Unit Vocabulary:

- Alpha particle
- Artificial transmutation
- Beta particle
- Fission
- Fusion
- Gamma radiation
- Half-life
- Radioactive tracer
- Radioisotope
- Transmutation

Unit Objectives:

Upon completion of this unit you should be able to do the following:

- Predict the stability of an isotope based on the ratio of neutrons and protons in its nucleus.
- Understand that while most nuclei are stable some are unstable and spontaneously decay emitting radiation.
- Calculate the initial amount of the fraction remaining, or the half life of a radioactive isotope, using the half life equation.
- Understand the concept of half life.
- Differentiate between the following emissions based on mass, charge, ionizing power, and penetrating power:
  - Alpha
  - Beta
  - Positron
  - Gamma
- Determine the type of decay (alpha, beta, positron, gamma) and write the nuclear equations.
- Compare and contrast fission and fusion reactions.
- Distinguish between natural and artificial transformations.
- Complete nuclear equations and predict missing particles from nuclear equations.
- Understand the change in energy in a nuclear reaction.
- Be aware of the risks associated with radioactivity.
- Recognize the beneficial uses and real world application of radioactive isotopes.
  - Radioactive dating
  - Tracing chemical and biological processes
  - Industrial measurement
  - Nuclear power
  - Detection and treatment of diseases
Nuclear Chemistry - study of reactions that are caused by a

**CHANGE IN THE NUCLEUS** of an atom (to **BECOME ANOTHER**

**ELEMENT**); has nothing to do with electrons, just protons and

neutrons (since these two reside in the nucleus!)
Stability of Nuclei:

※ Large atoms – elements with an ATOMIC NUMBER > 83 are NATURALLY RADIOACTIVE due to an UNSTABLE NUCLEUS (due to the ratio of protons/neutrons being “off”); they have no known stable isotopes so they are continually decaying

※ Small Atoms – nucleus is STABLE; NOT NATURALLY RADIOACTIVE if atomic number is less than 83

**Exception to “Small Atom Rule:”**

※ When an atom’s mass is NOT ITS TYPICAL MASS (is an isotope of the mass seen on Periodic Table), the atom will be radioactive (unstable).
※ Example: C-13 & C-14

Radioisotope (Table N): an isotope of ANY ELEMENT THAT IS UNSTABLE and therefore radioactive

Let’s Try Some:

<table>
<thead>
<tr>
<th>Element</th>
<th>Nuclear Symbol</th>
<th>Periodic Table Mass</th>
<th>Stable/Unstable</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ca</td>
<td>Ca</td>
<td>37</td>
<td>20</td>
</tr>
<tr>
<td>H</td>
<td>H</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>O</td>
<td>O</td>
<td>16</td>
<td>8</td>
</tr>
<tr>
<td>O</td>
<td>O</td>
<td>14</td>
<td>8</td>
</tr>
<tr>
<td>Np (#93)</td>
<td>Np</td>
<td>237</td>
<td>93</td>
</tr>
</tbody>
</table>

So what happens to a substance with an unstable nucleus?

It will naturally (spontaneously) decay to form a more stable substance/element
**Transmutation:** the changing of a nucleus of one element into the nucleus of another element (by gaining or losing nucleons); *always decays into a more stable element*

**Natural:** happens with unstable atoms (elements with atomic number > 83)

Ex: \[ ^{238}U \rightarrow ^{92}N + ^{4}He \]

(Natural Transmutation includes the following: 1. alpha, beta, positron emission 2. sun 3. electron capture)

**Induced/Artificial:** occur with stable atoms; need some kind of high energy particles to begin reaction & bombard nucleus

Ex: \[ ^{14}N + ^{4}He \rightarrow ^{7}He + ^{2}He \]

(Stable nucleus being bombarded)

