sr + 2n^o + \text{energy}$$

which shows U-235 splitting into xenon and strontium. Since the uranium was blasted by a neutron to cause this split, this is artificial transmutation. The two smaller atoms formed are Xe-134 and Sr-100. 2 more neutrons form along with the release of energy.

These 2 neutrons blast out and can split two more uranium atoms, releasing 4 neutrons and more energy. This reaction continues until so many uranium atoms are splitting and so many neutrons are blasting out, and so much energy is released, that the nuclear explosion happens.

In a controlled nuclear fission in a reactor, control rods (often made of cadmium) absorb neutrons, which slows down the chain reaction, releasing energy in controllable amounts. Fusion is when small hydrogen nuclei are forced together to form helium. This reaction is much more energetic than fission and cannot be safely controlled to be used in reactors. This is the reaction that drives the Sun. Nuclear bombs can be made to work by fusion, and are called hydrogen bombs. They are much more powerful than the fission type.

An example reaction for ***Fusion*** is:

$$^{2}H + {}^{3}H \text{ ----> } {}^{4}He + n^{o} + \text{energy}$$

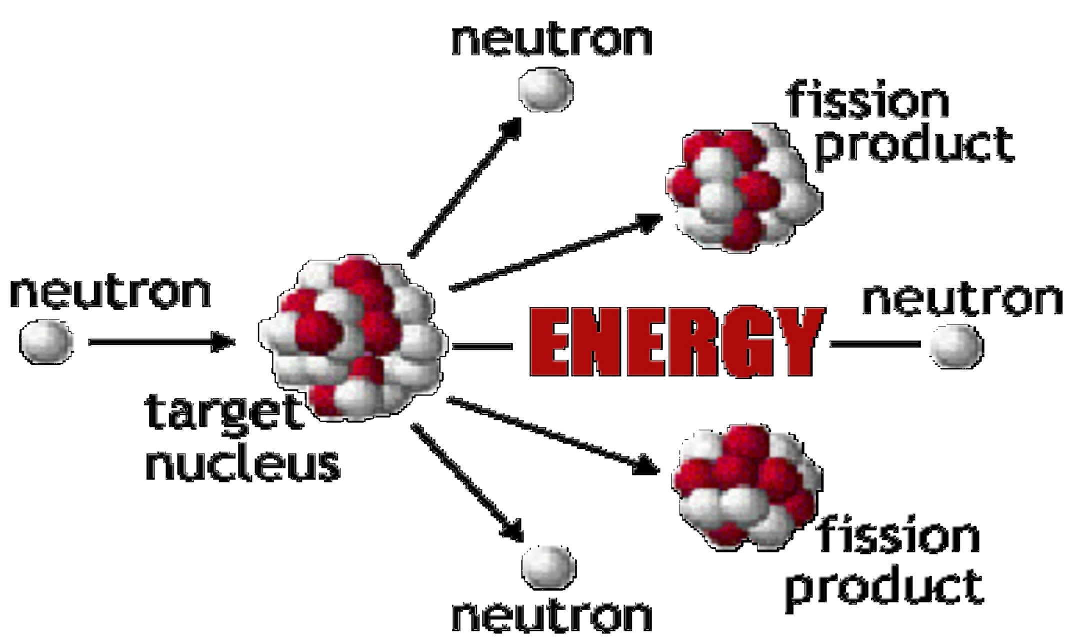
The H-2 is deuterium and the H-3 is tritium, both radioactive hydrogen atoms. They combine into helium under intense pressure and temperature (like the Sun) and form a lot of energy.

