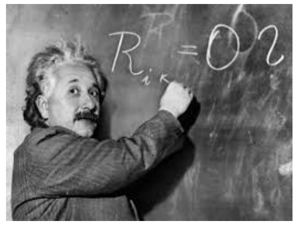
Basics of Radiation



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

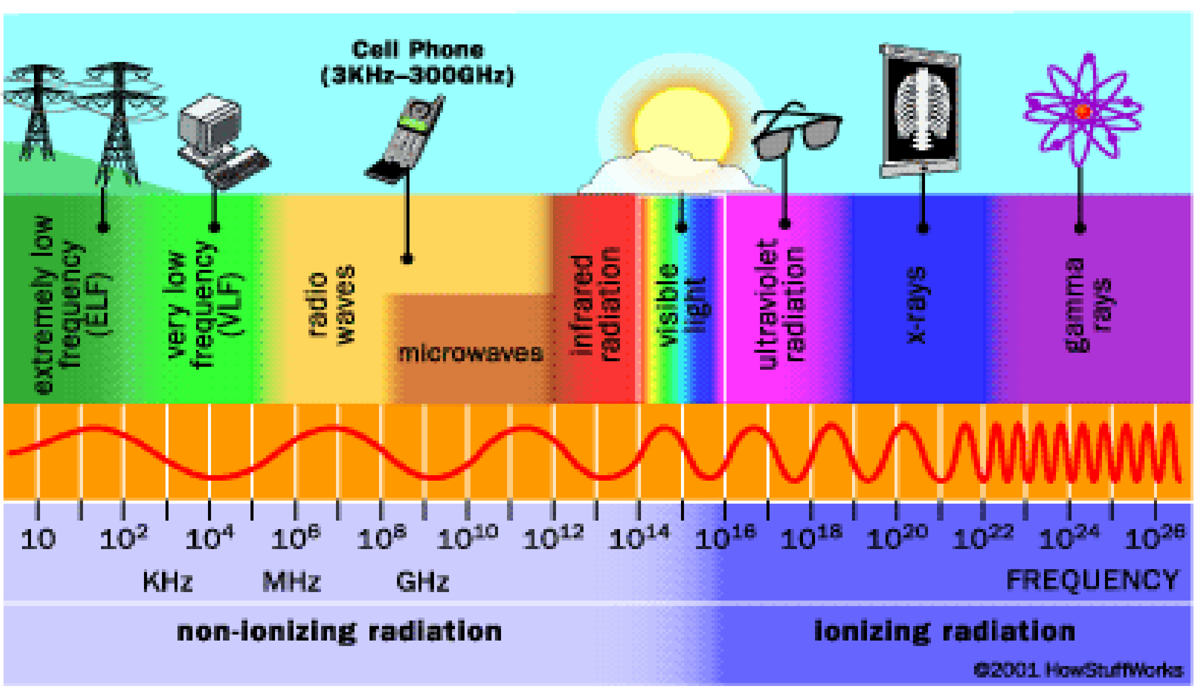
Radiation is energy released from a source.

- 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.

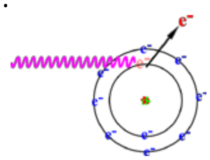
- Although our bodies cannot sense ionizing radiation, it is helpful to think ionizing radiation behaves similarly to light.
  - Travels in straight lines with decreasing intensity farther away from the source
  - May be reflected off certain surfaces (but not all)
  - Absorbed when interacts with materials

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.

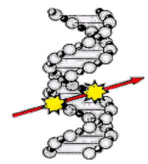


What is “ionizing radiation”?

- 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.

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 (same number of protons) may have different numbers of neutrons in the nucleus and are called isotopes.

Cobalt is the most common radioactive element used as a sealed source at the University. Naturally occurring cobalt is composed of one stable isotope Co-59. There are 28 radioisotopes that have been characterized with the most stable radioisotope being Co-60 with a half-life of 5.2714 years, Co-57 with a half-life of 271.8 days. The other radioisotopes of cobalt have a half-life of 77 days to less than one second. This element also has 11 meta states, all of which have half-lives less than 15 minutes.