(Induced Transmutation includes following: 1. the bombarding of any nucleus 2. fusion (combining nuclei/atoms) 3. fission (splitting the nuclei)
<table>
<thead>
<tr>
<th>Types of Radiation</th>
<th>Source</th>
<th>Notation</th>
<th>Mass</th>
<th>Hazard</th>
<th>Shielding Needed</th>
</tr>
</thead>
<tbody>
<tr>
<td>Alpha Particle α</td>
<td>naturally occurring elements</td>
<td></td>
<td></td>
<td>No external hazard, internal though!</td>
<td>Skin</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Paper</td>
</tr>
<tr>
<td>Beta Particle β⁻ or e⁻</td>
<td>Atomic nucleus of most radioisotopes</td>
<td></td>
<td></td>
<td>Dangerous internally &amp; externally</td>
<td>Cardboard</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Tin foil</td>
</tr>
<tr>
<td>Positron β⁺ or e⁺</td>
<td>Radioactive isotopes</td>
<td></td>
<td></td>
<td>Dangerous internally &amp; externally</td>
<td>Cardboard</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Tin foil</td>
</tr>
<tr>
<td>Gamma Rays γ</td>
<td>Nearly all nuclear reactions</td>
<td></td>
<td></td>
<td>Very dangerous (highly penetrating)</td>
<td>Very heavy lead shield or suit</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Concrete</td>
</tr>
</tbody>
</table>

Radiation can damage our cells and cause mutations to form!!!
Separation of Nuclear Particles by Electric/Magnetic Fields:

- Positive alpha particles attract to the negative plate (do not deflect as much as beta particles since they are heavier)

- Negative beta particles attract to the positive plate (lighter so they bend more toward plate than alpha particles)

- Neutral gamma rays have no charge so they are undeflected in the electrical field (so straight through between the two plates)

<table>
<thead>
<tr>
<th>Name</th>
<th>Notation</th>
<th>Symbol</th>
</tr>
</thead>
<tbody>
<tr>
<td>alpha particle</td>
<td>( ^4_2\text{He} \text{ or } ^4_2\alpha )</td>
<td>( \alpha )</td>
</tr>
<tr>
<td>beta particle (electron)</td>
<td>( ^0_{-1}\text{e} \text{ or } ^0_{-1}\beta )</td>
<td>( \beta^- )</td>
</tr>
<tr>
<td>gamma radiation</td>
<td>( ^0_0\gamma )</td>
<td>( \gamma )</td>
</tr>
<tr>
<td>neutron</td>
<td>( ^1_0\text{n} )</td>
<td>( \text{n} )</td>
</tr>
<tr>
<td>proton</td>
<td>( ^1_1\text{H} \text{ or } ^1_1\text{p} )</td>
<td>( \text{p} )</td>
</tr>
<tr>
<td>positron</td>
<td>( ^0_{+1}\text{e} \text{ or } ^0_{+1}\beta )</td>
<td>( \beta^+ )</td>
</tr>
</tbody>
</table>
Radioactive Decay: The following decays occur in nature as a result of UNSTABLE NEUTRON-TO-PROTON RATIOS.

1. **Alpha Decay:** This is a transmutation whereby an unstable nucleus emits alpha particles. ALPHA PARTICLES are PRODUCTS in the reaction and the nucleus becomes smaller with less positive charge. Alpha emission is characteristic of HEAVY NUCLEI (especially with atoms greater than 83).
   a. Example:

   ![Alpha Decay Diagram]

   b. Alpha decay can be summarized as follows:
      i. Atomic number decreases by 2
      ii. # protons decreases by 2
      iii. mass decreases by 4
      iv. # neutrons decreases by 2

\[
\alpha (\text{alpha particle}) = \text{He}^4
\]

**Plutonium 239 decays by alpha particle emission as follows:**

\[
\text{Pu}^{239}_{94} \rightarrow \text{U}^{235}_{92} + \text{He}^4_{2} \quad (\text{alpha particle})
\]
c. Complete the example problems below showing ALPHA DECAY (remember, CHARGE and MASS must be conserved!)

1) \( ^{220}_{87}Fr \rightarrow \quad \quad + \quad ^{4}_{2}He \)

2) \( ^{222}_{86}Rn \rightarrow \quad \quad + \quad \quad \)

2. **Beta Decay:** A nucleus whereby a BETA PARTICLE is EMITTED (PRODUCED) as a result of nuclear disintegration; something said to undergo beta decay is called a “beta emitter.”

a. Example:

\[ ^{137}_{55}Cs \rightarrow ^{137}_{56}Ba + e \]

b. Beta decay can be summarized as follows:

i. Atomic # increases by 1
ii. # protons increases by 1
iii. mass stays the same
iv. # neutrons decreases by 1
c. Complete the example problems below showing beta decay:

1) \[ ^{32}_{15}P \rightarrow \] + \[ ^{0}_{-1}e \]

2) \[ ^{14}_{6}C \rightarrow \] + \[ ^{0}_{-1}e \]

