Nuclear Chemistry Test Review Sheet

Important Reference Tables in This Unit- N & O

Table N Selected Radioisotopes

Nuclide	Half-Life	Decay Mode	Nuclide Name
^{198}Au	2.69 d	β^-	gold-198
^{14}C	5730 y	β^-	carbon-14
^{37}Ca	175 ms	β^+	calcium-37
^{60}Co	5.26 y	β^-	cobalt-60
^{137}Cs	30.23 y	β^-	cesium-137
^{53}Fe	8.51 min	β^+	iron-53
^{220}Fr	27.5 s	α	francium-220
^{3}H	12.26 y	β^-	hydrogen-3
^{131}I	8.07 d	β^-	iodine-131
^{37}K	1.23 s	β^+	potassium-37
^{42}K	12.4 h	β^-	potassium-42
^{85}Kr	10.76 y	β^-	krypton-85
^{16}N	7.2 s	β^-	nitrogen-16
^{19}Ne	17.2 s	β^+	neon-19
^{32}P	14.3 d	β^-	phosphorus-32
^{239}Pu	2.44×10^4 y	α	plutonium-239
^{226}Ra	1600 y	α	radium-226
^{222}Rn	3.82 d	α	radon-222
^{90}Sr	28.1 y	β^-	strontium-90
^{99}Tc	2.13×10^5 y	β^-	technetium-99
^{232}Th	1.4×10^{10} y	α	thorium-232
^{233}U	1.62×10^5 y	α	uranium-233
^{235}U	7.1×10^8 y	α	uranium-235
^{238}U	4.51×10^9 y	α	uranium-238

ms = milliseconds; s = seconds; min = minutes;
h = hours; d = days; y = years

Carbon - 14 undergoes a beta decay (β^-)

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

beta particle

Radium-226 undergoes an alpha decay (α)

$$^{226}_{88}Ra \rightarrow ^{222}_{86}Rn + ^{4}_{2}He$$

alpha particle

Iron - 53 undergoes positron emission (β^+)

$$^{53}_{26}Fe \rightarrow ^{53}_{25}Mn + ^{0}_{+1}e$$

positron

* All of the above are examples of natural transmutations.

The specific isotopes listed on this chart are radioactive. This means they will undergo a spontaneous decay of the nucleus. They decay mode symbol can be looked up on Table O. All elements with an atomic number greater than 83 will be radioactive.

The half-life is the amount of time required for exactly one half of the nuclei in a radioactive sample to decay. The shorter the half-life the faster a substance decays. The half-life is not affected by temperature or pressure.

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^+

During nuclear transmutations and radioactivity, particles are absorbed and released by the nucleus. The change (or transmutation) depends on the type of particles absorbed and /or released.

Radiation (or radioactivity) describes particles and energy related to nuclear changes.

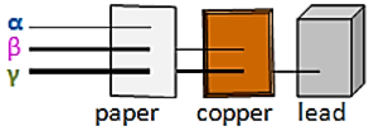
Particles and radiations most commonly involved in nuclear changes are given on the Table below. Some information on this table can also be found on Reference Table O.

Nuclear Particle	***Symbol***	***Mass***	***Charge***	***Penetrating power***
Alpha	${}^{4}_{2}He$, α	4 amu	+2	Low (weakest)
Beta	${}^{0}_{-1}e$, -β	0 amu	-1	Medium
Positron	${}^{0}_{+1}e$, +β	0 amu	+1	Medium
Gamma	${}^{0}_{0}y$	0 amu	0	High (strongest)
Neutron	${}^{1}_{0}n$	1 amu	0	------

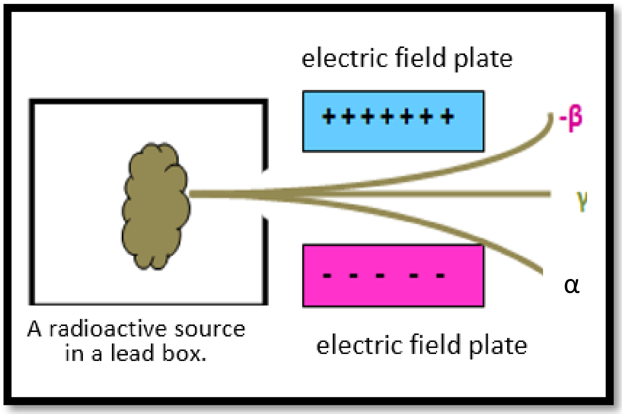
Penetrating power refers to the strength of a particle to go through an object.