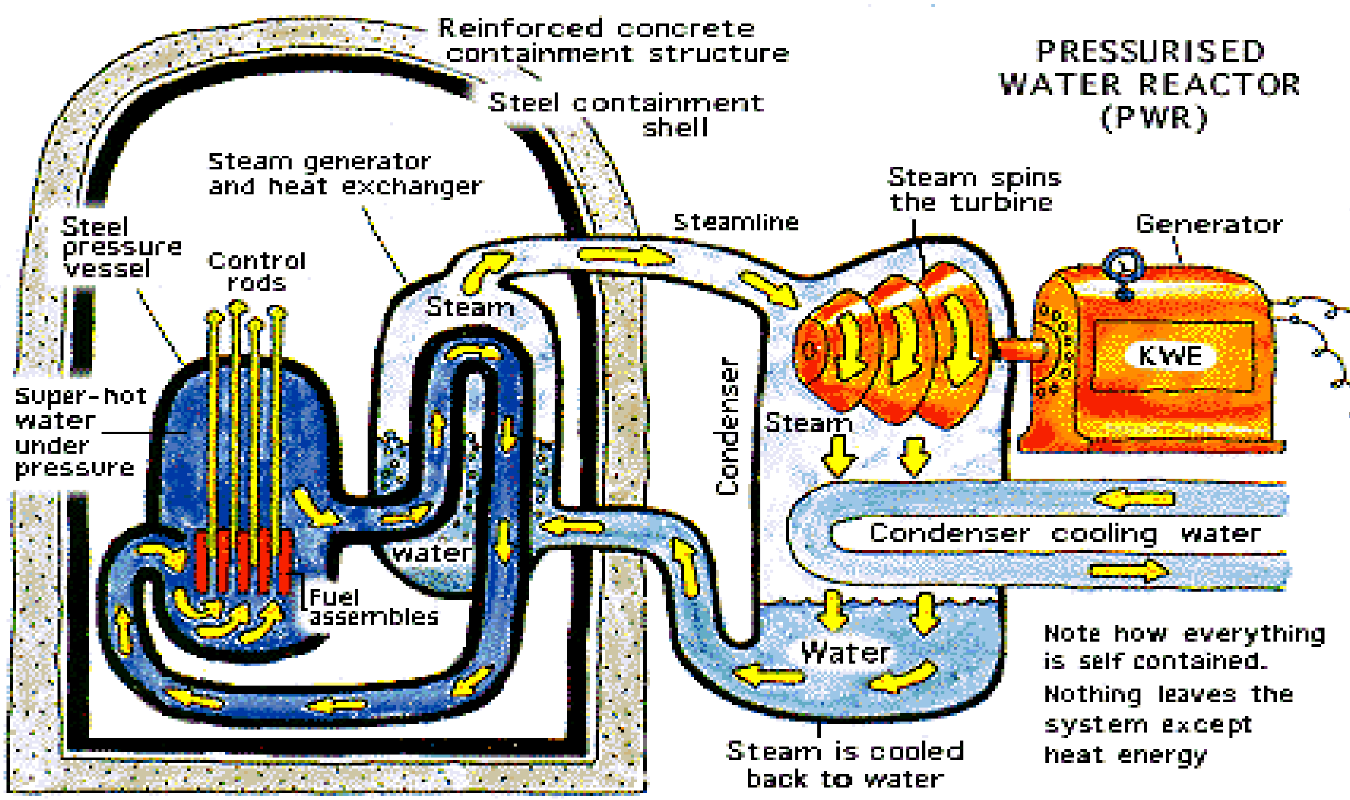
Note: mass is actually lost in this reaction, but Einstein's equation of $E=mc^2$ allows for this in that the missing mass was converted into that energy. In all nuclear reactions some mass is lost, converted into energy. Even a very small mass is equivalent to a lot of energy.

The Sun is believed to be several billion years old and is expected to last nearly several billion more, before it will undergo several transitions until it grows cold from the depletion of energy stores.

We cannot use fusion reactions in reactors because the amount of energy required to start these reactions often requires a fission nuclear bomb, and the amount of energy they would produce would be uncontrollable at this time. If technology could be created to solve these (huge) problems, there would likely be enough energy for all of Earth forever.

The beginning of a chain reaction, where a single neutron creates an unbelievably fast, uncontrolled nuclear explosion by artificial transmutation.





Nuclear Power plant diagrams

A controlled fission reaction occurs in the reactor core. It releases an enormous amount of heat, which drives the whole plant. The heat is transferred to a coolant, which heats water into steam. This steam is used to turn a turbine. Turbines contain strong magnets and a lot of copper. The magnets spin as they are turned by the steam. The moving magnetic fields cause an electric current to form in the wires. This current, electricity, is pumped out the of the power plant to power grids. Ultimately this electricity makes it to homes and businesses.