3) \[ ^{214}_{82}Pb \rightarrow \] + \[ ^{0}_{-1}e \]

3. **Positron Emission:** Occurs when a POSITRON is PRODUCED during the conversion of a proton to a neutron.

   a. Example:

   ![Positron Emission Diagram]

   \[ ^{1}_{1}p \rightarrow ^{1}_{0}n + ^{0}_{1}e \]

   b. Positron Emission can be summarized as follows:

   i. Atomic # decreases by 1
   ii. # protons decreases by 1
   iii. mass stays the same
   iv. # neutrons increases by 1
c. Complete the example problems showing positron emission:

1) 37
   K →
   19
   + 0
   + 1

2) 81
   Rb →
   37
   37
   +

3) 19
   Ne →
   10
   +

4. **Gamma Rays**: a highly penetrating type of nuclear radiation, similar to x-rays and light
   
a. Gamma rays have no mass and no charge, just energy
   
b. Makes them the most destructive form of nuclear radiation
**ARTIFICIAL TRANSMUTATION:** change in the nucleus caused by the
BOMBARDING OF A NUCLEUS with a HIGH ENERGY PARTICLE such as a neutron or alpha particle

**Nuclear Fission:** SPLITTING of the nucleus of an atom; LARGER PARTICLE(S) SPLIT into smaller particles

NOTE: ENERGY is also produced in the above nuclear reaction…

One disadvantage of Fission  thermal pollution is a byproduct
**Nuclear Fusion:** Lighter nuclei are combined to produce heavier nucleus or nuclei.

Another Example:

\[
\begin{align*}
\text{1}_1^1\text{H} + \text{1}_1^1\text{H} & \rightarrow \text{2}_1^1\text{H} + \text{0}_1^1\text{e} \\
\text{1}_1^1\text{H} + \text{1}_2^1\text{H} & \rightarrow \text{2}_2^2\text{He} + \text{0}_1^1\text{n} \\
\text{2}_1^1\text{H} + \text{2}_1^1\text{H} & \rightarrow \text{3}_1^3\text{He} + \text{1}_1^1\text{n} \\
\text{2}_1^1\text{H} + \text{3}_1^1\text{H} & \rightarrow \text{4}_2^2\text{He} + \text{1}_1^1\text{n} \\
\text{2}_1^1\text{H} + \text{3}_2^2\text{He} & \rightarrow \text{4}_2^4\text{He} + \text{1}_1^1\text{H}
\end{align*}
\]

**Advantages of Fusion** → Lots of energy given off, no waste produced

Example: The sun uses a fusion reaction to create energy (natural form of fusion); energy from fusion unavailable for most part on earth (“work in progress” for harnessing energy in the future)

**Disadvantages of Fusion** → Need to overcome the need for extreme heat, need to develop materials strong enough to withstand heat, difficult to contain the nuclei into a small enough area/hard to “control” the reaction
**NOTICE:** ENERGY IS PRODUCED AS A PRODUCT IN BOTH FUSION & FISSION REACTIONS!

But where does the energy come from?? Total mass of the product(s) is less than the original mass of the reactants which leads to…

**MASS DEFECT** = SMALL AMOUNT OF MASS INVOLVED IN REACTION IS LOST AND IS CONVERTED TO ENERGY! This involves Einstein’s famous formula…

\[ E = mc^2 \]  

(Energy = mass x speed of light)
HALF LIFE

Radioactive substances decay at a constant rate that is **NOT DEPENDENT ON** any other factors such as **TEMPERATURE, PRESSURE, OR CONCENTRATION**. It is impossible to predict when an unstable nucleus will decay because this is a completely **RANDOM PROCESS**. The only thing that can be determined is the number of unstable nuclei that will decay in a given time. Therefore, **half life**, **OR THE TIME IT TAKES FOR HALF OF THE MASS TO DECAY**, is a very important concept in nuclear chemistry. **Note:** half life varies per substance – see **TABLE N (below)** – this table is in your Reference Tables!

