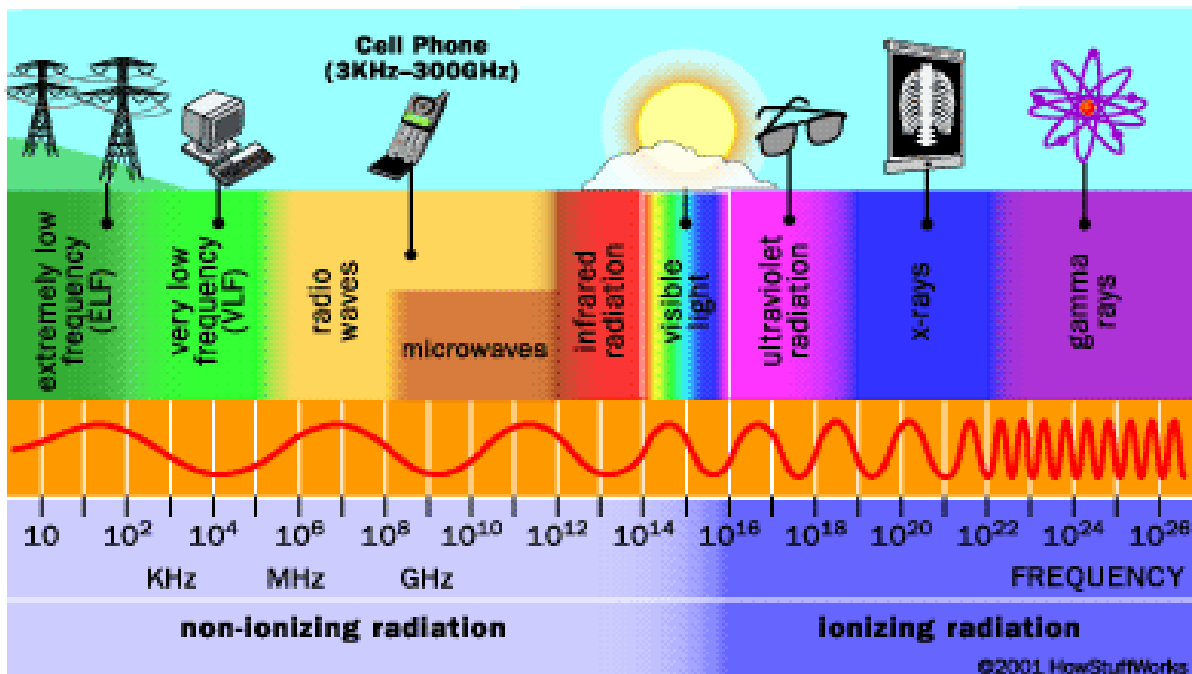


Before working with radioactive material, it is helpful to recall...

Radiation is energy released from a source.

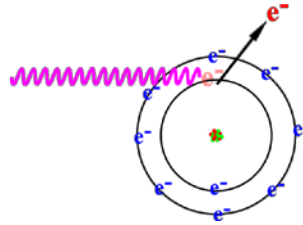
- Light is a familiar example of energy traveling some distance from its source. We understand that a light bulb can remain in one place and the light can move toward us to be detected by our eyes.
- The Electromagnetic Spectrum is the entire range of wavelengths or frequencies of electromagnetic radiation extending from gamma rays to the longest radio waves and includes visible light. Radioactive materials release energy with enough power to cause ionizations and are on the high end of the electromagnetic spectrum.
- Although our bodies cannot sense ionizing radiation, it is helpful to think ionizing radiation behaves similarly to light.
 - Travels in straight lines with decreasing intensity farther away from the source
 - May be reflected off certain surfaces (but not all)
 - Absorbed when interacting with materials

You will be using radioactive material that releases energy in the form of ionizing radiation. Knowing about the basics of radiation will help you understand how to work safely with radioactive material.

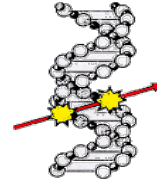


What is “ionizing radiation”?

- Ionizing radiation is energy with enough power to remove tightly bound electrons from the orbit of an atom, causing the atom to become charged or ionized.



- The charged atoms can damage the internal structures of living cells. The material near the charged atom absorbs the energy causing chemical bonds to break.



Are all radioactive materials the same?

No, not all radioactive materials are the same. Different elements decay in different ways and release different kinds of ionizing radiations.

What are isotopes?

