Nuclear PACK

BASICS & NOTES

Your name

Radioactivity, Decay, Natural Transmutation, Artificial Transmutation, Half-Life Math, Carbon Dating, Fusion, Fission, Bombs, Power Plants, Medicine, Alpha, Beta, and Gamma Radiation, Stable Isotopes, Unstable Isotopes, the Sun, $E = mc^2$, and more.

Table N
Selected Radioisotopes

Nuclide	Half-Life	Decay Mode	Nuclide Name
^{198}Au	2.695 d	β^-	gold-198
^{14}C	5715 y	β^-	carbon-14
^{37}Ca	182 ms	β^+	calcium-37
^{60}Co	5.271 y	β^-	cobalt-60
^{137}Cs	30.2 y	β^-	cesium-137
^{53}Fe	8.51 min	β^+	iron-53
^{220}Fr	27.4 s	α	francium-220
^{3}H	12.31 y	β^-	hydrogen-3
^{131}I	8.021 d	β^-	iodine-131
^{37}K	1.23 s	β^+	potassium-37
^{42}K	12.36 h	β^-	potassium-42
^{85}Kr	10.73 y	β^-	krypton-85
^{16}N	7.13 s	β^-	nitrogen-16
^{19}Ne	17.22 s	β^+	neon-19
^{32}P	14.28 d	β^-	phosphorus-32
^{239}Pu	2.410×10^4 y	α	plutonium-239
^{226}Ra	1599 y	α	radium-226
^{222}Rn	3.823 d	α	radon-222
^{90}Sr	29.1 y	β^-	strontium-90
^{99}Tc	2.13×10^5 y	β^-	technetium-99
^{232}Th	1.40×10^{10} y	α	thorium-232
^{233}U	1.592×10^5 y	α	uranium-233
^{235}U	7.04×10^8 y	α	uranium-235
^{238}U	4.47×10^9 y	α	uranium-238

Source: *CRC Handbook of Chemistry and Physics*, 91st ed., 2010–2011, CRC Press

Table O
Symbols Used in Nuclear Chemistry

Name	Notation	Symbol
alpha particle	$^{4}_{2}He$ or $^{4}_{2}\alpha$	α
beta particle	$^{0}_{-1}e$ or $^{0}_{-1}\beta$	β^-
gamma radiation	$^{0}_{0}\gamma$	γ
neutron	$^{1}_{0}n$	n
proton	$^{1}_{1}H$ or $^{1}_{1}p$	p
positron	$^{0}_{+1}e$ or $^{0}_{+1}\beta$	β^+

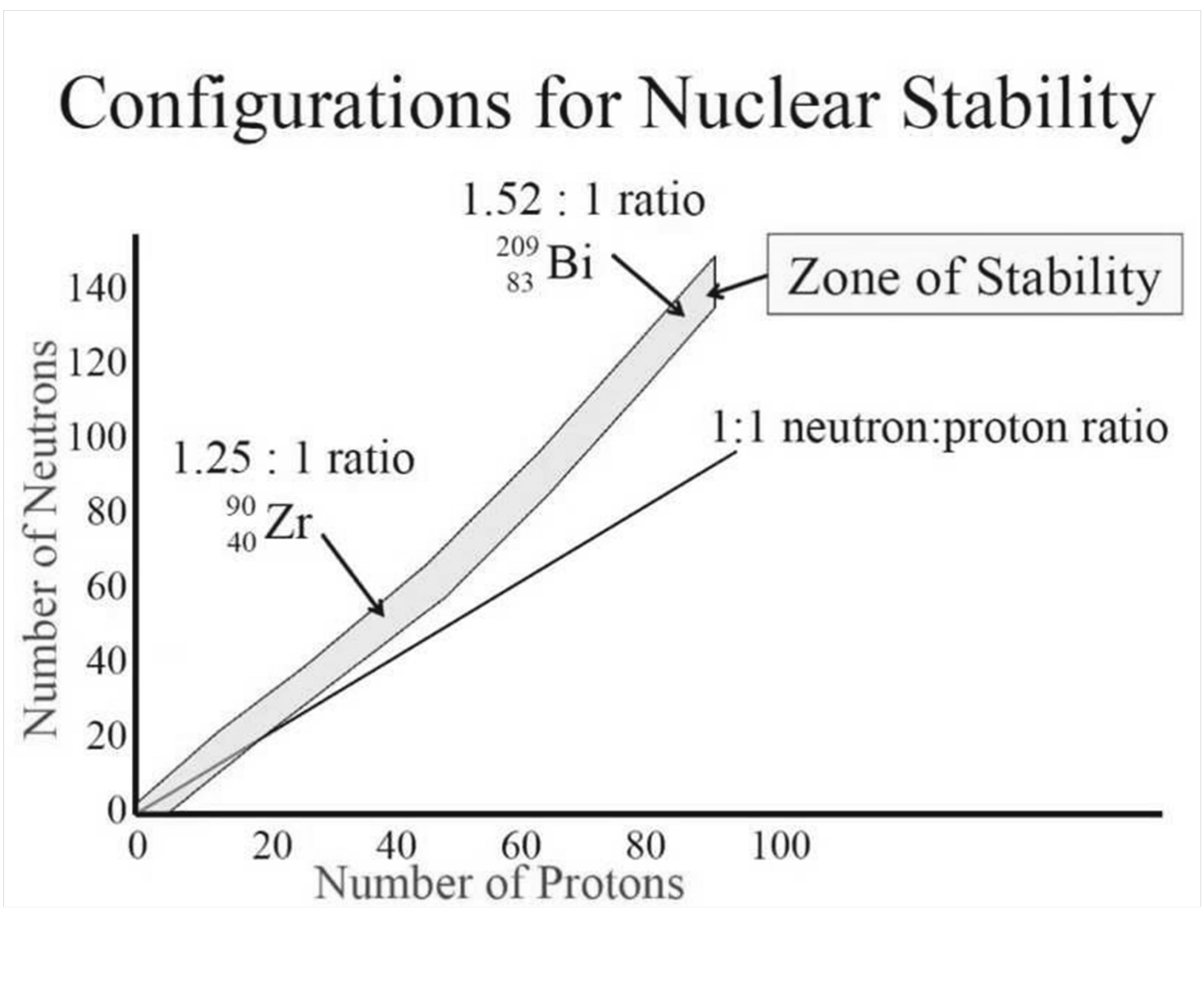
Nuclear Basics

Nuclear Chem covers radioactive isotopes, half lives, natural transmutation, artificial transmutation, fission and fusion reactions, nuclear power, carbon dating, fossil dating, medicinal uses for radioactivity, atomic bombs, how the Sun works, and we will discuss the Pro's and Con's about nuclear energy. We will use reference tables N and O to help us.

There are 118 atoms on the periodic table, and there are nearly 1500 isotopes. Isotopes are chemically identical atoms with different numbers of neutrons and therefore, different masses. Isotopes just exist, and each of the 118 atoms has several isotopes. Out of the approximately 1500 isotopes, over 1300 of them, are stable atoms, but about 150 of the isotopes are unstable. Unstable isotopes emit radioactivity.

By emitting particles and energy from their nucleus, these unstable nuclei attempt to change the ratio of neutrons to protons, to get more stable. Sometimes this is a one step process, sometimes many emissions is required to change this ratio into the band of stability. There is no one stable ratio, but smaller atoms are stable with a neutron proton ratio closer to 1:1. Larger atoms have a ratio of 1.25 neutrons per proton, and the largest atoms have a 1.5 neutrons per proton ratio. This graph below shows the band of stability, or the ratio of neutrons to protons for stable isotopes. If an atom's ratio is outside of this band, they are unstable and will emit radioactivity to change the unstable ratio for a more stable one.

My favorite atom Mercury is stable with 121 neutrons and just 80 protons, 121:80 is approximately a 1½ neutrons:1 proton ratio. Zirconium and Bismuth are noted in the graph, both of these isotopes fall inside the zone of stability, these are NOT radioactive. Zr has a 50 neutrons : 40 protons ratio (1.25 ratio), while Bi has 126 neutrons : 83 protons (1.52 ratio), and both are stable, they do not emit radiation.