![Table N](https://hyperphysics.phy-astr.gsu.edu/hbase/nuc/nucdec2.html)

**Table N**

<table>
<thead>
<tr>
<th>Nuclide</th>
<th>Half-Life</th>
<th>Decay Mode</th>
<th>Nuclide Name</th>
</tr>
</thead>
<tbody>
<tr>
<td>$^{109}\text{Au}$</td>
<td>2.69 d</td>
<td>$\beta^-$</td>
<td>gold-198</td>
</tr>
<tr>
<td>$^{14}\text{C}$</td>
<td>5730 y</td>
<td>$\beta^-$</td>
<td>carbon-14</td>
</tr>
<tr>
<td>$^{35}\text{Ca}$</td>
<td>175 ms</td>
<td>$\beta^+$</td>
<td>calcium-37</td>
</tr>
<tr>
<td>$^{58}\text{Co}$</td>
<td>5.26 y</td>
<td>$\beta^-$</td>
<td>cobalt-60</td>
</tr>
<tr>
<td>$^{137}\text{Cs}$</td>
<td>30.23 y</td>
<td>$\beta^-$</td>
<td>cesium-137</td>
</tr>
<tr>
<td>$^{57}\text{Fe}$</td>
<td>6.51 min</td>
<td>$\beta^+$</td>
<td>iron-53</td>
</tr>
<tr>
<td>$^{220}\text{Fr}$</td>
<td>27.5 s</td>
<td>$\alpha$</td>
<td>francium-220</td>
</tr>
<tr>
<td>$^{3}\text{H}$</td>
<td>12.26 y</td>
<td>$\beta^-$</td>
<td>hydrogen-3</td>
</tr>
<tr>
<td>$^{131}\text{I}$</td>
<td>8.07 d</td>
<td>$\beta^-$</td>
<td>iodine-131</td>
</tr>
<tr>
<td>$^{37}\text{K}$</td>
<td>1.23 s</td>
<td>$\beta^+$</td>
<td>potassium-37</td>
</tr>
<tr>
<td>$^{42}\text{K}$</td>
<td>12.4 h</td>
<td>$\beta^-$</td>
<td>potassium-42</td>
</tr>
<tr>
<td>$^{85}\text{Kr}$</td>
<td>10.76 y</td>
<td>$\beta^-$</td>
<td>krypton-85</td>
</tr>
<tr>
<td>$^{16}\text{N}$</td>
<td>7.2 s</td>
<td>$\beta^-$</td>
<td>nitrogen-16</td>
</tr>
<tr>
<td>$^{19}\text{Ne}$</td>
<td>17.2 s</td>
<td>$\beta^+$</td>
<td>neon-19</td>
</tr>
<tr>
<td>$^{32}\text{P}$</td>
<td>14.3 d</td>
<td>$\beta^-$</td>
<td>phosphorus-32</td>
</tr>
<tr>
<td>$^{238}\text{Pu}$</td>
<td>$2.44 \times 10^4$ y</td>
<td>$\alpha$</td>
<td>plutonium-239</td>
</tr>
<tr>
<td>$^{222}\text{Ra}$</td>
<td>1600 y</td>
<td>$\alpha$</td>
<td>radium-226</td>
</tr>
<tr>
<td>$^{222}\text{Rn}$</td>
<td>3.82 d</td>
<td>$\alpha$</td>
<td>radon-222</td>
</tr>
<tr>
<td>$^{90}\text{Sr}$</td>
<td>28.1 y</td>
<td>$\beta^-$</td>
<td>strontium-90</td>
</tr>
<tr>
<td>$^{90}\text{Tc}$</td>
<td>$2.13 \times 10^5$ y</td>
<td>$\beta^-$</td>
<td>technetium-99</td>
</tr>
<tr>
<td>$^{232}\text{Th}$</td>
<td>$1.4 \times 10^{10}$ y</td>
<td>$\alpha$</td>
<td>thorium-232</td>
</tr>
<tr>
<td>$^{235}\text{U}$</td>
<td>$1.62 \times 10^5$ y</td>
<td>$\alpha$</td>
<td>uranium-233</td>
</tr>
<tr>
<td>$^{235}\text{U}$</td>
<td>$7.1 \times 10^5$ y</td>
<td>$\alpha$</td>
<td>uranium-235</td>
</tr>
<tr>
<td>$^{238}\text{U}$</td>
<td>$4.51 \times 10^6$ y</td>
<td>$\alpha$</td>
<td>uranium-238</td>
</tr>
</tbody>
</table>

**Note:**
- ms = milliseconds; s = seconds; min = minutes;
- h = hours; d = days; y = years

**Basically:**
- **The SHORTER THE HALF LIFE of an isotope the LESS STABLE it is.**
- **The LONGER THE HALF LIFE of an isotope the MORE STABLE it is.**
Half Life Word Problems: see Table T for formulas!