Alpha particles (α) has the weakest penetrating power. It can be stopped by a sheet of paper.

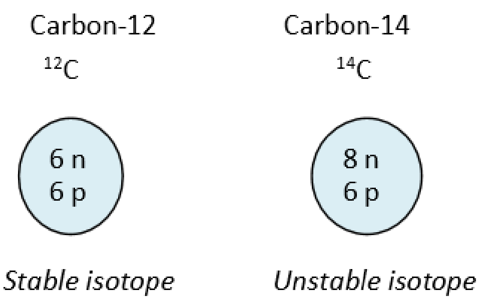
Gamma radiation (γ) has the strongest penetrating power. Gamma rays can only be stopped by high density metals such as lead.



Separation of alpha, beta, and gamma in an electric field.



Below, a comparison of two carbon isotopes.



A carbon-14 nucleus contains two extra neutrons that make it unstable and radioactive.

The stability of an isotope depends on the **neutron-to-proton** ratio.

Elements with atomic #'s 1-20 are most stable with a neutron-to-proton ratio of ~1:1.

Elements 21-83 require a greater number of neutrons to protons. The average neutron-to-proton ratio for these elements is ~1.5.

Elements 84-above have no stable isotopes and are all radioactive.

Natural & Artificial Transmutation

Transmutation is the changing (converting) of one atom to a different atom. Transmutation can be natural or artificial.

Natural transmutation occurs when a single unstable radioactive nucleus spontaneously changes by decaying (breaking down).

- Alpha decay, beta decay, and positron emission are types of natural transmutation

Artificial transmutation occurs when a stable nonradioactive nucleus is hit (bombarded) with a high speed particle and is changed to an unstable nucleus.

Decay mode refers to the type of radiation that a radioisotope will release as it decays. *Reference Table N lists* selected radioisotopes and their decay modes.

A **radioisotope** is any radioactive isotope of an element. A radioisotope can be described as one of the following depending on its decay mode.

An **alpha emitter** is a radioisotope that decays by releasing an alpha particle.

Radioisotopes with atomic number 83 and above tend to be alpha emitters.

Ex. Francium–220 and uranium–238 are alpha emitters.

A **beta emitter** is a radioisotope that decays by releasing a beta particle.

Ex. Cobalt–60 and strontium–90 are beta emitters.

A **positron emitter** is a radioisotope that decays by releasing a positron.

Ex. Iron–53 and neon–19 are positron emitters.

Radioisotopes of small atomic numbers tend to be beta and positron emitters.

Alpha decay (natural transmutation)

$$^{226}_{88}\mathrm{Ra} \rightarrow \, ^{222}_{86}\mathrm{Rn} + \, ^{4}_{2}\mathrm{He}$$

Beta decay (natural transmutation)

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

Positron emission (natural transmutation)

$$^{226}_{88}\mathrm{Ra} \rightarrow \, ^{226}_{87}\mathrm{Fr} + \, ^{0}_{+1}\mathrm{e}$$

Artificial transmutation occurs when a stable non-radioactive nucleus is bombarded (hit) with a high speed particle, and is changed (transmuted) into a different atom.

Example of artificial transmutation:

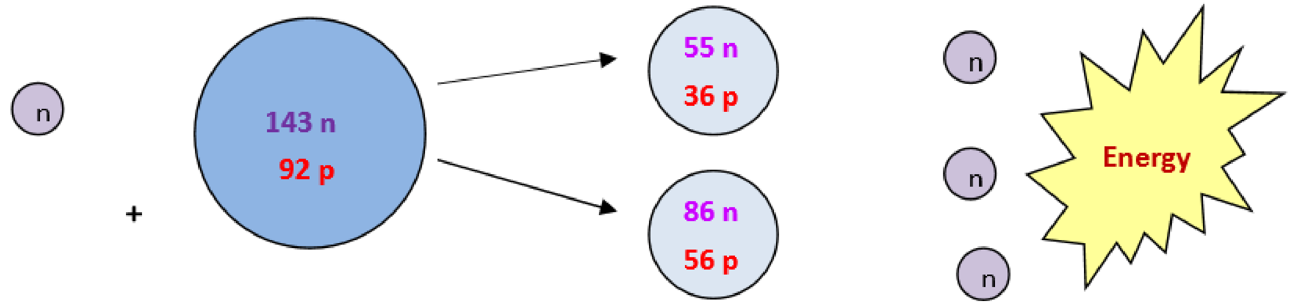
$^{4}_{2}\mathrm{He}$	+	$^{9}_{4}\mathrm{Be}$	→	$^{12}_{6}\mathrm{C}$	+	$^{1}_{0}\mathrm{n}$
accelerated high speed particles		*stable non-radioactive*		*unstable radioisotope*		*neutron released*