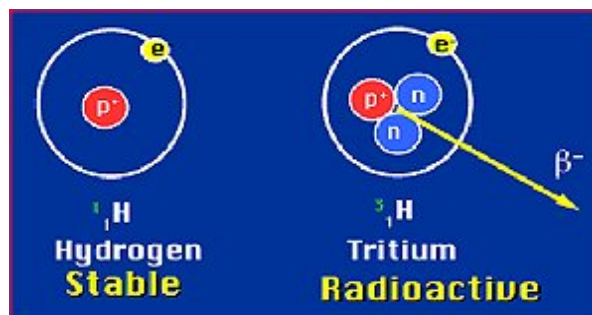
It's helpful to think of the radioactive material in its elemental form. There can be different forms of an element called isotopes. The same element may have different numbers of neutrons in the nucleus (the number of protons remains the same) and are called isotopes.

Hydrogen is a common radioactive element used at the University. Hydrogen has one proton in its nucleus. Hydrogen has no neutrons, deuterium has one, and tritium has two neutrons. The isotopes of hydrogen have mass numbers of one, two, and three. Their nuclear symbols are therefore H-1, H-2, and H-3. The atoms of these isotopes have one electron to balance the charge of the one proton.

What is a radioisotope?

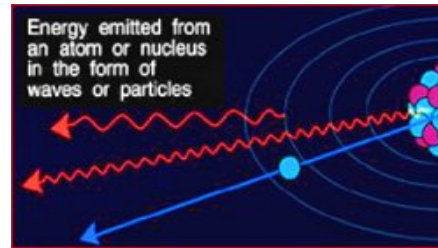
Some isotopes are unstable and they are called radioisotopes. Radioisotopes spontaneously seek a stable ratio between the number of protons and neutrons in the nucleus. This process releases energy in the form of ionizing radiation and is referred to as a decay.

Hydrogen (H-1) has no neutron, deuterium (H-2 or heavy hydrogen) has one, and tritium (H-3) has two neutrons. Only tritium (H-3) is unstable and radioactive.



Do all radioisotopes decay the same way?

There are different forms of ionizing radiation released by different radioisotopes. Some ionizing radiation is in the form of waves; some is in the form of particles. Knowing what you are working with will allow you to make choices about how to stay safe.



What are the forms of ionizing radiation?

Particles

Some radioisotopes release particles from their nucleus with enough energy that they could cause ionizations when the particle reaches your body. For the radioactive materials used at the University, the radioisotopes that emit particles are easy to block or shield and they do not travel very far. There are four types of radioactive particle emissions and knowing what type you are working with helps you to know how to block them to stay safe.

Alpha particles

Alpha particles are very large and heavy compared to other ionizing radiation particles. An alpha particle is the same as a Helium nucleus. Both have 2 protons bonded with 2 neutrons and are positively charged. Although they have very high energy, they are big and heavy. They are absorbed within a few micrometres of air or by your outer layers of (dead) skin. The key to staying safe is to keep the radioactive material outside of your body.

- Alpha particles are very damaging when inhaled. A common source of alpha radiation is cigarette smoke. Cigarette smoke has minute quantities of naturally occurring radioisotopes (Po-210 and Pb-210) that decay by releasing alpha particles. The Po-210 and Pb-210 come from the fertilizer used to grow tobacco.
 - When we breathe in cigarette smoke, the radioisotopes release alpha particles while inside our lungs that can damage the lung tissue. There is no 'skin' to protect the very sensitive lung tissue and the damage can accumulate and result in cancer.¹
 - Our eyes have a very thin outer layer. When alpha radiation from cigarette smoke reaches the lens of the eye, it would be very damaging and may explain why smokers have a higher incidence of cataracts (radiation damage) than non-smokers.
- At the University there are no 'open source' Radioisotope Permits to use alpha emitters. The source of alpha radiation are sealed sources and most are in devices. Alpha sources at the University are bigger than a nickel making them difficult to inhale or ingest. And, it is easy to keep your eyes and lungs more than several micrometers away and stay safe!

Beta particles

Beta particles are very small (they are the size of an electron). These particles have a range of energies depending on the radioisotope. Most beta emitting radioisotopes used at the University release beta particles with a negative charge (*negatrons*).