To become stable, these unstable nuclei will emit radiation, which is literally pieces of their nucleus (and or pure energy) to change their ratio of neutrons to protons to a more stable ratio. Sometimes an unstable atom only emits radiation particles one time, and they get a stable nucleus and the radioactive part of their "life" is over. Sometimes it takes more than one step, it must emit radiation more than one time, to keep changing until it gets stable.

Each radioactive (unstable) isotope emits a particular type of radiation. Each isotope emits the same radiation and they do it at a timed, predictable rate. A radioisotope (an unstable isotope) emits radiation and becomes stable, this process ends. If the radioisotope emits radiation and is still unstable, it must emit more radiation on its path towards stability.

The particulars for each isotope are well known and are in data tables. Of the 200 unstable radioisotopes, only 24 of them are listed in table N. Once you get the hang of how each kind of radiation particle emission changes the nucleus, you can apply the same process to other isotopes you might meet in class or on the regents exam.

There are several forms of radiation, each radioactive isotope emits one kind of radiation at a time (although sometimes particles plus pure energy together). They follow patterns that are known.

When a radioactive isotope changes by emitting radioactivity (particles or energy or both), this is called natural transmutation. Natural, because it just happens without help from anyone, and transmutation which means changing into something else.

Often unstable atoms will change from one kind of atom (or element) into a different kind of atom, because the number of protons changes.

This is sort of crazy, it's like a boy turning into a puppy, or a Prince turning into a Llama than "normal chemistry".

Nuclear chem is filled with unusual events. The "simple" process of radioactive decay, or transmutation, is just the first of many weird things that occur.

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

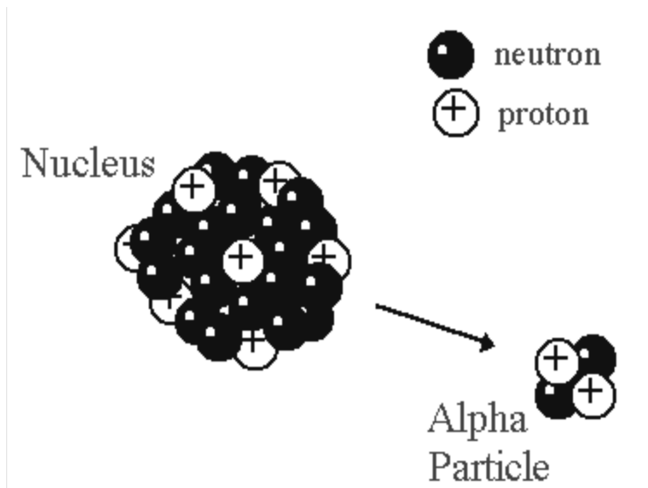


Table O
Symbols Used in Nuclear Chemistry

Name	Notation	Symbol	Relative size and charge
alpha particle	$^{4}_{2}He$ or $^{4}_{2}\alpha$	α	mass = 4 amu +2 charge
beta particle	$^{0}_{-1}e$ or $^{0}_{-1}\beta$	β^-	mass = 0 -1 charge
gamma radiation	$^{0}_{0}\gamma$	γ	no mass and no charge, this is pure energy
neutron	$^{1}_{0}n$	n	mass = 1 amu no charge
proton	$^{1}_{1}H$ or $^{1}_{1}p$	p	mass = 1 amu +1 charge
positron	$^{0}_{+1}e$ or $^{0}_{+1}\beta$	β^+	mass = 0 +1 charged electrons

As far as "strength" or penetrating power, alpha particles are hardly a match even for your skin (but don' eat them, I'm not kidding) Here is alpha, beta, and gamma radiation bumping into paper, plastic, hands, steel, and concrete. Gamma is hard to stop.

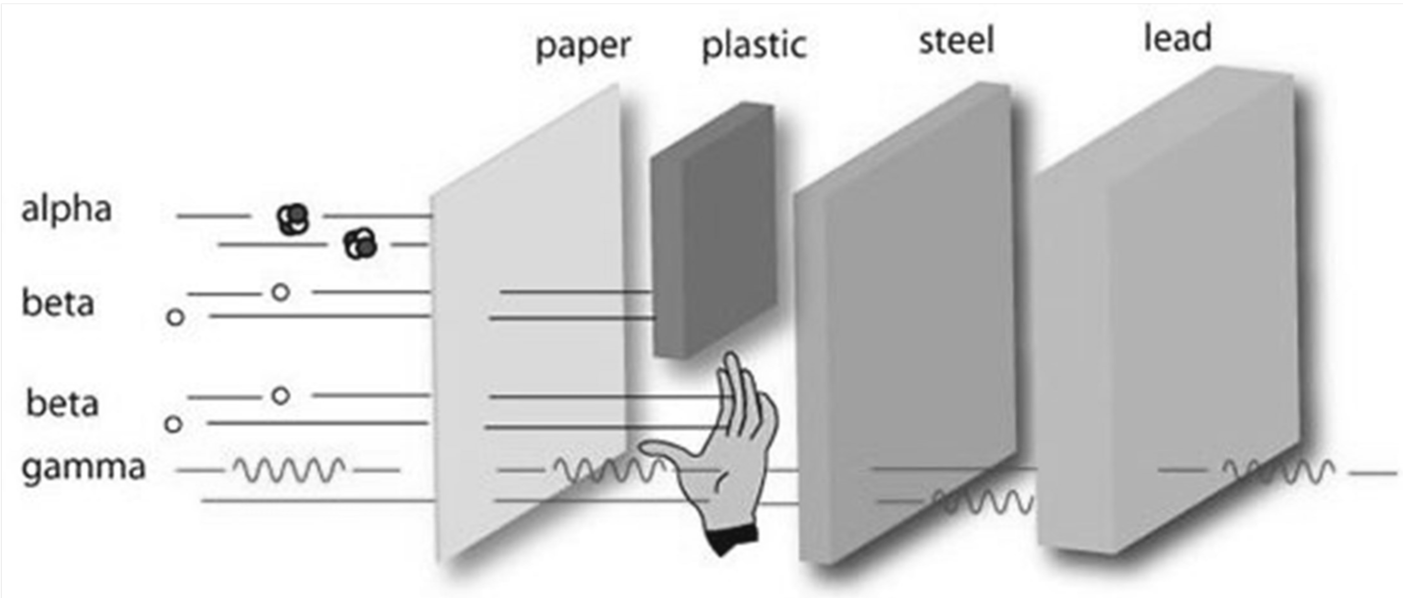


Table N: Selected Radioisotopes

The column headers on table N include nuclide or isotope (these nuclides are all radioactive) as well as the half life, decay mode and name.

For example, the first radioisotope is ^{198}Au is called gold-198. Underneath the 198 should be the isotope's atomic number. All gold atoms have are #79 on the periodic table, they have 79 protons (and 79 electrons). Not all gold atoms are radioactive. Since the mass of this isotope is 198 and there are 79 protons, that means that this isotope has 198-79= 119 neutrons.

Another way to write this radioisotope symbol would be: $^{198}_{79}\text{Au}$

It would be sensible for the state education board to include that 79, since EVERY gold atom in the universe has 79 protons, but they are (quite literally) trying to torture you. These details matter, don't slip up!

^{14}C stands for Carbon-14, one type of radioactive carbon, the one used in carbon dating of bones and frozen mammals like mammoths. Since every carbon atom in the universe has six protons, it's written this way: $^{12}_{6}\text{C}$

The second column on Table N is called half life. A half life is the amount of time it takes for one half the mass of a radioactive isotope to decay, or to breakdown, or change into something more stable. When an isotope decays, it quite literally emits part of its nucleus as a radioactive particle, to change the neutron proton ratio. The loss of particles leads to a more stable nucleus, which is what the isotopes is attempting to gain. Each isotope changes (or it transmutes) at its own rate. This rate is called the HALF LIFE. It is like a CLOCK, exactly half is able to change in the time called the half life. How this happens is still unexplained.

