Radiation and Life

Intro to Radiation

- Atom structure
- Types of radiation
- Properties of ionizing radiation
- Detection methods
- Dose reduction methods

Understanding Radiation

Types of Ionizing Radiation

1. Alpha Radiation
2. Beta Radiation
3. Gamma Radiation
4. Neutron Radiation

1. Alpha Radiation, α - A form of ionizing radiation that consists of 2 neutrons and 2 protons ejected from an atomic nucleus, or the nucleus of a Helium atom. Alphas therefore have large mass & charge, and as a result, they are not very penetrating. Alphas are generally emitted during the decay of heavy naturally occurring radioisotopes such as uranium and radium (because of this, they are the major sources of background radiation in the form of radon gas - more on this later).
Understanding Radiation

### Types of Ionizing Radiation

2. **Beta Radiation, β**

There are two forms of Beta Radiation, Beta Minus Decay and Beta Plus Decay. Beta Minus consists of high-energy, high-speed electrons that are emitted by certain radioactive nuclei, whereas Beta Plus emits positrons.

- **Beta Minus** – stems from an unstable nucleus with excess neutrons that undergoes decay in which a neutron is converted to a proton that stays in the nucleus, and an electron and an antineutrino are emitted.

\[ \text{neutron} \rightarrow \text{proton} + \text{electron} + \text{antineutrino} \]

3. **Photon Radiation** –

There are two forms of Photon Radiation (emitted energy), X-Ray Radiation and Gamma Radiation. The two types of radiation are distinguished by their origin, with X-rays emitted by electrons outside the nucleus, and gamma rays emitted by the nucleus. Each is created by multiple means, however, only one method produces only gamma rays – gamma decay.

- **γ Decay** – Gamma rays from radioactive gamma decay are produced when a nucleus emits an α or β particle and the daughter nucleus is unexcited. The amount of energy released by a radioactive decay is represented by a decay scheme, where the arrows indicate emitted particles of type noted in the diagram. This allows for visual representation of complex decay reactions.
Understanding Radiation

Types of Ionizing Radiation

3. Photon Radiation Continued –

Characteristic X-Rays:

As specified previously there are multiple manners for producing x-rays, however, we will focus on one direct method similar to gamma decay for gamma ray emission: Characteristic X-Rays.

Characteristic X-Rays:

In order to emit a characteristic x-ray, a high energy electron interacts with a bound electron in an atom ejecting it. The high energy electron transfers its energy to an electron orbital and is scattered. In order for this to occur, the energy of the incident electron must exceed the binding energy of the target electron. The electron is then left with the remainder of its energy. This energy is more likely to be emitted in the form of an x-ray photon than as a secondary electron. The energy of the x-ray photon is characteristic of the atom it belongs to, as it is directly proportional to the difference in energy between the energy level from which the electron fell and the energy level into which it fell.

![Diagram of X-ray process]

Some other important methods for producing photon radiation – gamma and x-rays, include:

- Compton Scattering
- Photoelectric Effect
- Pair Production
- Bremsstrahlung
- Etc.

4. Neutron Radiation

Neutron radiation is a kind of ionizing radiation that consists of free neutrons. These Neutrons may be emitted from the fission of atomic nuclei, as well as from interactions of different subatomic particles from different decay reactions. Neutrons also play a role in various industrial processes. Neutron radiation is known to interact with a wide range of materials to form new isotopes of previously non-isotopic elements, resulting in chain reactions of harmful radiation production.

Neutron Reaction (n,\alpha):

\[ ^{1} \text{n} + ^{7} \text{Li} \rightarrow ^{4} \text{He} + ^{4} \text{He} \]
**Alpha Hazards**

- Made of Two protons and two neutrons
- Very large radiation therefore it is generally the least penetrating form of ionizing radiation
- Alpha particles can’t penetrate the dead skin layer
- They are typically only an internal exposure hazard

**Beta Hazards**

- At least 70 KeV to penetrate the dead skin layer
- Average Beta energy is 1/3 of the max energy
- Range in air is about 12ft /MeV
- Can cause localized Skin exposures (hot particles)
- Can create Bremstrahlung radiation if shielded with high Z material

**Gamma Hazards**

- Travels at the speed of light (also called a photon)
- X-rays and gamma radiation are both photons
- Gammas originate in the nucleus
- X-rays originate from the energy transition of orbital electrons or as bremsstrahlung (therefore they originate outside the nucleus)
- Very small radiation therefore it is generally the most penetrating form of ionizing radiation
**Neutron Hazards**

- Part of the atom's nucleus that is shed
- Neutral charge
- Interacts readily in hydrogenous materials
  - Tissue is mostly hydrogen (by atomic abundance)

**Radiation quantities and units**

- Dose: Rad, Grey
- Dose equivalence: Rem, Seiverts
- Activity: Curie, Becquerel

1 Becquerel = 1 radioactive decay per second
1 Curie = 3.7x10^{10} decays per second

**Half life \((T_{1/2})\)**

- Time at which the radiation emitted from a source will be half of its initial radiation emitted
- Every isotope that emits radiation will have a half life
- Can range from microseconds to billions of years
Counting data over time:

\[ y = 100000e^{-0.3092x} \]

Y intercept is 100000
Slope is rise/run
\[
\text{Rise} = \frac{100000}{-3.2} = -31.25
\]