- \( t = \) total time elapsed
- \( T = \) half-life (get from table N)

<table>
<thead>
<tr>
<th>Number of Half-Life Periods (n):</th>
<th>Fraction Remaining = ( \frac{1}{2} ) (^{\left( \frac{t}{T} \right)})</th>
</tr>
</thead>
<tbody>
<tr>
<td>( n = \frac{t}{T} )</td>
<td>or ( (\frac{1}{2})^n )</td>
</tr>
</tbody>
</table>

Example: Most Chromium atoms are stable, but Cr - 51 is an unstable isotope with a half-life of 28 days. \( T = \) _____ days

(a) What fraction of a sample of Cr-51 will remain after 168 days? \( t = \) _____ days

\[ n = \frac{t}{T} = \frac{168}{28} = 6 \text{ half-lives} \]

fraction remaining = __________

(b) If a sample of Cr-51 has an original mass of 52.0 g what mass will remain after 168 days?

(c) How much was present originally in a sample of Cr-51 if 0.75 mg remains after 168 days? (Hint: Calculate the number of half-lives have passed, then use the “Fraction Remaining” equation given above.)
Half-Life Practice Problems

1. Which of the radioisotopes from Table N has the longest half-life?

2. Which of the radioisotopes from Table N has the shortest half-life?

3. What mass of a 100g sample of C-14 will remain after approximately 23,000 years?

4. If 1.25 g of I-131 remains after 40.4 days, what was the mass of the original sample?

5. How many half-lives will U-238 go through in $2.255 \times 10^9$ years?

6. What percentage of a sample of Ra-226 will remain after 3,200 years?

7. What happens to the half-life of K-42 after 12.4 hours?
Graphing Half-Life Data:

How do we detect something we can’t see like the decay of a radioactive isotope? As a radioactive substance decays something called a Geiger counter can be used to record the individual decay events. It consists of a metal tube filled with argon or neon and is kept at low pressure. Into the center of this tube a wire has been anchored with high voltage set up between the wire and the tube. When ionizing particles enter this tube, it ionizes the entrapped gas and causes an electrical pulse. By adding up the number of pulses, the intensity of radiation can be detected.

When the data from a Geiger counter is graphed it can be used to determine the half life of an isotope:

Steps to determine half life from a graph:

1) Draw a vertical line (anywhere from one y value on the curve to half its y -value)
2) Now turn 90 degrees and draw a horizontal line (to the right) over to the curve → horizontal distance is the half life for that particular substance

Example: What is the half life of the substance illustrated in the above graph?
Present Day Uses of Particular Radioisotopes:

Carbon-14 → **DATING** (not that kind, radioactive)

Uranium-238 to Lead-206 → **NUCLEAR ENERGY**

<table>
<thead>
<tr>
<th>Radioisotope</th>
<th>Medical Function</th>
<th>Uses</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fluorine-18</td>
<td>Tracer (PET Scan)</td>
<td>Cancer detection/evaluation, cardiac and brain imaging</td>
</tr>
<tr>
<td>Iodine-131</td>
<td>Radionuclide Therapy (RNT)</td>
<td>Thyroid cancer treatment</td>
</tr>
<tr>
<td>Iridium-192</td>
<td>Radionuclide Therapy (RNT)</td>
<td>Head and breast cancer treatment</td>
</tr>
<tr>
<td>Strontium-89</td>
<td>Palliative</td>
<td>Pain relief</td>
</tr>
<tr>
<td>samarium 153</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Rhenium-186</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Technetium-99m</td>
<td>Diagnostic Radiopharmaceuticals</td>
<td>Monitoring organ function</td>
</tr>
</tbody>
</table>

What is a radioactive “tracer”?

- A tracer is a substance containing a radioisotope

What do tracers do?

- Tracers can be used to
  1. measure the speed of chemical processes
  2. track the movement of a substance through a natural system such as a cell or a tissue

How do tracers work?

- **Example 1:**
  - It is possible to make a molecule of water in which one of the two hydrogen atoms is a radioactive tritium (hydrogen-3) atom.
  - This molecule behaves in almost the same way as a normal molecule of water. The main difference between the tracer molecule containing tritium and the normal molecule is that the tracer molecule continually gives off radiation that can be detected with a **Geiger counter** or some other type of radiation detection instrument in order to:
    - monitor plant growth by watering plants with it. The plants would take up the water and use it in leaves, roots, stems, flowers, and other parts in the same way it does with normal water. In this case, however, it would be possible to find out how fast the water moves into any one part of the plant. One would simply pass a Geiger counter over the plant at regular intervals and see where the water has gone.