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

This decay is a random process, you cannot predict that "this" atom will decay and "that" one won't. Half of the atoms will decay in a half life. The length of time a half life takes is dependent upon the isotope. They all have their own rate and their own process and it takes what ever time it takes. Table N shows 24 half life time frames — from milliseconds to billions of years.

The decay mode shows the individual particles of radiation that the nucleus of an isotope gives off. Some isotopes emit alpha particles, some emit beta particles, some emit positron particles. Some emit gamma radiation, which is NOT even a particle, just energy. All radiation is unsafe to living things. It's best to be avoiding this as the radiation can harm or kill cells outright, or cause your DNA to change, which can cause genetic damage which can show as cancerous cells growing in an organism or person.

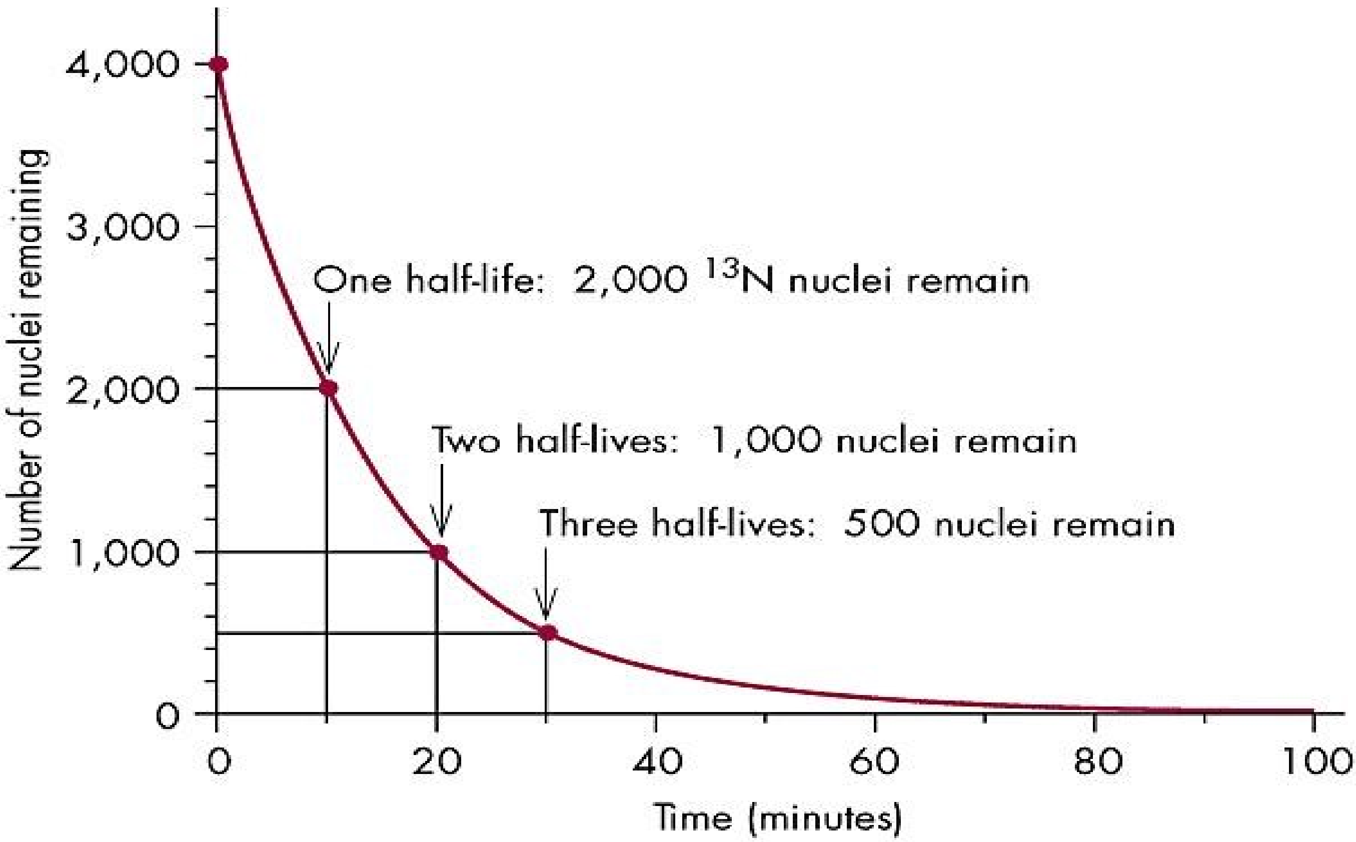
We can use the decay mode to determine what new atom the radioactive isotope will transmute into (become) when they emit or give off these radioactive decay particles.

When isotopes emit particles and transmute into different types of atoms, this process can be described as:

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

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

This graph shows the half life of radioactive nitrogen-13. This graph starts out with 4,000 radioactive nitrogen atoms. After EACH half life, there are only ½ the number of isotopes left. The ½ life is 10 minutes.



All half life graphs are identical, the only difference being the actual time in half life. Some half lives are seconds long, some millions of years. After each half life, only half of the original isotope remains.

Below are three types of natural transmutation (all from table N). Watch how the math works - for the first transmutation, francium has 220 total neutrons and protons, when it emits an alpha particle, it emits 4 of them, and that leaves it with just 216. It starts with 87 protons, but when 2 are emitted in the alpha particle, it has just 85 left over. The only atom in the world with 85 protons is astatine. Francium transmuted into astatine. ALL DECAY MODES WORK WITH THIS SIMPLE ARITHMETIC PROCESS.

Decay mode	Radioisotope	Decay Products
Alpha	$^{220}_{87}\text{Fr} \rightarrow$	$^{4}_{2}\text{He} + {}^{216}_{85}\text{At}$
Beta	$^{198}_{79}\text{Au} \rightarrow$	$^{0}_{-1}\text{e} + {}^{198}_{80}\text{Hg}$
Positron	$^{19}_{10}\text{Ne} \rightarrow$	$^{0}_{+1}\text{e} + {}^{19}_{9}\text{F}$

Half life examples

^{198}Au = 2.695 days ^{14}C = 5715 years ^{37}Ca = 182 milliseconds

If you have 100 grams of a radioisotope, when only 50 grams remains — because 50 grams decayed into different atoms and radiation, the time it took for that is a half life. All radioisotopes have their own half life, the amount of time it takes for half of what is present to decay, or transmute, into something else.

There is no real reason for these time frames, but they are exact and unchanging. A half life means enough time passes so that only one half of the mass of the original, unstable radioactive isotope remains. Sometimes it is a one step process to nuclear stability, but often it takes multiple steps. The amount of time it takes varies greatly. The times, or half life of the radioisotopes, are listed for you in Table N.

Table O decay particles and their symbols explained

Alpha Particle: 4 is the total mass of 4 AMU. The 2 is for 2 protons included 4 AMU total
(2 protons + 2 neutrons = 4 AMU total)
He stands for helium, an alpha particle is identical to a He nucleus, with no electrons.

Beta Particle: 0 for no mass in high school, -1 is for a negative one charge, e for electron.
Beta particles are LIKE electrons

Gamma Radiation: no mass, no charge, pure energy and very much 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^+ plus 1 n° Tritium has 1 p^+ and 2 n° with a mass of 3 AMU.
"Normal" or non-radioactive hydrogen has no neutrons at all.

Positron: 0 for no mass in high school, +1 for a positive one charge, and the e is for electron.
Strange things happen in nuclear chemistry. Positron particles are very strange.
They have the e like an electron, but they are positively charged, which is opposite of electrons.

FISSION VS. FUSION Reactions

The transmutation of radioactive isotopes into more stable isotopes occurs without any help from scientists. It occurs at it's own rate which can't be speeded up or slowed either. These are NATURAL transmutations because they occur naturally, without human intervention.