Fission & Fusion

Fission = Division

Fission is a nuclear reaction in which a large nucleus is split into smaller nuclei.

The diagram and equation below show a nuclear fission reaction. In the reaction, a neutron hits a uranium nucleus, causing it to break into two smaller nuclei fragments. Three neutron, energy and radiation are also produced.



$^{1}_{0}n$	+	$^{235}_{92}U$	$\rightarrow$	$^{91}_{36}Kr$	+	$^{142}_{56}Ba$	+	$3\,^{1}_{0}n$
neutron (slow moving)		*large fissionable nucleus*		*two smaller nuclei*				*neutrons released*

Concept Facts: Study to remember the following facts about fission reactions

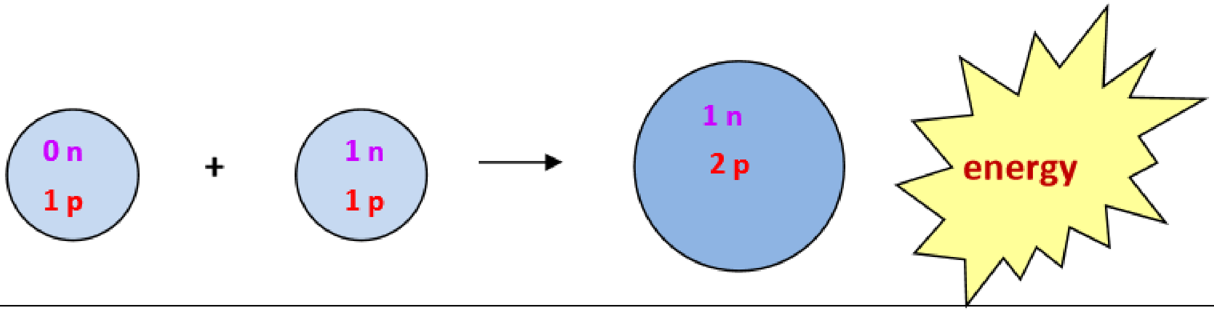
- A large fissionable (splitable) nucleus absorbs slow moving neutrons
  The large nucleus is split into smaller fragments, and a release of more neutrons.
- Tons of nuclear energy is released. Energy is converted from mass
  Energy released is less than that of fusion reactions.
- In nuclear power plants, the fission process is well controlled.
  Energy produced is used to produce electricity
- In nuclear bombs, the fission process is uncontrolled
  Energy and radiations released are used to cause destruction.
- Nuclear wastes are also produced
  Nuclear wastes are dangerous and pose serious health and environmental problems.
  Nuclear wastes must be stored and disposed of properly.

Fusion= Fusing

Fusion is a nuclear reaction in which small nuclei are joined (fused) to create a larger nucleus.

Only small atoms like those of hydrogen and helium can be fused (joined) in a nuclear fusion reaction.

The diagram and equation below show a nuclear fusion reaction. In the reaction, two small hydrogen nuclei join (fuse) to produce a larger helium nucleus. High amount of energy is also produced.



$${}^{1}_{1}\mathrm{H} \quad + \quad {}^{2}_{1}\mathrm{H} \quad \rightarrow \quad {}^{3}_{2}\mathrm{He} \quad + \quad \text{energy}$$

small nuclei *a larger nucleus*

Concept Facts: Study to remember facts about fusion reactions

- Two small nuclei are brought together under extreme high temperature and pressure
  The two nuclei are fused (joined) to create a slightly larger nucleus.
- Tons of nuclear energy are released. Energy is converted from mass.
  Energy released is much greater than that of fission reaction.
- Fusion produces no nuclear waste, unlike fission.
- Energy from the sun is due to fusion reactions that occur in the core of the sun.
- High temperature and high pressure are required for a fusion reaction to occur.
  High temperature and pressure are necessary to overcome the repelling force of the two positive nuclei that are to be fused.
  Recall that the nucleus is positively charged. In fusion, two positive nuclei must be brought (joined) together. Opposites attract, BUT similar charges repel. Therefore, a very high temperature and pressure are needed to make two positively charged nuclei join together in a fusion reaction.