- Radiation from low energy beta emitters, such as the radiation that comes from H-3 (tritium), C-14, S-35, Ca-45 and P-33 are stopped by your outer layer of (dead) skin and the beta particles are absorbed in a few centimeters of air.
- Radiation from medium energy beta particles, such as the radiation that comes from P-32 can travel through your skin to deposit its potentially damaging radiation in your body. The medium energy particles are easily stopped by plastic or wood shielding and beta particles from P-32 are absorbed within one meter of air. It is important to keep P-32 shielded with plastic or wood and limit the time you are within one meter of unshielded P-32 to less than an hour per day.
- At the University, there are no high-energy beta sources.

Some beta particles have a positive charge and are called **positrons**. When positrons interact with electrons the charge is neutralized and the excess energy is released as a gamma ray (more on positrons with gamma rays below).

Neutron particles

Neutrons can be 'bounced' out of the nucleus with sufficient energy to ionize the material that eventually absorbs them. Neutrons are very damaging because they are very efficient at transferring their energy when they collide with your body. They are easy to shield using hydrogen rich materials (like water).

At the University there are no 'open source' Radioisotope Permits to use neutron emitters. The source of neutrons are sealed sources or are in specialized devices that measure soil moisture. Sealed sources are the size of a coin and workers are not at risk of inhaling or ingesting them. At the University, neutron devices are bigger than a mailbox and it is impossible to inhale or ingest them. The devices are self-shielding so the radiation only travels a few centimeters from the stored shielded device and the sealed sources and devices are locked when not in use to keep workers safe!

Rays

When a particle moves within a radioactive material, ionizing radiation in the form of rays are sometimes released. Rays have no mass and need dense material like lead to absorb and shield them. Rays move deep through the body and are not readily absorbed in air so they travel farther than particles. There are two types of rays and they are indistinguishable other than where they come from.

Gamma Rays

Gamma rays originate from the nucleus.

X-rays

X-rays originate from electron orbits.

- Cr-51 decays when an electron is absorbed into the nucleus increasing the number of protons. To re-balance the energy, a gamma ray is emitted. Tc-99m also releases a gamma ray after releasing a beta particle. Both are considered low energy emissions. It is important to keep gamma emitters like Cr-51 and Tc-99m shielded with lead and limit the time you are within 1 meter when unshielded.
- F-18 and I-124 decay by releasing a positron. When the positron interacts with nearby electrons, a gamma ray is released to balance the energy. This gamma radiation is much more energetic than radiation from Cr-51 or Tc-99m. It is important to keep gamma emitters shielded with lead and limit the time you are within 2 meters when unshielded.

Is the energy of the radiation important?

The energy of the emission is a characteristic of the atomic structure of the radioisotope. The energy of ionizing radiation is measured in electronvolts (eV). High energy radiation can penetrate farther and can penetrate higher density matter compared to lower energy radiation.

By knowing the radioisotope, you know the type of emission and the energy. You can then use this information to work with the radioactive material safely.

The most commonly used radioisotopes at the University are:

Radioisotope	Type of Emission	Energy (MeV)
H-3	Beta-	Lowest 0.018
C-14	Beta-	Low 0.156
S-35	Beta-	Low 0.167
P-32	Beta-	Mid 1.71
I-125	X-ray/ Gamma	Low 0.035
Tc-99m	Gamma	Low 0.14 (85%)
Cr-51	X-ray/ Gamma	Low 0.32 (10%)
F-18	Beta+/ Gamma	Mid 0.633/0.511
I-124	Beta+/ Gamma	Mid 1.532/0.511

How much radioactivity will you be working with?

The amount of radioactivity is referred to as activity.

The SI unit of activity is the Becquerel (Bq).

1 Becquerel = 1 disintegration per second (dps)

1 Mega-Becquerel (MBq) = 1 000 000 dps

1 MBq = 27 uCi



A non-SI unit used is the curie (Ci):

1 curie = 2.2×10^{12} disintegrations per minute (dpm) or 37 billion dps

1 curie = 37 000 MBq or 37 000 000 000 Bq

1 mCi = 37 MBq



What is the concentration of the radioisotope?

There is chemical concentration with units like mole/litre, mg/g etc.

Radiological concentration, the amount of radioactivity per unit mass of a radioisotope, is referred to as specific activity with units like Bq/litre, Bq/kg, uCi/mol etc.

How long will the radio-labelled chemical remain radioactive?

The radioactivity of your product will diminish with time. How fast depends on the half-life of the radioisotope.