Some transmutations only occur when humans get mixed up in it. These are called artificial transmutations. They include FISSION reactions, which mean the "splitting of atoms" which occurs in many nuclear bombs and in all nuclear reactors. There are many kinds of fission reactions (like there are many compounds that could combust, or many types of synthesis reactions). All fission reactions have humans blasting an atom's nucleus with particles to make it unstable, these unstable nuclei split apart immediately.

When they split, they release 2 or more daughter nuclei (smaller atoms), some extra neutrons to expand the reaction, and some energy too. This process repeats over and over, making the reaction get bigger and bigger each cycle, releasing more and more energy. With enough fuel to start with this will literally explode with crazy energy, a nuclear bomb type explosion. To explode like this, sufficient radioisotope must be present to split. If not enough is present, the reaction continues, but the explosion is much smaller.

An example of FISSION reactions follow: U-235 forms U-236 when bombed by a neutron. This splits into the 2 daughter isotopes (Kr and Ba) releasing 3 more neutrons and energy. This cycles over and over, releasing more energy and then a new cycle expands the reaction and releases more energy.

$$^{235}U + n^o \rightarrow {}^{236}U \rightarrow {}^{92}Kr + {}^{141}Ba + 3n^o + \text{energy}$$

In a power plant, this reaction is controlled (by control rods) which mechanically move into the reactor core, and absorb neutrons. This allows the chain reaction to run, but not get out of control. It keeps the fission going, but limits the rate, which allows the reactor to just stay very hot. The heat is used to produce energy to turn a turbine to make electricity.

FUSION reactions are not the same as fission, although they release even more energy. In fusion, small atoms (hydrogen usually) are squished together under extreme heat and pressure to make helium atoms. On the Sun, the process is different than on Earth. Humans have been able to make fusion happen, but in a slightly different (easier) way. The amount of energy released in fusion reactions is so great that it is uncontrollable. The Sun produces heat this way, humans have made fusion bombs (AKA hydrogen bombs) which are much more powerful weapons than fission bombs, and totally uncontrollable at present.

Simplified Fusion on Earth is done this way	$^{2}H + {}^{3}H \rightarrow {}^{4}He + n^o + \text{energy}$
Fusion on the Sun is done this way	$4H^{+1} \rightarrow He + 2n^o + 2\text{ positrons} + \text{energy}$
Note:	The second process requires vast pressure and heat, available in the center of the Sun but not on Earth.

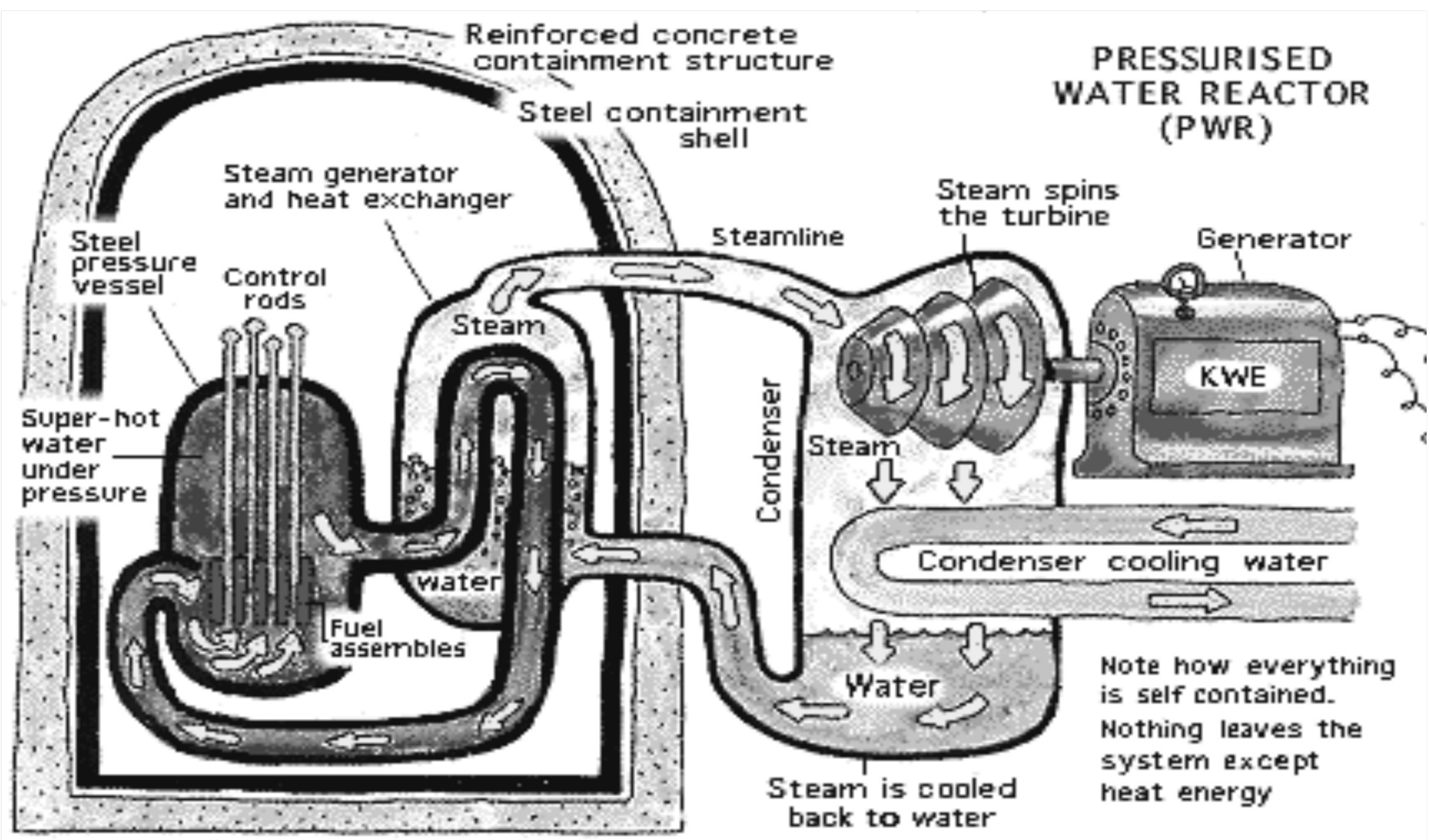
In both Fission and Fusion reactions there is a small loss of mass, which can be explained with Einstein's famous equation of $e = mc^2$ or energy equals matter times the speed of light squared.

What that really means is that this is WAY to complicated to really explain, but in fact, some mass of the reactants is lost, and converted into huge amounts of energy. In that equation, the "important" thing to see is that e=m, energy and mass are the SAME THING. A small bit of mass can be multiplied by a huge constant (squared) to equal energy. A little mass is equal to A LOT of energy.
How this happens is not easily explained in high school, but it happens nonetheless.

A fission reaction nuclear power plant operates to produce electricity. All power plants make heat, to boil water into high pressure steam. The steam pumps through pipes, and turns the blades of a turbine (like a big propeller) to turn the magnets around wires. This moving magnetic field creates motion in electrons (electricity). That's been known for a hundred years, but it is still more complex than this few sentences makes it seem.

Burning coal, oil, or gases to make heat to do this occurs all of the time. The use of a controlled fission reaction, one that does not get out of control, is a way to make heat. The US has about 99 reactors in 61 plants (some plants have more than one reactor). As of April 2025, there are about 440 nuclear power plants in 32 countries (including the US). There are 85 new plants being built today.
The country of France has the most reactors under construction at this time.

Below is a cartoon diagram showing a simple version of how a plant works.



Negative points to nuclear power:

- Nuclear wastes are extremely toxic to living things, and can cause horrific environmental problems. Until a technology for safe, permanent containment of radioactive wastes has been developed and tested, it's irresponsible to continue producing them.
- Nuclear wastes remain dangerous for extremely long periods of time, no governments or buildings have lasted even close to long enough to be sure that they will remain stored away "safe".
- 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 catastrophes have occurred, but many troubling incidents have.
- Plants in Fukushima, Japan and in Chernobyl, Ukraine had real meltdowns, radiation leaked and poisoned the land. .
- The 3-Mile Island (PA) plant had a near meltdown in March 1979, but it was averted at the last minute.