- **Example 2:**
  - In **medicine** tracers are applied, such as **Technetium-99** in autoradiography and nuclear medicine, including **single photon emission computed tomography** (SPECT), **positron emission tomography** (PET) and scintigraphy.
    - An **autoradiograph** is an image on an x-ray film or nuclear emulsion produced by the pattern of decay emissions (e.g., beta particles or gamma rays) from a distribution of a radioactive substance.
These images allow us to monitor organ function and diagnose organ problems.

- **Single photon emission computed tomography (SPECT, or less commonly, SPET)** is a nuclear medicine tomographic\(^1\) imaging technique using gamma rays.
  - This technique combines the concepts of *radioactivity* and *chemical bonding*:
    - The radioisotope provides detection and imaging.
    - The ligand is chosen specifically for its unique bonding properties (different ligands are chosen to monitor different tissues).

The basic technique requires injection of a gamma-emitting radioisotope (also called radionuclide) into the bloodstream of the patient. Occasionally the radioisotope is a simple soluble dissolved ion, such as a radioisotope of gallium(III), which happens to also have chemical properties which allow it to be concentrated in ways of medical interest for disease detection. However, most of the time in SPECT, a marker radioisotope, which is of interest only for its radioactive properties, has been attached to a special radioligand, which is of interest for its chemical binding properties to certain types of tissues. This marriage allows the combination of ligand and radioisotope (the radiopharmaceutical) to be carried and bound to a place of interest in the body, which then (due to the gamma-emission of the isotope) allows the ligand concentration to be seen by a gamma-camera.

A radioisotope used for diagnosis must emit gamma rays of sufficient energy to escape from the body and it must have a half-life short enough for it to decay away soon after imaging is completed.

The radioisotope most widely used in medicine is technetium-99m, employed in some 80% of all nuclear medicine procedures - 70,000 every day. It is an isotope of the artificially-produced element technetium and it has almost ideal characteristics for a nuclear medicine scan. These are:

- It has a half-life of six hours which is long enough to examine metabolic processes yet short enough to minimise the radiation dose to the patient.
- Technetium-99m decays by a process called "isomeric"; which emits gamma rays and low energy electrons. Since there is no high energy beta emission the radiation dose to the patient is low.
- The low energy gamma rays it emits easily escape the human body and are accurately detected by a gamma camera. Once again the radiation dose to the patient is minimised.
- The chemistry of technetium is so versatile it can form tracers by being incorporated into a range of biologically-active substances to ensure that it concentrates in the tissue or organ of interest.

### INDUSTRY

<table>
<thead>
<tr>
<th>Radioisotope</th>
<th>UseS</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Isotopes used in Medicine

Many radioisotopes are made in nuclear reactors, some in cyclotrons. Generally neutron-rich ones and those resulting from nuclear fission need to be made in reactors, neutron-depleted ones are made in cyclotrons. There are about 40 activation product radioisotopes and five fission product ones made in reactors.

**REACTOR RADIOISOTOPES** (half-life indicated)

**Bismuth-213 (46 min)**: Used for targeted alpha therapy (TAT), especially cancers.

**Chromium-51 (28 d)**: Used to label red blood cells and quantify gastro-intestinal protein loss.

**Cobalt-60 (5.27 yr)**: Formerly used for external beam radiotherapy, now used more for sterilising

**Dysprosium-165 (2 h)**: Used as an aggregated hydroxide for synovectomy treatment of arthritis.

**Erbium-169 (9.4 d)**: Use for relieving arthritis pain in synovial joints.

**Holmium-166 (26 h)**: Being developed for diagnosis and treatment of liver tumours.

**Iodine-125 (60 d)**: Used in cancer brachytherapy (prostate and brain), also diagnostically to evaluate the filtration rate of kidneys and to diagnose deep vein thrombosis in the leg. It is also widely used in radioimmuno-assays to show the presence of hormones in tiny quantities.

**Iodine-131 (8 d)**: Widely used in treating thyroid cancer and in imaging the thyroid; also in diagnosis of abnormal liver function, renal (kidney) blood flow and urinary tract obstruction. A strong gamma emitter, but used for beta therapy.