Nuclear power plants need to be built near large bodies of water. Water is sucked into the plant and that water absorbs heat from the steam that turned the turbine, allowing that water to be reheated back into steam to turn the turbine again. The water that is sucked in takes the heat and allows the steam to condense back to water. The hotter water is pumped back out to the large lake or river. This puts heat pollution out of the plant.

When the plant works perfectly, without leaks or other problems, the only waste is the heated water, and the “spent” nuclear fuel. As long as the fuel is contained safely, the tradeoff of pumping hot water out is well worth the electricity generated. (Fish don’t vote).

Nuclear Power in the USA

Positive points to nuclear power:

- Disposal of wastes is a problem, but all wastes ever produced would fit into a football field
  sized box, only 3 feet deep.
- Finding a new way to store, or deal with wastes might be just around the corner.
- Small volume of waste produced makes them easy to control and protect.
- There is no carbon dioxide produced by nuclear power, better for global warming problem
- Shipping of nuclear fuel has never been compromised in the past 20 years
- There has never been a nuclear reactor failure in the USA ever.

Negative points to nuclear power:

- Until a technology for safe, permanent containment of radioactive wastes has been developed and tested, it is irresponsible to continue producing them.
- Nuclear wastes remain dangerous for extremely long periods of time, no human institutions or physical buildings have lasted even close to long enough to be sure that they will remain "safe".
- Nuclear wastes could get into our environment at any time over millions of years, causing unbelievable harm to life.
- Ethically, we do not have the right to burden future generations with the potential risks posed by nuclear wastes.
- The alleged "perfect" record of nuclear transport is flawed. No major accidents have occurred, but many troublesome incidents have.
- Chernobyl and Three Mile Island (these 2 disasters speak for themselves).

Nuclear Bombs dropped on Japan

At the end of World War Two, America dropped 2 atomic bombs on Japan to force it to surrender and end the war. Both bombs were fission bombs, meaning that a chain reaction was allowed to occur which lead to a near instantaneous release of enormous energy, killing many thousands of people immediately, and exposing many more thousands to high doses of radiation, which poisoned them.

The bomb dropped on Hiroshima was called "Little Boy", on August 6, 1945. The bomb consisted of enriched uranium (concentrated radioactive isotope). Approximately 600 milligrams of this uranium was converted into energy. About 140,000 humans were killed in total (blast and radioactive poisoning).

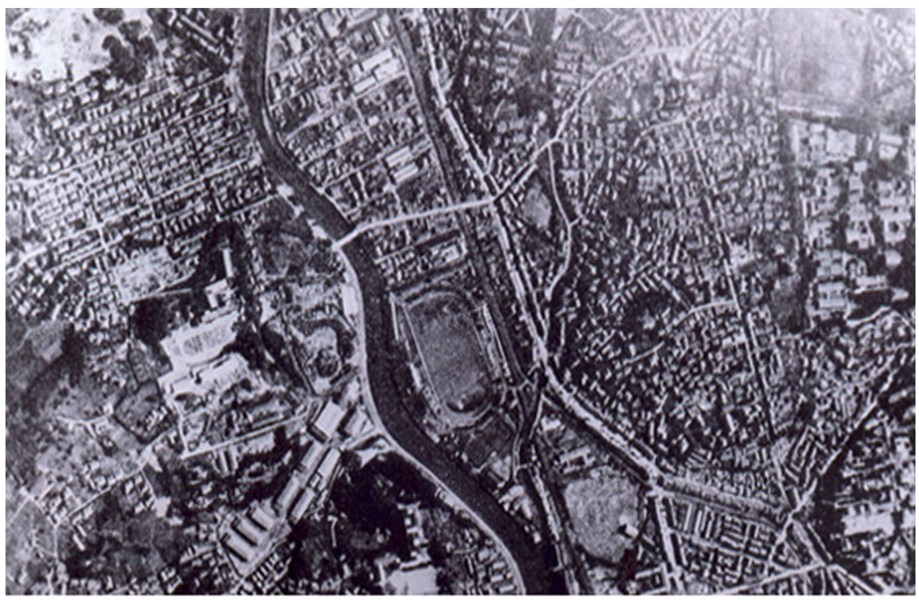
The bomb dropped on Nagasaki came three days later. It was called "Fat Man", and was a plutonium bomb. This bomb exploded about 1800 feet over the city, and killed about 40,000 people instantly. Many thousands more died from radiation poisoning. This bomb was actually stronger in explosive power but due to the hilly terrain was less destructive than the bomb in Hiroshima where it was flatter.