Positive points to nuclear power:

- Finding a new way to store, or deal with wastes might be just around the corner.
- A relatively small volume of waste produced makes them easy to control and protect.
- There is no carbon dioxide produced by nuclear power, there will be less global warming.
- Shipping of nuclear fuel has never been compromised in the past 20 years
- There has never been a nuclear reactor failure in the USA, we know how to do things right.
- The electricity produced is relatively cheap, minus clean up costs of accidents and long term waste storage.

Nuclear Bombs dropped on Japan

At the end of World War Two, America dropped two 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 thousands more to high doses of radiation, which poisoned them.

The bomb dropped on Hiroshima on August 6, 1945 was called "Little Boy". 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.

Modern nuclear bombs are much bigger and some are hydrogen bombs. A fission bomb is a million times more powerful than a regular military bomb. A fusion bomb is about 4X bigger than a fission bomb. It uses a fission bomb as a trigger for the fusion reaction.

The politics of using or even having weapons like this is fraught with ethical issues and creates global stress even when these weapons are not being used.

Dirty Bombs

A dirty bomb is not nearly as destructive as an actual nuclear bomb. A dirty bomb is a small explosive device that is wrapped with radioactive material. The bomb blasts the radioactive material into the environment, causing little physical damage, it is a device of terror and intended to cause economic harm rather than outright destruction and death. The clean up would be difficult, expensive, possibly impossible. This weapon is designed to cause havoc and economic damage rather than kill many people. This is an important reason that radioactive wastes be kept protected for the thousands of years it will take until they are finally stable.

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 in college you can check that it is still constant (it is) . Since this ratio is constant, and all living things take in carbon (plants take in carbon dioxide, animals eat plants, or other animals that ate plants, humans eat animals and plants), all living organisms have this same ratio of C-12 to C-14 in their bodies as is found in nature.

When we are alive we consume carbon in the ratio that it exists, and we excrete it too, so the ratio remains constant in organisms. When we die we stop absorbing carbon (we stop eating).

Since 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.

Because of scientists ability to measure accurately, this carbon dating process can be confidently measured on organisms that have died 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.

Carbon dating can be used to date old stuff, but not nearly accurate 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, and this is not something that we can do in a high school lab tomorrow. It is commonplace in colleges and is scientifically accepted to work accurately to about 70,000 years.

Willard Frank Libby was awarded the Nobel Prize in Chemistry in 1960 for his work on radiocarbon dating, a method using carbon-14 to determine the age of organic materials.

Medical uses for radioactive materials

Doctors can use radioactive cobalt-60 to produce beams of beta particle radiation which can be carefully aimed at tumors and cancers that cannot be operated on because of their locations. The radiation kills most of the cells it hits, including the healthy ones that are not cancer. The general plan is to kill all of the bad cancer cells, and as few of the good ones as possible. Once the tumor or cancer is treated or destroyed, the body will begin to repair most of what was damaged by the treatments.

The net result is better than letting the tumor kill a person, but radiation is not good for living cells, this treatment works but the side effects are not to be taken lightly.

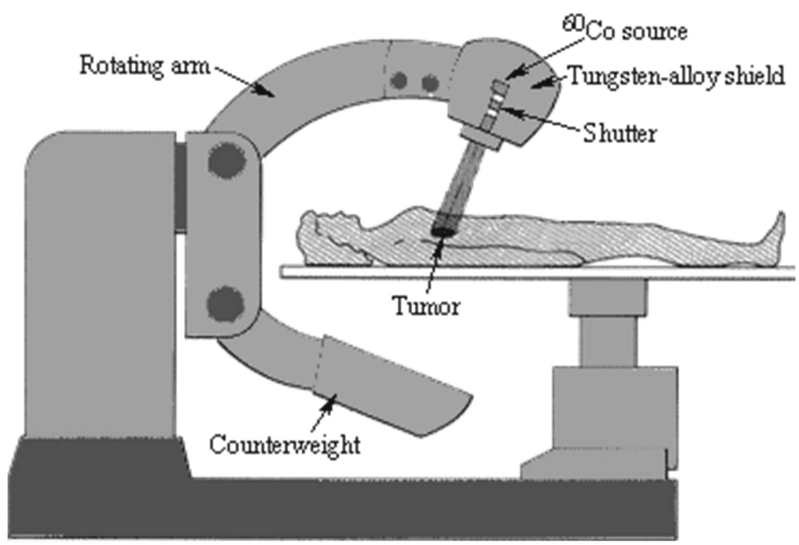
Doctors can also use radioactive iodine-131 to inject into people, to diagnose how well a thyroid gland is absorbing iodine. After a period of time a radiograph (type of image) can be taken of the thyroid gland in the patient's neck. Doctors can measure how much of the radioactive iodine was absorbed and compare that amount to "normal" uptake. Radiation is always bad, but here a small amount is injected to a person and the results "are worth more" than the expected negative effects.

Radioactive iodine is chemically identical to stable iodine. Doctors can also inject radioactive iodine into patients with some thyroid cancers, and the thyroid gland can absorb this radioactive iodine, and while this I-131 is in the gland it will emit beta radiation, killing cancerous cells.

Cobalt-60 is used to treat tumors or cancers.

Iodine-131 is used to diagnose and also to treat tumors or cancer.

Uranium or other radioactive elements are not used medically by doctors.



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!)

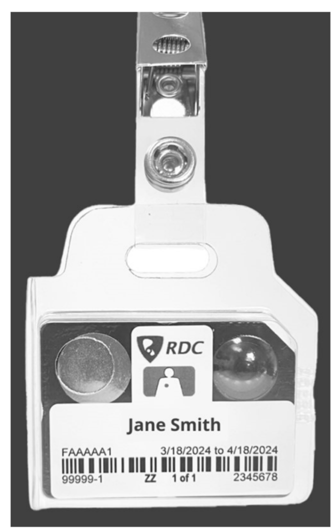
A modern Geiger Counter is at left, and the way the device works is shown in blue. The gas atoms are ionized and "counted" by the high voltage wire strung through the center.

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, 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. The Federal government sets 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.
(ask your doctor or X-ray tech the next time you get an X-ray).
An X-ray exposure badge is at right.



If you are overexposed to radiation you may die. Radiation can kill cells outright, or you may develop cancer. Different radiations and different levels of exposure will produce various effects.

Radiation sickness is describe as and 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, or death.

Nuclear Chem Notes

1 Nuclear Chem is about the ______________________, not the electrons,

and nuclear chem is _________________.