**Iridium-192 (74 d)**: Supplied in wire form for use as an internal radiotherapy source for cancer treatment (used then removed).

**Iron-59 (46 d)**: Used in studies of iron metabolism in the spleen.

**Lutetium-177 (6.7 d)**: Lu-177 is increasingly important as it emits just enough gamma for imaging while the beta radiation does the therapy on small (eg endocrine) tumours. Its half-life is long enough to allow sophisticated preparation for use. It is usually produced by neutron activation of natural or enriched lutetium-176 targets.

**Molybdenum-99 (66 h)**: Used as the 'parent' in a generator to produce technetium-99m.

**Palladium-103 (17 d)**: Used to make brachytherapy permanent implant seeds for early stage prostate cancer.

Potassium-42 (12 h): Used for the determination of exchangeable potassium in coronary blood flow.

Rhenium-186 (3.8 d): Used for pain relief in bone cancer. Beta emitter with weak gamma for imaging.

Rhenium-188 (17 h): Used to beta irradiate coronary arteries from an angioplasty balloon.

Samarium-153 (47 h): Sm-153 is very effective in relieving the pain of secondary cancers lodged in the bone, sold as Quadramet. Also very effective for prostate and breast cancer. Beta emitter.

Selenium-75 (120 d): Used in the form of seleno-methionine to study the production of digestive enzymes.

Sodium-24 (15 h): For studies of electrolytes within the body.

Strontium-89 (50 d)*: Very effective in reducing the pain of prostate and bone cancer. Beta emitter.

Technetium-99m (6 h): Used in to image the skeleton and heart muscle in particular, but also for brain, thyroid, lungs (perfusion and ventilation), liver, spleen, kidney (structure and filtration rate), gall bladder, bone marrow, salivary and lacrimal glands, heart blood pool, infection and numerous specialised medical studies. Produced from Mo-99 in a generator.

Xenon-133 (5 d)*: Used for pulmonary (lung) ventilation studies.

Ytterbium-169 (32 d): Used for cerebrospinal fluid studies in the brain.

Ytterbium-177 (1.9 h): Progenitor of Lu-177.

Yttrium-90 (64 h)*: Used for cancer brachytherapy and as silicate colloid for the relieving the pain of arthritis in larger synovial joints. Pure beta emitter and of growing significance in therapy.

Radioisotopes of caesium, gold and ruthenium are also used in brachytherapy.

* fission product

Cyclotron Radioisotopes

Carbon-11, Nitrogen-13, Oxygen-15, Fluorine-18: These are positron emitters used in PET for studying brain physiology and pathology, in particular for localising epileptic focus, and in dementia, psychiatry and neuropharmacology studies. They also have a significant role in cardiology. F-18 in FDG (fluorodeoxyglucose) has become very
important in detection of cancers and the monitoring of progress in their treatment, using PET.

Cobalt-57 (272 d): Used as a marker to estimate organ size and for in-vitro diagnostic kits.

Copper-64 (13 h): Used to study genetic diseases affecting copper metabolism, such as Wilson's and Menke's diseases, and for PET imaging of tumours, and therapy.

Copper-67 (2.6 d): Beta emitter, used in therapy.

Fluorine-18 as FLT (fluorothymidine), F-miso (fluoromisonidazole), 18F-choline: tracer.

Gallium-67 (78 h): Used for tumour imaging and localisation of inflammatory lesions (infections).

Gallium-68 (68 min): Positron emitter used in PET and PET-CT units. Derived from germanium-68 in a generator.

Germanium-68 (271 d): Used as the 'parent' in a generator to produce Ga-68.

Indium-111 (2.8 d): Used for specialist diagnostic studies, eg brain studies, infection and colon transit studies.

Iodine-123 (13 h): Increasingly used for diagnosis of thyroid function, it is a gamma emitter without the beta radiation of I-131.

Iodine-124: tracer.

Krypton-81m (13 sec) from Rubidium-81 (4.6 h): Kr-81m gas can yield functional images of pulmonary ventilation, e.g. in asthmatic patients, and for the early diagnosis of lung diseases and function.

Rubidium-82 (1.26 min): Convenient PET agent in myocardial perfusion imaging.

Strontium-82 (25 d): Used as the 'parent' in a generator to produce Rb-82.

Thallium-201 (73 h): Used for diagnosis of coronary artery disease other heart conditions such as heart muscle death and for location of low-grade lymphomas.