A picture of Nagasaki, Japan before and after the nuclear bomb exploded is on the next page.

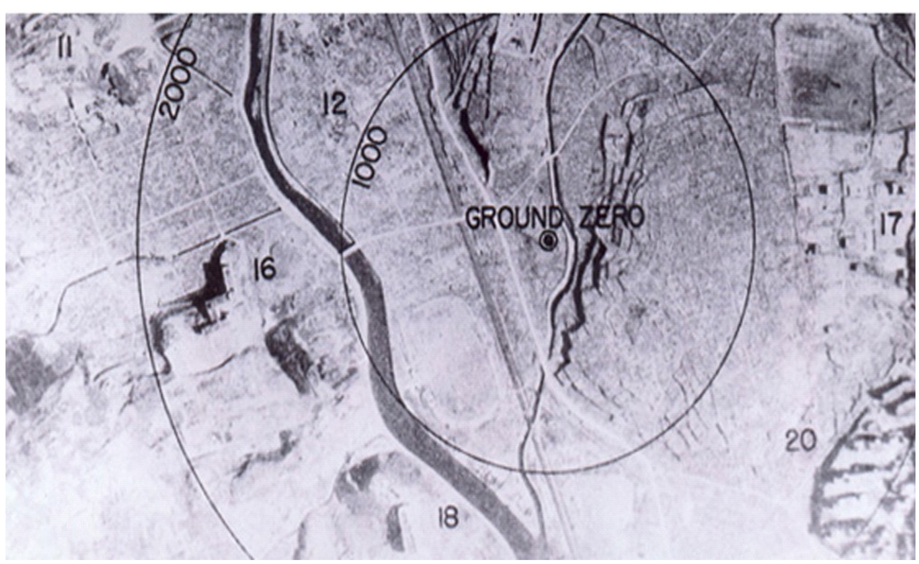
Dirty Bombs

A dirty bomb is not nearly as destructive as an actual nuclear bomb. A dirty bomb is a relatively small explosive device that is wrapped with radioactive material. The bomb blasts this radioactive material into the environment, causing little physical damage, but a lot of psychological fear, and causing the deaths of few people by radiation poisoning. Clean up would be difficult, expensive, and possibly impossible. This bomb is designed to cause havoc and economic damage rather than kill many people.

Before

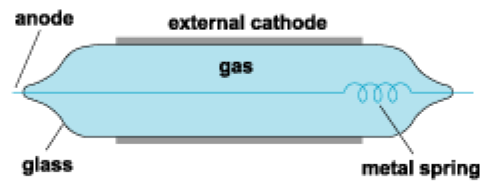


After



Geiger Counters

These are devices that measure the presence and concentration of radioactive particles. Developed by Hans Geiger and others. The cylinder of gas is affected by the particles, and these radioactive particles ionize some of the gas.



These ionized gas particles ionize others, and the amount of particles is measured electrically along a high voltage wire in the tube. The more particles ionized, the greater amount of radioactivity is present.

Often these devices will count the amount of energy by audible clicks that can be heard by the person with the Geiger counter in hand. The more clicks, the greater radioactivity. (run!)

A modern Geiger Counter is at left, and the way the device works is shown in blue. The gas atoms are ionized and "counted" by the high voltage wire strung through the center.

Measuring Radiation exposure in humans:

Radiation is usually measured in millirems. Americans are usually are exposed to 300 millirems of naturally occurring radiation in a year and about 60 more millirems of man-caused radiation (smoking, smoke detectors, fallout from nuclear tests of the past, X-rays, color televisions, cell phones, and nuclear power plant leakages, etc.).

Measuring the amount of radiation you are exposed to can be done electronically, or with old fashioned "film" badges which get developed and checked for "darkness" or exposure to radiation. Federal and state governments set standards for allowable exposure to radiation. Workers in health fields (dentist, doctor, X-ray technicians, etc.) all are monitored and limited to certain exposures per day, week, or year. If people are accidentally over exposed, they are not permitted to work until a period of time passes.