2 Atoms have protons and neutrons in the nucleus, the electrons fly around outside.
In every atom the number or protons =

3 The ATOMIC NUMBER =

4 Atomic MASS in high school =

5 Atomic Mass =

6

Element	Atomic Mass	Molar Mass
He	4 amu (2 p + 2 n)	4 g/mole
Hg		
Cu		

7 Every atom has a unique number of protons (& electrons too).

If you are an atom with 12 protons:

8 If you have 29 protons:

9 Atoms with 90 protons:

10 Every atom has a certain number of neutrons, but there are many

11 Isotopes are atoms of an element with a different number of neutrons, but…

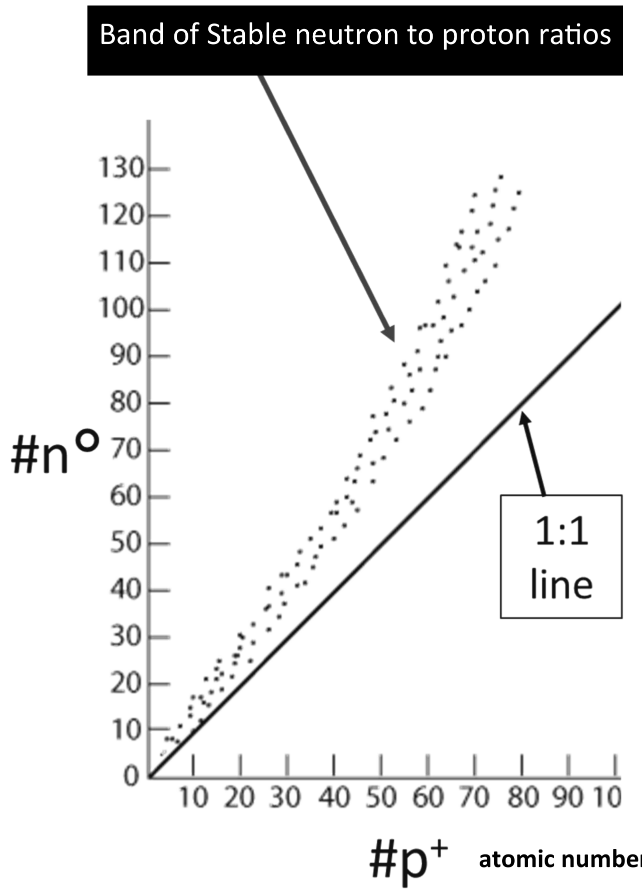
12 How many protons, neutrons and electrons are in the most common isotope of radium on the Periodic table?

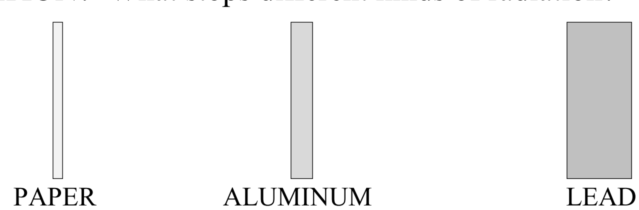
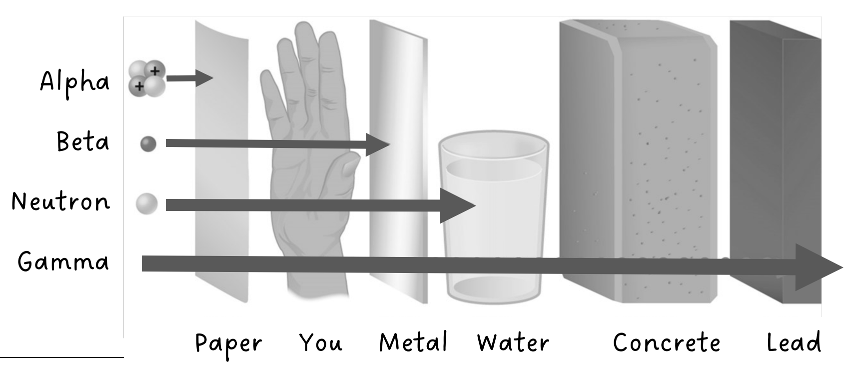
(226)	+2
Ra	
88	
-18-32-18-8-2	

14	Determine protons, neutrons and electron count for C-12	
15	Determine protons, neutrons and electron count for C-14	
16	Determine protons, neutrons and electron count for P-31	Determine protons, neutrons and electron count for P-32
17	Of the 118 known elements, there are about 1500 known ISOTOPES. There are 3 different isotopes of even tiny HYDROGEN.	
18	Of these 1500 isotopes, most are stable and not radioactive.	
19	Stable means that the neutron to proton ratio falls into a	
20	About 150 isotopes are UNSTABLE. *(write this big, so you don't forget why some isotopes are radioactive!)* They need to FIX this ratio to become stable.	

21	FIXING this neutron to proton ratio means they will — or parts of their nucleus.
22	Emitting radiation means emitting a variety of nuclear particles and/or energy,

23. The neutron to proton ratio for STABLE ISOTOPES (atoms) is close to…		
Smaller atoms	up to Ca (#20)	
Medium atoms	up to Zr (#40)	
Larger atoms	all the rest	
All nuclei with ratios outside this band are unstable, and that's what we will study during this unit of chem.		



24	Can you be protected from RADIATION? What stops different kinds of radiation? ALPHA BETA GAMMA 
25	What can stop… neutron particles? What can stop… gamma radiation? 

26. FILL IN THIS CHART about RADIOACTIVE PARTICLES and energy, FROM TABLE “O”

	Mass	Charge	Symbols	Penetrating power
ALPHA				
BETA				
GAMMA				
NEUTRON				
PROTON				
POSITRON				

27	Radiation is emitted by unstable isotopes...
28	Emitting different types of radiation…
29	...or emit radiation once, and they become stable.
30	...or transmutations before they get stable.
31	The types of emissions, and the amount of time it takes to emit this radiation,
32	A nucleus emits radiation to change its nucleus, to change its neutron to proton ratio. It changes into a different kind of atom...

33	This process is called…
34	It happens on its own, naturally.
35	Unstable radioisotope nuclei literally spit out parts of themselves, to...
36	Doing this changes them from one kind of an atom to another, which is called →
37	The last radioisotope on Table N is Uranium-238 atomic mass of this isotope 238 = protons plus neutrons 238—92 = 146 neutrons $^{238}_{92}U$
38	^{238}U Is really… There is no reason to ever get fooled by this again. Just be smarter than the folks up in Albany!
39	Table N says that this stuff will undergo ALPHA decay. $^{238}_{92}U \longrightarrow$
40	A lot just happened. Let's examine this. (write small!)

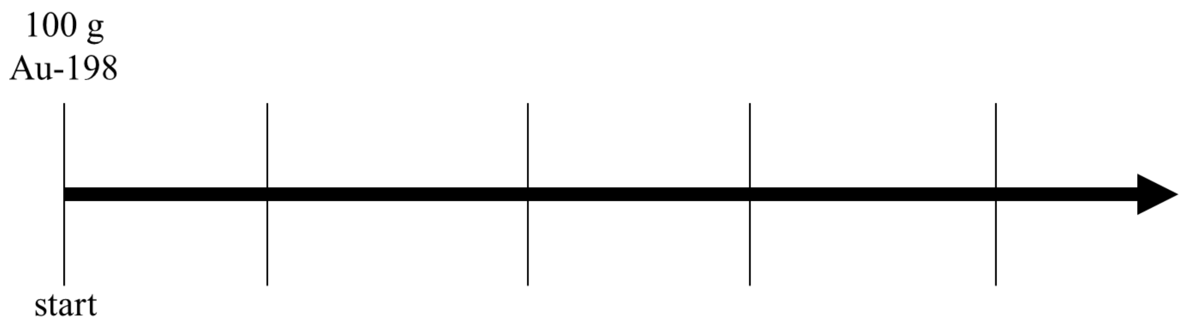
41	Determine the decay mode and write the complete decay reaction for carbon-14.	
42	C-14 emits beta radiation. It undergoes beta decay…	
43	Determine the decay mode and write the complete decay reaction for calcium-37	
44	Radioactive Ca-37 emits a positron from it's nucleus, it transmutes into K-37…	
45	Determine the decay mode and write the complete decay reaction for radium-226.	`
46	Radium-226 undergoes alpha decay. This is natural transmutation, it **JUST HAPPENS** all by itself.	
47	Determine the decay mode and write the complete decay reaction for Cs-137	
48		
49	Determine the decay mode and write the complete decay reaction for Iron-53.	
50		

51	Determine the decay mode and write the complete decay reaction for gold-198.	
52	when it undergoes radioactive decay.	
53	Determine the decay mode and write the complete decay reaction for neon-19	
54	...to change the neutron - proton ratio of its nucleus.	
55	Determine the decay mode and write the complete decay reaction for Fr-220	`
56		
57	Beta Decay. A beta particle is essentially an electron, but it comes from inside the nucleus. Somehow, a neutron emits the negative charge without mass, it turns itself into a proton! A neutron emits a negative charge of “no mass”, (a beta particle) and…	

58	A positron particle is essentially an electron with a positive charge, it comes from inside the nucleus. Somehow, a proton emits the positive charge without mass, it turns itself into a neutron! A proton emits a positive charge of “no mass”, (positron particle)...
59	… is the amount of time it takes for one half of a given radioisotope to transmute.