What is a radioisotope?

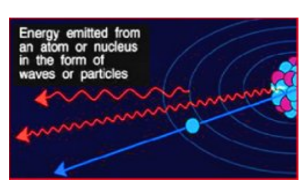
Some isotopes are unstable and they are called radioisotopes. Radioisotopes spontaneously seek a stable ratio between the number of protons and neutrons in the nucleus. This process releases energy in the form of ionizing radiation and is referred to as a decay.

All isotopes of cobalt have 27 protons.

Isotope	Abundance	Half-life ($t_{1/2}$)	Decay mode	Product
^{56}Co	synthetic	77.27 d	ε	^{56}Fe
^{57}Co	synthetic	271.79 d	ε	^{57}Fe
^{58}Co	synthetic	70.86 d	ε	^{58}Fe
^{59}Co	100%	stable	None	none
^{60}Co	synthetic	5.2714 y	β^-, γ	^{60}Ni

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 shielding and about how long you will work close to the radioactive material.



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 breathed in. 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.[i]
    - Our eyes have a very thin outer layer. When alpha radiation from cigarette smoke reaches, 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 sealed sources of alpha emitters. Most of the sealed sources of alpha radiation are in devices and the most common device is the smoke detector (like the one in your home) that contain a small amount of Am-241. Alpha sources at the University are bigger than a nickel and it is relatively easy to NOT inhale or ingest them. 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 that University release beta particles with a negative charge (negatrons).

- Radiation from low energy beta emitters, such as the radiation that comes from Ni-63 or Tl-204 is stopped by your outer layer of (dead) skin and the beta particle are absorbed in a few centimeters of air.
- The mid energy beta radiation from Sr-90 is easily shielded by plastic (or wood). It would be important to limit the amount of time spend closer than one meter of an unshielded source of large activity. Radiation from medium energy beta particles, is often coupled with the release of gamma radiation that is more penetrating and would require lead (or concrete) for more shielding (see below).
- 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 gamma rays below).

Neutron particles

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

At the University, the source of neutrons are sealed sources in specialized devices that measure soil moisture. At the University, neutron devices are bigger 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, sometimes ionizing radiation in the form of rays are released as well. Rays have no mass and need dense material like lead to absorb and shield them. Rays move deep through the body. Rays 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.

- Ba-133 and Co-57 decay when an electron is absorbed into the nucleus increasing the number of protons. To re-balance the energy, a gamma ray is emitted. Both are considered lower energy emissions. It is important to keep gamma and X-ray emitters like Ba-133 and Co-57 shielded with lead and limit the time you are within 1 meter when unshielded.
- Cs-137 and Co-60 decay by releasing an X-ray (along with a beta particle). Cs-137 emissions are lower energy but still warrant shielding. Co-60 is more energetic and requires shielding and restricting the time working close to the unshielded source.
- Ge-68 and Na-22 decay by releasing a positron. When the positron interacts with nearby (within mm) electrons, a gamma ray is released to balance the energy. This gamma radiation is much more energetic than from Ba-133 or Co-57. 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 use this information to keep yourself safe and to work with the radioactive material safely.

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The most commonly used radioisotopes at the University are:

Radioisotope	Type of Emission	Energy (MeV)
Am-241	Alpha, gamma	5.49, 0.60
Ba-133	gamma	0.36
Co-57	gamma	0.122
Co-60	Beta-, gamma	0.32, 0.17 and 1.33
Cs-137	Beta-, gamma	0.51, 0.662
Ge-68	Beta+, gamma	1.9, 0.511
Na-22	Beta+, gamma	0.54, 0.511 and 1.27
Ni-63	Beta-	0.067
Ra-226	Alpha, gamma	4.78, 0.19
Sr-90	Beta-	0.54 and 2.28
Tl-204	Beta-	0.76