If you are overexposed to radiation you may die. You may develop cancer, and you may get sick in the short term. Different radiations and different levels of exposure will produce various effects. Radiation sickness is describe as: Illness induced by exposure to ionizing radiation, ranging in severity from nausea, vomiting, headache, and diarrhea to loss of hair and teeth, reduction in red and white blood cell counts, extensive hemorrhaging, sterility, and death.

There is no treatment for radiation sickness, although it is sometimes possible for persons to survive otherwise lethal doses of radiation if bone marrow transplants are performed.

The genetic damage from the atomic bombs dropped on Japan is still evident and such damage will continue to surface in people directly affected by the nuclear disaster at Chernobyl. This includes thyroid and other cancers, and children being born with profound physical and mental defects.

Persons working with radioactive materials or X rays protect themselves from excessive exposure to radiation by shields and special clothing usually containing lead. Processes involving radioactive substances are observed through thick plates of specially prepared glass that exclude the harmful rays. A dosimeter, a device measuring the amount of radiation to which an individual has been exposed, is always worn by persons working in radioactive areas.

Carbon Dating

On Earth there is a known ratio of "normal" non-radioactive carbon C-12 and of radioactive carbon C-14. This ratio is a constant on the whole planet and is checked from time to time. Since this ratio is constant, all living things take in carbon (plants take in carbon dioxide, animals eat plants, or other animals that ate plants), and all living things have this same ratio of C-12 to C-14 in their bodies as is found in nature. The half life of radioactive carbon is also known (about 5730 years according to our reference tables).

When we are alive we consume carbon in the ratio that it exists. When we die we stop absorbing carbon (C-12 and C-14). The C-14 continues to decay and over time the ratio between C-12 and C-14 changes, because we are not replacing the decayed carbon anymore because we stopped eating when we died.

Using some fancy math, and good tools, the change in the ratio between the carbons can be measured, and mathematically it can be determined how long ago the "fossil" stopped eating, or how long ago it died, or, how old it is.

This will work for organic material up to about 70,000 years or so. Older material has so little radioactive carbon left that the errors inherent in measuring the amount exceed the precision of the measurement. Thus, this can be used to date old stuff, but not nearly old enough to date dinosaur fossils or the Earth itself. For that we use the changing ratios of other, longer half life radioisotopes.

This is a simple explanation, of a relatively simple process, but this is not something that we can do in lab tomorrow. It is commonplace and very well accepted to work accurately to about 70,000 years.

U-238 undergoes a long process of 14 steps until it reaches stable Pb-204.
The steps in order follow here with the [half life times in brackets]

U-238 transmutes to alpha particle + Th-234 [4,500,000,000 years]
Th-234 transmutes to beta + gamma + Pa-234 [25 days]
Pa-234 transmutes to beta + gamma + U-234 [6.7 hours]
U-234 transmutes to alpha + Th-230 [2,500,000 years]
Th-230 transmutes to alpha + gamma + Ra-226 [80,000 years]
Ra-226 transmutes to alpha + gamma + Rn-222 [23,000 years]
Rn-222 transmutes to alpha + Po-218 [4 days]
Po-218 transmutes to alpha + Pb-214 [3 minutes]
Pb-214 transmutes to beta + gamma + Bi-214 [27 minutes]
Bi-214 transmutes to beta + gamma + Po-214 [20 minutes]
Po-214 transmutes to alpha + Pb-210 [0.00016 seconds]
Pb-210 transmutes to beta + gamma + Bi-210 [22 years]
Bi-210 transmutes to beta + Po-214 [5 days]
Po-214 transmutes to alpha + Pb-206 (stable) [138 days]

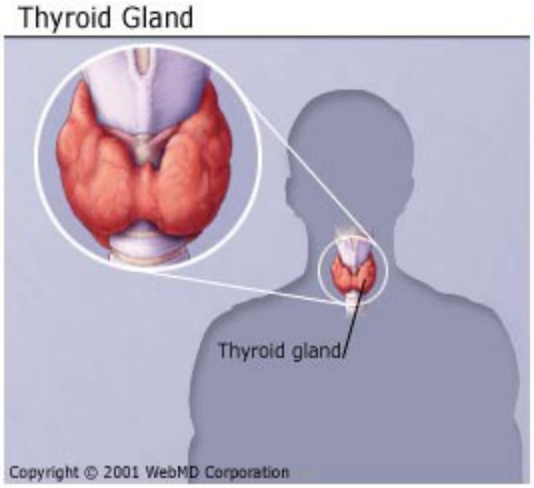
Many steps here form "elements" that are not naturally occurring and that decay. These elements are known as TRANS-URANIUM elements, meaning that they only exist during the radioactive decay of U-238.