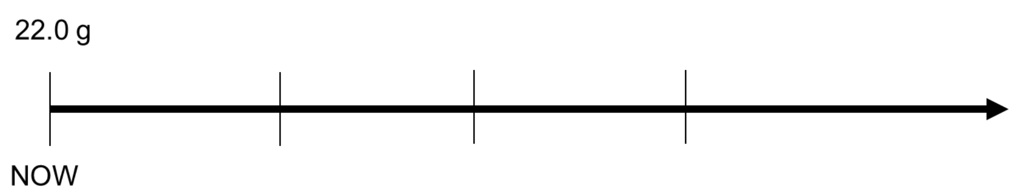
How long is the half life of each isotope?			
☺	Nuclide	Half Life	Units mean
69	Au-198		
61	C-14		
62	Ca-37		
63	U-238		
64	Pu-239		

65 The half-life of radioactive gold-198 is 2.695 days. That means…

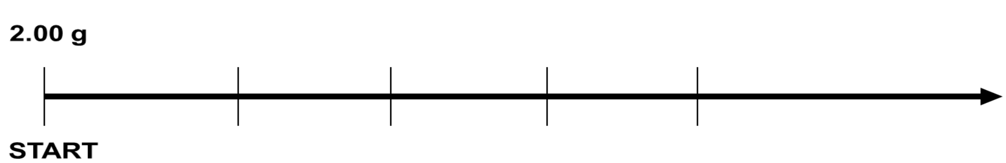


In half-life problems… Make the T-chart. You can solve for the % transmuted, or % left untransmuted, or
the grams transmuted, or grams unchanged or the fraction transmuted, or fraction unchanged
how long (seconds to years) that's passed
how long until something happens. It's all math, it's in the T-chart

66 You accumulate 22.0 grams of the radioisotope carbon-14 How long before only 2.75 grams of the C-14 remains unchanged?



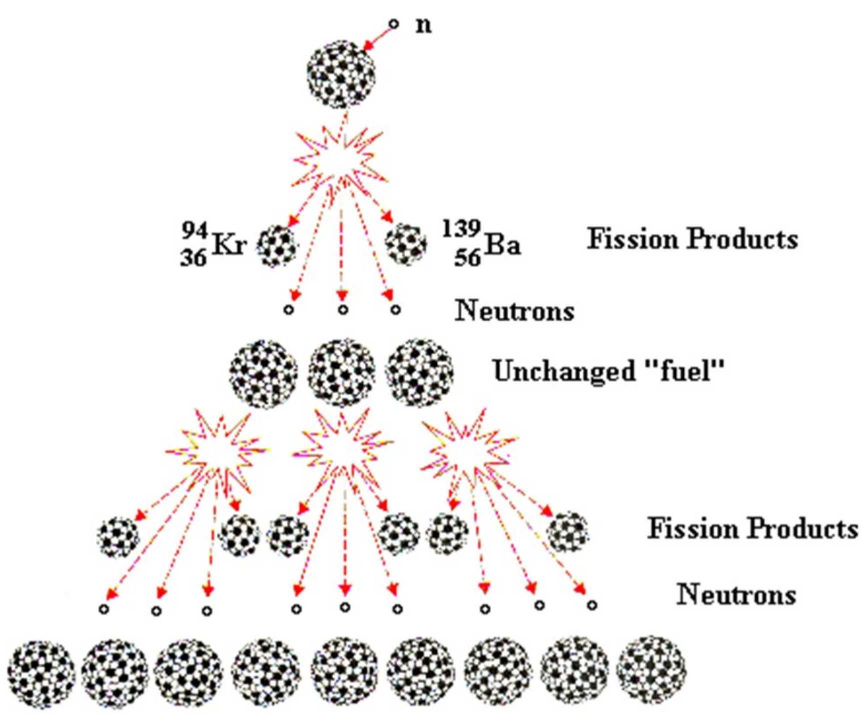
67 The doctor injects you with 2.00 g radioactive I-131 to measure your thyroid uptake. How long until you have just 0.125 g left in you?



68	You put 400.0 g of Fe-53 in your pocket. How long until you have 12.5 grams of this iron left? What has the other 387.5 grams become? Draw your own T-chart here.
69	If a scientist purifies 1.0 gram of radium-226, how many years must pass before only 0.50 gram of the original radium-226 sample remains unchanged?
70	Based on Reference Table N, what fraction of a radioactive Sr-90 sample would remain unchanged after 58.2 years? A. ½ B. ¼ C. $^1/_8$ D. $^1/_{16}$ (do math, make a T-chart too!)
71	What is the half-life & decay mode of Rn-222? A. 1.910 days and alpha decay B. 1.910 days and beta decay C. 3.823days and alpha decay D. 3.823 days and beta decay
72	What is the half-life of sodium-25 if 1.00 gram of a 16.00-gram sample of sodium-25 remains unchanged after 237 seconds? A. 47.4 s B. 59.3 s C. 79.0 s D. 118 s
73	Show the complete alpha decay reaction for U-233
74	Show the complete beta decay reaction for H-3
75	Show the complete positron decay reaction for Ne-19

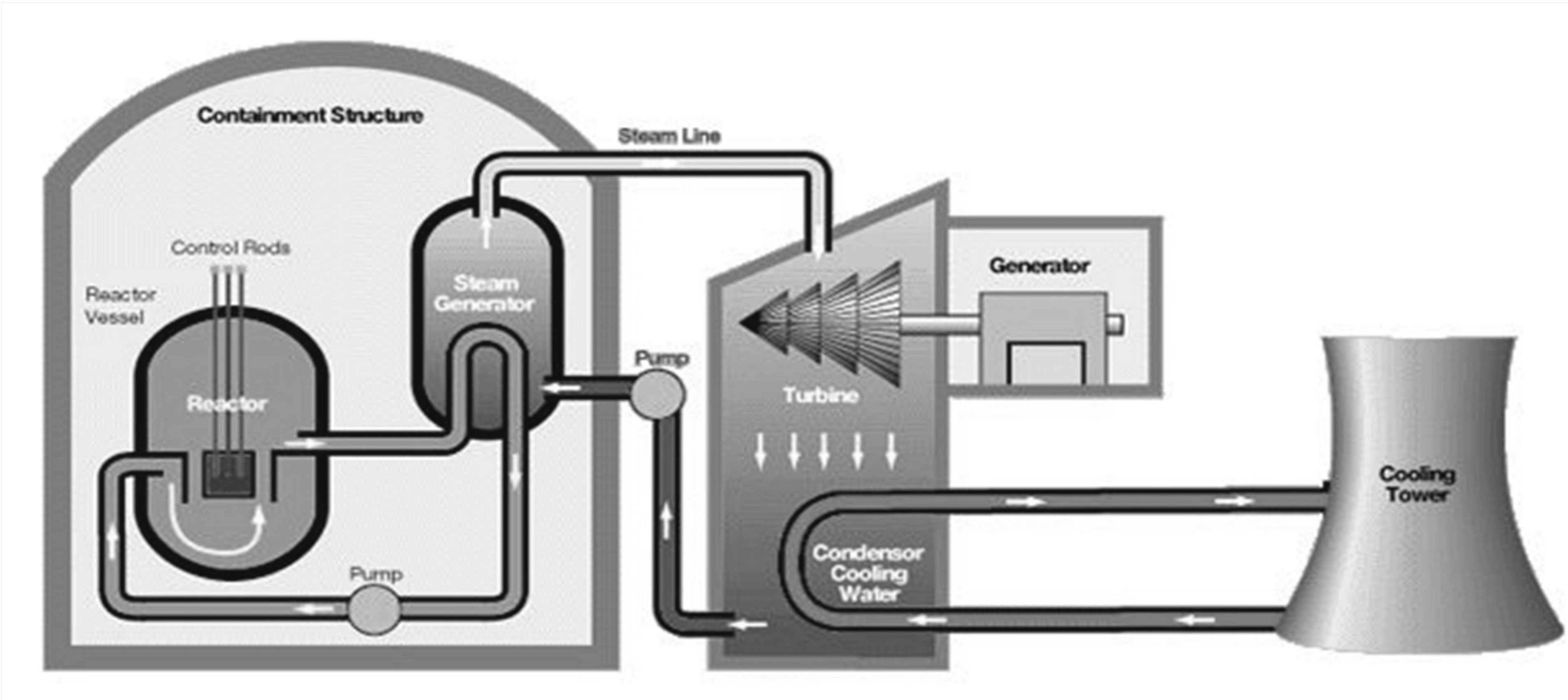
76	
77	COPY the artificial transmutation from the board. Ernest Rutherford (my hero) artificially transmutes N → O!
78	Beryllium is artificially transmuted with alpha particles by James Chadwick in 1932 (he discovered the neutron!)
79	In1934 Marie Curie transmutes Al-27 → P-30into radioactive phosphorous (1st artificially created radioisotope)
80	
81	