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 = 2.2x1012 disintegrations per minute (dpm) or 37 billion dps
1 curie = 37 000 MBq or 37 000 000 000 Bq
1 mCi = 37 MBq

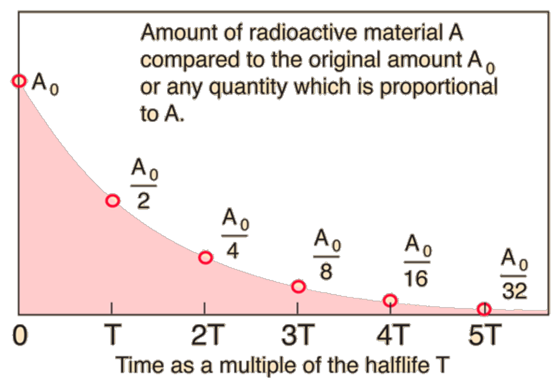
How long will the sealed source remain radioactive?

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 on time.

Half-life (T ½)
Is a time period in which the original activity decays to one half.
T ½ 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!



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The most commonly used radioisotopes at the University are:

Radioisotope	Type of Emission	Energy (MeV)	Half-life
Am-241	Alpha, gamma	5.49, 0.60	432 years
Ba-133	gamma	0.36	10.51 years
Co-57	gamma	0.122	270 *days*
Co-60	Beta-, gamma	0.32, 0.17 and 1.33	5.27 years
Cs-137	Beta-, gamma	0.51, 0.662	30.17 years
Ge-68	Beta+, gamma	,0.511	271 *days*
Na-22	Beta+, gamma	0.54, 0.511 and 1.27	2.6 years
Ni-63	Beta-	0.067	101 years
Ra-226	Alpha, gamma	4.78, 0.19	1602 years
Sr-90	Beta-	0.54 and 2.28	28.8 years
Tl-204	Beta-	0.76	3.78 years

How can the activity of a sealed source relative to a particular time be calculated?

$$N=N_o e^{-(0.693\ t/T½\ )}$$

Where: N - activity after t

N_0 – initial activity

t - time period elapsed since the initial activity was measured

T ½ – half-life of your radioisotope

Example: The label on the Cobalt-57 source listed the activity as 925 MBq on March 1, 2017. You plan to use the source March 10, 2018. How much activity will still be present?

T ½ = Half-life of Co-57 is 272 days
N_0 = 925 MBq
t = 374 days

N= $18.5*e^{-(0.693 \times 374/272)}$ = 356.7 MBq

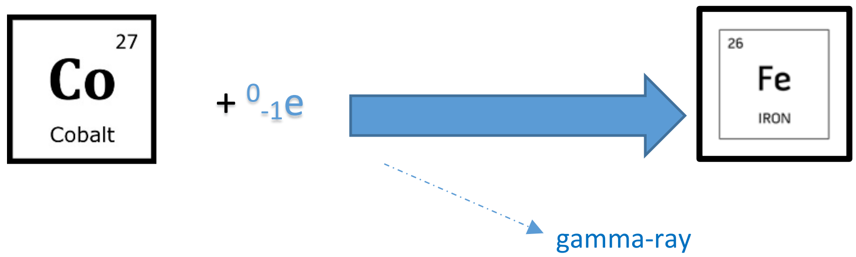
Remember, the units for time must be the same!

What will happen to the decayed Co-57?

The molecule that was cobalt-57 did not just disappear, it is converted to stable iron.

$$^{57}_{27}Co + ^{0}_{-1}e \text{ ----> } ^{57}_{26}Fe + \text{gamma ray}$$

An electron is 'captured' changing a proton to a neutron.
Since the number of protons defines the isotope, cobalt becomes iron.
Notice the mass number is unchanged (the gain of an electron is not significant to mass number.)



What happens to the sealed source when it is no longer required?

Contact radsafety@umanitoba.ca and the source will be properly disposed.

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[i] https://www3.epa.gov/radtown/tobacco.html