Some steps are quick as pie, a couple are millions, or even billions of years! It's hard to get rid of this stuff.

Since the relative ratios of U-238 and other isotopes is known, how much U-238 is present in a sample can help scientists "date" rocks or fossils similar to the way radioactive carbon is used to date much more recent materials.

Nuclear Reactor Waste

Nuclear reactors use radioactive uranium to produce energy to generate electricity. The "spent" fuel contains radioactive uranium and plutonium isotopes, which can remain dangerous to living things for long periods of time. Half life time frames would be about 9,000 years to 1,000,000,000 years. Some spent fuel will decay in the shorter time frame into weapons grade uranium. This could create a dangerous place, that would be highly desirable to access (if you are a really bad guy). Full decay takes a long, long time, but that shorter nine thousand years would, in transition to full stability, produce very dangerous materials.



Thyroids and I-131

Thyroid glands in your neck absorb iodine and use it biologically to keep you healthy. When you have enough iodine and your glands work well, all is fine. If you live where you get very little iodine in your diet, your glands can swell up and you get what is called a "goiter", which is a very enlarged gland, making your neck swell very large.

To test how well your thyroid glands are absorbing iodine a doctor might inject you with a small but measured amount of radioactive iodine (I-131) and then after a measured time period measure how much is present in your thryoid gland. They have previously determined the "normal" rates of iodine absorption, and if you have enough, good, if not, they can figure out how to help you fix your glands.

start point	1 half life 8.07 days	2 half life 16.14 days	3 half life 24.21 days	4 half life 32.28 days	5 half life 40.35 days
2.4 grams	1.2 grams	0.60 grams	0.30 grams	0.15 grams	0.075 grams

The half life of I-131 is short—only 8.07 days, and although it is radioactive, it will decay relatively quickly from your body, doing little harm. That harm is offset by the gain in medical information the doctor gains in diagnosis.

If you are injected with 2.4 grams, this is how it will decay:

If the half life was longer, say 236 days instead of eight days, the radioactive material would linger in your body so long that the gain of diagnosis of your thyroid function would like be less valuable than the injury you would sustain from all the radioactive decay that would continue to happen in your body.

Doctors use radioactive isotopes often in the treatment of disease and diagnosis. X-rays are also a form of radiation, and we get them all the time (thankfully!). Co-60 or cobalt sixty is used to treat tumors. It kills all cells that the radiation is beamed at, but the plan would be to focus well, kill the tumor and hope that the good cells that die will grow back but the cancer is killed. It is a plan of action to do some harm to the body for the benefit of destroying the cancer, with as little damage occurs to the healthy parts of the person as possible.

Nuclear Accidents   Chernobyl, Russia.

In a small town called Pripyat in Ukraine, a nuclear reactor disaster occurred on April 26, 1986. The Soviet Union government tried to cover this up, but nuclear fallout that traveled to other countries was detected and finally they admitted what had happened.

56 people are said to have died nearly immediately from the radiation poisons. Other news agencies say that more than 4,000 people died from radiation sickness directly after the accident. It is thought that well over six million people were exposed to radiation.

The accident was caused by string of errors, all of them human, resulting in a melt down of a reactor core. Too much heat was generated by the fission reaction, and it got so hot that it melted through all of the containers holding it.