82 + 83



84	The splitting of atoms by artificial transmutation is called...
85	Einstein proposed $E = mc^2$ He proved that energy = mass (times a really big number). In Fission, some mass is converted into energy. The Law of Conservation of Mass…
86	This missing mass from a nuclear reaction is called the...
87	Copy these 2 examples of fission reactions, there are many more. U-235 is used in both.
88	The daughter nuclei that form are usually radioactive as well. They will undergo natural transmutation. *By chance* all 4 of these fission products undergo beta decay
copy	Ba-140 → Kr-93 → Xe-144 → Ba-140 →
89	In a nuclear bomb, the chain reaction is designed to release an "out of control" amount of energy… The same reaction, controlled inside of a nuclear power plant… usually many months.

90	Another type of artificial transmutation reaction is
91	Fusion is the squishing together of smaller atoms and making larger ones. There is a loss of mass during (mass defect) in fusion reactions. Fusion…
92	The Sun...
93	The Sun squashes 4 hydrogen atoms into helium this way
94	Scientists cannot make atoms of H-1 fuse together…
95	Scientists have been able to fuse together isotopes of hydrogen, like this…
96	Heat produced by burning turns water into steam. Steam is shot at the turbine blades, which spin like crazy. Waste includes carbon dioxide (green house gas), ash, and heat lost to the air. In the gases, often there are chemicals that lead to acid rain, such as sulfates.
97	How does a nuclear power plant make electricity? (simple!, not really) which makes water turn into steam, to turn turbine blades, to spin the generator, to make electricity.


Containment Structure
Steam Line
Control Rods
Reactor
Vessel
Steam
Generator
Reactor
Pump
Pump
Generator
Turbine
Condensor
Cooling
Water
Cooling
Tower

98	Nuclear Power Plants Work like this (read, and get this into your heads, it's important) A fission reaction is starts in the reactor core. It's controlled with cadmium rods that can absorb excess neutrons. Once the reaction starts, the Cd absorbs neutrons, the reaction starts but doesn't really expand the way a bomb does. Lots of heat is created, steam reaches 450°C. The water that touches this material is highly radioactive and remains sealed in the "inner" water loop. The steam pulls heat from the core. The steam transfers it's heat to a middle loop of water, making that boil as well, although not quite as hot. That steam spins the turbine blades. Once past the blades, this steam is condensed back to water, so it can absorb maximum heat when it approaches that inner water pipe. The blades spin the magnets in the generator, which induces an electric current. Water from outside (ocean or large lake) cools the middle loop steam back to water before it picks up heat from the inner core steam. This cooling loop produces the only constant "waste", which is hot water, which is real pollution, but is not a terrible problem. The radioactive waste is a terrible problem. It's radioactive, for 20,000 + years, so it must be put out of our environment, and guarded from terrorists forever. If it gets into the environment, it can kill or cause cancer. The spent fuel is cooled for several years, then put into long term concrete storage on site at nuclear power plants.
99	Pro's of nuclear power
100	Con's of nuclear power
101	Right now…
102	How does radioactive carbon dating work? Copy the equation On Earth there is a certain amount of radioactive carbon by percent. It's measurable if you're college level smart and you have some fancy tools. There is a "normal" level of radioactive carbon in our environment, and it's been stable a long time. The ratio of radioactive carbon to stable carbon is a constant. Although some is always transmuting, there is always more being made, by a variety of means, all involving the bombardment of carbon with high energy particles from the Sun.

103	Which kind of animal DOES NOT EAT regularly?
104	
105	
Nuclear Medicine	
106	Iodine-131 or I-131
107	Cobalt-60 or Co-60
108	

PERIODIC TABLE OF ELEMENTS

RADIOACTIVE ELEMENTS
Radioactive elements have no stable isotopes.

1 H Hydrogen																	2 He Helium
3 Li Lithium	4 Be Beryllium											5 B Boron	6 C Carbon	7 N Nitrogen	8 O Oxygen	9 F Fluorine	10 Ne Neon
11 Na Sodium	12 Mg Magnesium											13 Al Aluminium	14 Si Silicon	15 P Phosphorus	16 S Sulfur	17 Cl Chlorine	18 Ar Argon
19 K Potassium	20 Ca Calcium	21 Sc Scandium	22 Ti Titanium	23 V Vanadium	24 Cr Chromium	25 Mn Manganese	26 Fe Iron	27 Co Cobalt	28 Ni Nickel	29 Cu Copper	30 Zn Zinc	31 Ga Gallium	32 Ge Germanium	33 As Arsenic	34 Se Selenium	35 Br Bromine	36 Kr Krypton
37 Rb Rubidium	38 Sr Strontium	39 Y Yttrium	40 Zr Zirconium	41 Nb Niobium	42 Mo Molybdenum	43 Tc Technetium	44 Ru Ruthenium	45 Rh Rhodium	46 Pd Palladium	47 Ag Silver	48 Cd Cadmium	49 In Indium	50 Sn Tin	51 Sb Antimony	52 Te Tellurium	53 I Iodine	54 Xe Xenon
55 Cs Caesium	56 Ba Barium	57 La* Lanthanum	72 Hf Hafnium	73 Ta Tantalum	74 W Tungsten	75 Re Rhenium	76 Os Osmium	77 Ir Iridium	78 Pt Platinum	79 Au Gold	80 Hg Mercury	81 Tl Thallium	82 Pb Lead	83 Bi Bismuth	84 Po Polonium	85 At Astatine	86 Rn Radon
87 Fr Francium	88 Ra Radium	89 Ac** Actinium	104 Rf Rutherfordium	105 Db Dubnium	106 Sg Seaborgium	107 Bh Bohrium	108 Hs Hassium	109 Mt Meitnerium	110 Ds Darmstadtium	111 Rg Roentgenium	112 Cn Copernicium	113 Nh Nihonium	114 Fl Flerovium	115 Mc Moscovium	116 Lv Livermorium	117 Ts Tennessine	118 Og Oganesson

*	58 Ce Cerium	59 Pr Praseodymium	60 Nd Neodymium	61 Pm Promethium	62 Sm Samarium	63 Eu Europium	64 Gd Gadolinium	65 Tb Terbium	66 Dy Dysprosium	67 Ho Holmium	68 Er Erbium	69 Tm Thulium	70 Yb Ytterbium	71 Lu Lutetium
**	90 Th Thorium	91 Pa Protactinium	92 U Uranium	93 Np Neptunium	94 Pu Plutonium	95 Am Americium	96 Cm Curium	97 Bk Berkelium	98 Cf Californium	99 Es Einsteinium	100 Fm Fermium	101 Md Mendelevium	102 No Nobelium	103 Lr Lawrencium

Source: U.S. Nuclear Regulatory Commission - As of February 2023