Radioactive decay

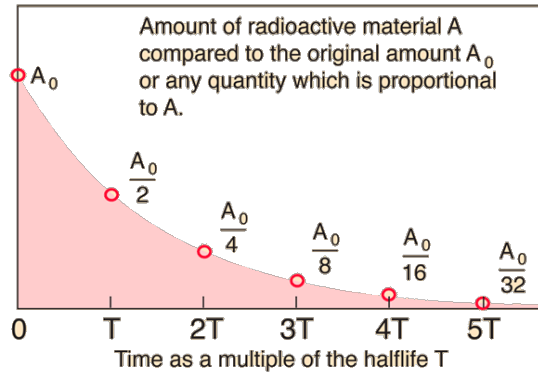
Remember decay occurs spontaneously and the activity of a radioisotope decreases exponentially but it can be calculated at any point in time.

Half-life ($T_{1/2}$)

Is a time period in which the original activity decays to one half.

$T_{1/2}$ is specific to a radioisotope and cannot be altered by temperature, pressure or any chemical process.

Remember the date or time is always part of the activity information!



The most commonly used radioisotopes at the University are:

Radioisotope	Type of Emission	Energy (MeV)	Half-life
H-3	Beta-	Lowest 0.018	12 years
C-14	Beta-	Low 0.156	5730 years
S-35	Beta-	Low 0.167	88 days
P-32	Beta-	Mid 1.71	14 days
I-125	X-ray/ Gamma	Low 0.035	60 days
Tc-99m	Gamma	Low 0.14 (85%)	6 hours
Cr-51	X-ray/ Gamma	Low 0.32 (10%)	28 days
F-18	Beta+/ Gamma	0.633/0.511	109.8 minutes
I-124	Beta+/ Gamma	1.532/0.511	4.18 days



How can the activity in the vial relative to a particular time be calculated?

$$N = N_0 e^{-(0.693t/T_{1/2})}$$

Where: N - activity after t

N_0 – initial activity

t - time period elapsed since the initial activity was measured

$T_{1/2}$ – half-life of your radioisotope

Example: The label on the vial containing dATP labelled with the radioisotope P-32 reads that on Monday, November 3rd the vial contained 18.5 MBq. You received it November 7th. How much activity do you have left in that vial?

$T_{1/2}$ = Half-life of P-32 is 14 days

N_0 = 18.5 MBq

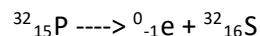
t = 4 days

$$N = 18.5 * e^{-(0.693 \times 4/14)} = 15.2 \text{ MBq}$$

Remember, the units for time must be the same!

What will happen to the decayed P-32?

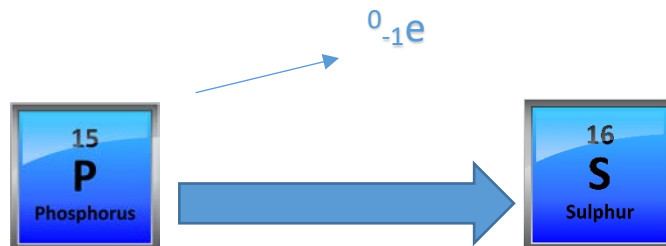
The molecule that was phosphorus-32 did not just disappear, it is converted to sulfur.



An electron is released during the decay process of changing a neutron into a proton.

Since the number of protons defines the isotope, phosphorus becomes sulphur.

Notice the mass number (32) is unchanged (the loss of an electron is not significant to mass number.)



For radiolabelled chemicals - Do not forget Radiolysis!

TECH TALK: WHAT IS RADIOLYSIS?

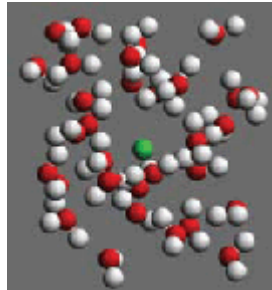
Radiolysis is the process when molecules break down into other molecules when exposed to ionizing radiation. It is the breaking of one or several chemical bonds of the original chemical.

*The rate a **chemical** degrades is not related to the radioisotope half-life.*

How long the chemical (let's say ATP) remains as ATP and isn't 'spoiled' or broken down into other chemicals is sometimes much shorter than the radiological half-life. The radioisotope might still be present in the vial but no longer part of the original chemical. Another example could be H-3 Thymidine in a water solution could lyse to become H-3 (tritiated) water and (non-radioactive) Thymidine.

Some bonds within the chemical may also be broken reducing the chemical purity.

Check the technical data sheet for the rate of decomposition. Keeping chemicals in a solution for decades doesn't mean they are useful for further experiments. You may need to re-purify the chemical before using the chemical for another experiment or you may not be able to trust your results.



ⁱ <https://www3.epa.gov/radtown/tobacco.html>