Writing Nuclear Equations

A nuclear equation is balanced when the sum of masses (top numbers) and sum of charges (bottom numbers) are equal on both sides of the equation.

Example of a balanced nuclear equation is demonstrated below:

$$^{222}_{86}\mathrm{Rn} \rightarrow {}^{4}_{2}\mathrm{He} + {}^{218}_{84}\mathrm{Po}$$

This nuclear equation is balanced because:

The mass (top) number on the *left* (*222*) is equal to the sum of the masses on the *right* (*4 + 218 = 222*).

The charge (bottom) number on the *left* (*86*) is equal to the sum of charges on the *right* (*2 + 84 = 86*)

An unbalanced nuclear equation is usually given as an incomplete equation in which the missing particle (X) must be determined.

Example of an unbalanced nuclear equation is given below:

$$^{37}_{18}\mathrm{Ar} + {}^{0}_{-1}\mathrm{e} \rightarrow \mathrm{X}$$

The X can be determine with a simple math

$$^{37}_{18}\mathrm{Ar} + {}^{0}_{-1}\mathrm{e} \rightarrow {}^{37}_{17}\mathrm{X}$$

Top (mass) number of X (37) must equal sum of 0 + 37

Bottom (charge) number of X (17) must equal sum of 18 + -1

X is $^{37}_{17}\mathrm{Cl}$

Bottom number of X is determined to be 17

17 is the atomic number for chlorine (Cl)

Writing Decay Equations

On Reference Table N, you are given radioisotopes and their decay modes.

Concept Task: Be able to write or determine a balance nuclear equation for a radioisotope if its decay mode is known.

Note: This is generally done by piecing together information from Reference Tables N, O, and the Periodic Table.

Examples

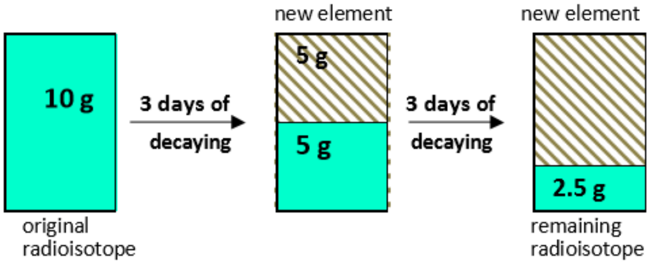
Write nuclear equations for the decay of plutonium-239 and iodine-131.

Study the steps below to learn how to do the same for any radioisotope whose decay mode is known.

	Step 1: Write		*Step 2: Write*		*Step 3: Determine missing*	
	Nuclide symbol (Use Table N)	→	Decay mode symbol (Use Table N and O)	+	Top #, bottom #, and atom's symbol (numbers must make for a balanced equation)	
Plutotonium-239	$^{239}_{94}\mathrm{Pu}$	→	$^{4}_{2}\mathrm{He}$	+	$^{235}_{92}\mathrm{U}$	Note: The bottom # of each symbol is the atomic number (from the Periodic Table)
Iodine-131	$^{131}_{53}\mathrm{I}$	→	$^{0}_{-1}\mathrm{e}$	+	$^{131}_{54}\mathrm{Xe}$	

Half-Life

Half-life is the length of time it takes for a radioactive substance to decay to half its original mass. During a radioactive decay, the radioisotope is converted to a different substance. Over time, fewer and fewer atoms of the original radioactive substance remains while more and more of the new atoms are formed. At a certain time in the decay process, exactly half of original radioactive atoms remain unchanged. The time (seconds, minutes, hours, or years) it takes the substance to decay to half its original amount is the half-life of the substance.



This diagram shows a 10-gram sample of a radioisotope decaying to 5 grams after 3 days, and to 2.5 grams in another 3 days.