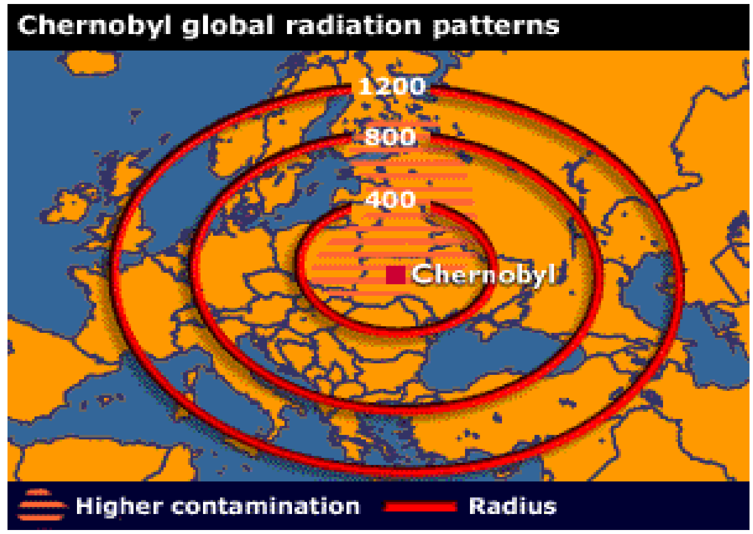
Not only did the reactor fail, but much of the radioactive material was blasted into the air. This was not a nuclear explosion, rather a major leak of radioactive material.

The radioactive iodine and strontium released were the more serious problems, as those isotopes accumulate in the food chain and become toxic in the higher animals and of course in humans. Much of the radioactive gases were also released into the air, and were spread out over a vast area, including measurable changes in radioactivity in North America.

The photo shows the extent of the damage at the plant caused by the meltdown.

A circle around the plant of 18 miles in radius has been totally evacuated, although many scientists believe that this is much too small an area to isolate. Still, nearly 300,000 people live “too close” according to Western science. Well over 600,000 people were overexposed to radiation and experience high cancer rates and many problems with bearing healthy children.

As the buildings deteriorate there are many concerns that more radioactivity would be released into the air, adding more biological concerns to people throughout Russia and Europe. There seems little money or effort to contain this disaster as the Soviet Union has collapsed and their economy is weak.



Recent news said that Bechtel Corp. of the US will be finally putting a top over this melted down reactor more than 20 years after the disaster.

At right is a map showing how far the radiation from Chernobyl expanded. Most went north due to the winds.

Three Mile Island, Pennsylvania Disaster March 28, 1979
(10 miles from the state capital)

This nuclear plant suffered a partial meltdown and nearly completely failed. The plant did release some nuclear material and luckily was not as bad as it could have been.

Human error dealing with pumps and coolant resulted in an overheating, and then to the meltdown. The reactor was so radioactive it could not be approached for nearly 10 years. It remains off line. Cleanup took until 1990.

Although this accident did not result in any direct death or destruction, it was used dramatically by anti-nuclear protesters to ban nuclear power as dangerous and unsafe. Politically it was a real blow to the industry. Not a single nuclear power plant has been built since that time in the United States.

Strangely, a Hollywood movie about a nuclear disaster, called **The China Syndrome**. It was released March 16, 1979, just 12 days before a nuclear disaster happened! In the movie a reporter (Jane Fonda) chanced upon a nuclear accident that is being covered up, and she works to present what “really” happened. Diabolical villains bent on profits try to cover it up, to the point of killing a loyal but honest employee (Jack Lemmon). The title refers to how a meltdown would melt all the way to China, on the other side of the world.

Nuclear Material as a tool for killing

In November 2006 a former Russian KGB officer - Alexander V. Litvenko, who was living in England, was murdered by polonium poisoning. Polonium releases alpha particles which would bounce off your skin. It is fatal when swallowed.

It took months, but the British intelligence service has "proved" that another former KGB officer - Andrei Lugovoi - should be charged with this murder. Apparently Mr. Litvenko met with this other man over a meal in a restaurant, and ingested radioactive polonium. Polonium decays by emitting alpha particles. Alpha particles cannot break through your skin, but once eaten, easily start destroying your cells, from the inside out. Mr. Litvenko died a painful and extended (several weeks) death.

Rumors were that he was saying bad things about the President of Russia, Vladimir Putin, yet another former KGB officer in this story. Putin is reputed to have killed off several other prominent detractors and his civil rights record is up for criticism in the international press.

No one was ever brought to justice for this murder. The alleged killer is living in Russia at this time, and Russia does not have any extradition protocols with other countries. Russia has said that if England provides this "proof", it would try Mr. Lugovoi in Russia instead.

Alexander Litvinenko

Healthy, then near death.