The half-life of the radioisotope is 3 days.
The number of half-life periods (how halves) is 2.
The total length of time is 6 days.

- The decaying of a radioisotope is at a constant rate, therefore, half-life of a radioisotope is constant.
- Temperature, pressure, and amount do not change the half-life of a radioisotope.
- Each radioisotope has its own half-life

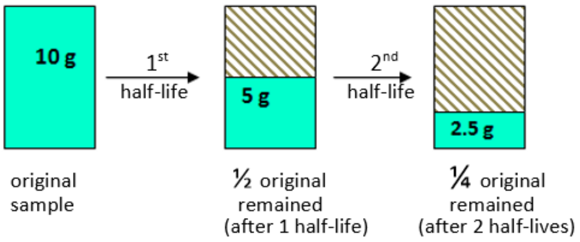
Reference Table N list selected radioisotopes, their decay modes and half-lives.

The **number of half-life periods** of a decay is the number of times a radioactive substance decays in half to go from one mass to another. In all half-life problems the number of half-life periods must be known in order to solve the problem. Determining the number of half-life periods depends on the information that is given in the question.

The length of time of a decaying process is the total time it takes for a radioisotope to decay from one mass to another. **Half-life** is the time it takes for just half the amount of the substance to decay to a new substance. Either of the two can be determined if certain information is known about the decaying process of a radioisotope.

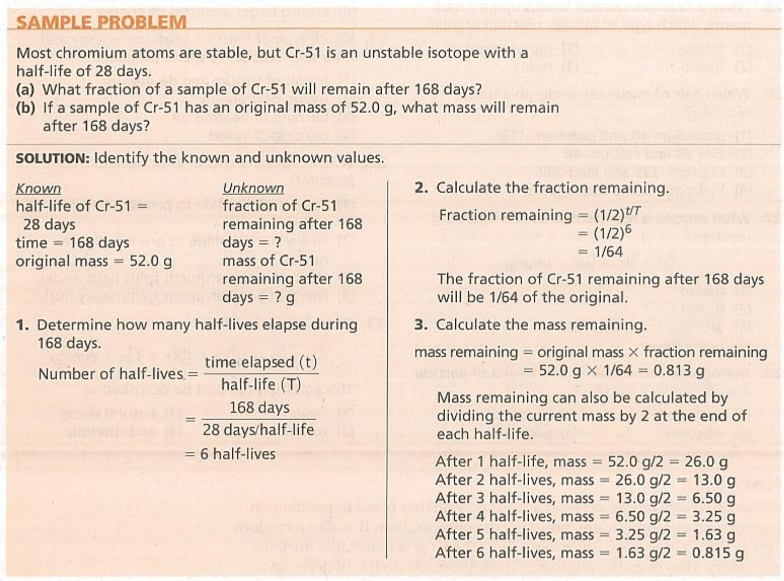
Original mass of a radioisotope is the amount of the radioisotope that was present at the beginning of a decaying process. **Remaining mass** is the amount that remained after a given length of time of decaying. Either of the two masses can be determined if certain information is known about the decaying process of a substance.

Fraction remaining expresses the remaining mass of a radioisotope in terms of ratio.



The fraction of a sample of a radioactive substance remaining after a given # of half-lives is calculated using the relationship

Fraction remaining = $(\frac{1}{2^n})$ where n is equal to the number of half-lives. The number of half-lives is equal to the total length of time divided by the half-life of the isotope.



SAMPLE PROBLEM

Most chromium atoms are stable, but Cr-51 is an unstable isotope with a half-life of 28 days.
(a) What fraction of a sample of Cr-51 will remain after 168 days?
(b) If a sample of Cr-51 has an original mass of 52.0 g, what mass will remain after 168 days?

SOLUTION: Identify the known and unknown values.

Known	*Unknown*
half-life of Cr-51 = 28 days	fraction of Cr-51 remaining after 168 days = ?
time = 168 days	mass of Cr-51 remaining after 168 days = ? g
original mass = 52.0 g	

1. Determine how many half-lives elapse during 168 days.

$$\text{Number of half-lives} = \frac{\text{time elapsed } (t)}{\text{half-life } (T)} = \frac{168 \text{ days}}{28 \text{ days/half-life}} = 6 \text{ half-lives}$$

2. Calculate the fraction remaining.

$$\text{Fraction remaining} = (1/2)^{t/T} = (1/2)^6 = 1/64$$

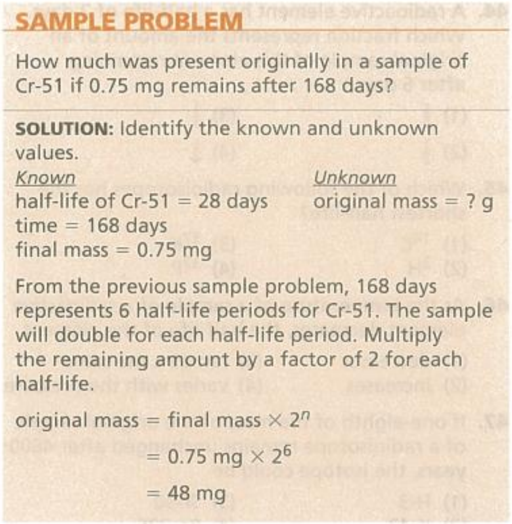
The fraction of Cr-51 remaining after 168 days will be 1/64 of the original.

3. Calculate the mass remaining.

$$\text{mass remaining} = \text{original mass} \times \text{fraction remaining} = 52.0 \text{ g} \times 1/64 = 0.813 \text{ g}$$

Mass remaining can also be calculated by dividing the current mass by 2 at the end of each half-life.

After 1 half-life, mass = 52.0 g/2 = 26.0 g
After 2 half-lives, mass = 26.0 g/2 = 13.0 g
After 3 half-lives, mass = 13.0 g/2 = 6.50 g
After 4 half-lives, mass = 6.50 g/2 = 3.25 g
After 5 half-lives, mass = 3.25 g/2 = 1.63 g
After 6 half-lives, mass = 1.63 g/2 = 0.815 g



SAMPLE PROBLEM

How much was present originally in a sample of Cr-51 if 0.75 mg remains after 168 days?

SOLUTION: Identify the known and unknown values.

Known	*Unknown*
half-life of Cr-51 = 28 days	original mass = ? g
time = 168 days	
final mass = 0.75 mg	

From the previous sample problem, 168 days represents 6 half-life periods for Cr-51. The sample will double for each half-life period. Multiply the remaining amount by a factor of 2 for each half-life.

$$\text{original mass} = \text{final mass} \times 2^n = 0.75 \text{ mg} \times 2^6 = 48 \text{ mg}$$

Radioactivity Applications and Benefits

Some radioisotopes listed on Reference Table N have common usages in areas such as medicine, research, and geological (rock) and archeological (fossil) dating.

A **tracer** is a radioisotope that is used to follow path of a chemical reaction.

Radioisotope tracers in medical treatments and **diagnoses** must have short half-lives and be quickly eliminated from the body.

Radioisotopes for dating usually have very long half-lives.

The table below gives a list of radioisotopes and their common applications.

Radioisotope name	*Radioisotope symbol*	*Common applications and benefits*	*Field of application*
Iodine-131	^{131}I	Thyroid disorder; diagnosis and treatment	Medical
Technetium-99	^{99}Tc	Cancer tumor diagnosis	Medical
Cobalt-60	^{60}Co	Cancer treatment	Medical
~~**Iron-56**~~	~~^{56}Fe~~	~~Blood disorder treatment~~	~~Medical~~
Carbon-14 *(alone)*	^{14}C	Tracer for chemical reactions	Research
Carbon-14 *with* **Carbon-12** / ^{14}N	^{14}C ^{12}C	Fossil dating	Archeology
Uranium – 238 *with* **Lead - 206**	^{238}U ^{206}Pb	Rock dating	Geology

Radioactive Wastes and Radiations

Radiations and wastes produced from nuclear reactors can be very dangerous to life on earth.
Prolonged and high dose exposures to radiation can cause serious health issues, and sometimes death.

- *Radiation* from nuclear power plants must be well contained to protect humans and other living things.
- *Nuclear wastes* are equally dangerous because they are highly radioactive.
- *Nuclear wastes* have to be stored in safe areas to protect the public from being exposed to them.

Solid Wastes (Highly radioactive): Sr-90 Cs-137 **Gaseous Wastes:** Rn-222 Kr-85 N-16