- Time (minutes)
- Counts
- \[ y = 100000e^{-0.3092x} \]
Determine Half life from data

\[ A_0 \cdot e^{-\lambda t} \quad 100000 \cdot e^{-0.3092 \cdot t} \]

- Y intercept is the \( A_0 \)

\[ \lambda = \frac{\ln(2)}{t \frac{1}{2}} \quad 0.3092 = \frac{\ln(2)}{t \frac{1}{2}} \]

\[ t \frac{1}{2} = \frac{\ln(2)}{0.3092} = 0.693 \quad \frac{0.693}{0.3092} = 2.24 \text{ min} \]

Half life answers compared

- From data slope method \( T_{1/2} = 2.21 \text{ min} \)
- From data fit equation \( T_{1/2} = 2.24 \text{ min} \)
- Use the website to determine possible isotopes based on half life
  - [http://nucleardata.nuclear.lu.se/nucleardata/topcharted.htm](http://nucleardata.nuclear.lu.se/nucleardata/topcharted.htm)

How do we detect radiation?

- Radiation detectors
  - Geiger Mueller (GM)
    - operates by collecting charge the of an ion pair (with gas multiplication) ionizing all the detector gas
How do we detect radiation?

- Scintillation counters
  - Operates by light production from radiation interaction in the detector and the photomultiplier or photodiode to convert the light to an electrical output.

How do we detect radiation?

- Ion Chambers
  - Large numbers of charged particles interacting in the gas that creates a current that can be proportional to dose (dose to tissue if the detector wall material is the same Z as tissue).

How do we detect radiation?

- Proportional counters
  - Operates by gas multiplication to amplify charge from the original ion pair and measure low number of counts.
How to keep doses As Low As Reasonably Achievable (ALARA)

- **TIME** - Decrease your time spent near a radiation source
- **DISTANCE** - Increase your distance from the radiation source
- **SHIELDING** - Increase shielding between yourself and the radiation source

**TIME**

DOSE RATE: 4000 mrem/hr

- Dose in 60 min: 4000 mrem
- Dose in 30 min: 2000 mrem
- Dose in 15 min: 1000 mrem
- Dose in 1 min: 66 mrem
- Dose in 1 sec: 1 mrem

**Distance**

DOSE RATE: 4000 mrem/hr @ 1m

\[ \text{DoseRate} @ x = \frac{\text{DoseRate} @ 1 \text{m}}{x^2} \]

- Dose rate @ 2m: 1000 mrem/hr
- Dose rate @ 3m: 444 mrem/hr
- Dose rate @ 4m: 250 mrem/hr
- Dose rate @ 5m: 160 mrem/hr
- Dose rate @ 6m: 111 mrem/hr
Sources of Radiation Exposures to the US population (NCRP 160)

<table>
<thead>
<tr>
<th>Source</th>
<th>Volume (mrem/yr)</th>
<th>Percent of Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Background</td>
<td>228</td>
<td>37%</td>
</tr>
<tr>
<td>Radon Inhalation</td>
<td>20</td>
<td>3%</td>
</tr>
<tr>
<td>Thoron Inhalation</td>
<td>20</td>
<td>3%</td>
</tr>
<tr>
<td>External (cosmic)</td>
<td>15</td>
<td>2%</td>
</tr>
<tr>
<td>Internal (ingestion)</td>
<td>15</td>
<td>2%</td>
</tr>
<tr>
<td>Medical</td>
<td>300</td>
<td>48%</td>
</tr>
<tr>
<td>Computed tomography</td>
<td>147</td>
<td>24%</td>
</tr>
<tr>
<td>Nuclear medicine</td>
<td>77</td>
<td>12%</td>
</tr>
<tr>
<td>Fluoroscopy and radiography</td>
<td>62</td>
<td>10%</td>
</tr>
<tr>
<td>Trauma</td>
<td>19</td>
<td>3%</td>
</tr>
<tr>
<td>Endoscopy</td>
<td>1</td>
<td>0.08%</td>
</tr>
<tr>
<td>Medical, Nuclear medicine</td>
<td>9.1</td>
<td>1.44%</td>
</tr>
<tr>
<td>Other medical, Nuclear</td>
<td>0.3</td>
<td>0.05%</td>
</tr>
<tr>
<td>TOTAL (6.2mSv)</td>
<td>620</td>
<td></td>
</tr>
</tbody>
</table>
Ingestion of Radionuclides: 5% Background Radiation

Another source of background radiation is the ingestion of radionuclides found naturally in the foods that we eat. One of the most prominent sources of ingested radionuclides is Potassium-40 (K-40) found in numerous foods. However, nearly everything we eat has radionuclides as anything that comes from the ground naturally acquires these from the soil and similarly anything that survives from eating products from the soil acquires these as well. The concentration of the natural radioactivity in food is often in the range of 40 to 600 becquerel per kilogram of food. Examples of food products known to contain certain radionuclides can be seen below.

$^{40}$K : The radioactivity from potassium alone may typically be 90 Bq/kg in milk, 420 Bq/kg in milk powder, 165 Bq/kg in potatoes, and 125 Bq/kg in beef.

$^{14}$C : Carbon-14 is present in the atmosphere, oceans, and all organic material. Carbon-14 occurs in the ratio of 6 picocuries (pCi) of carbon-14 per gram of total carbon, and it is assimilated into tissues of all plants and animals. As such, Carbon-14 can be taken into the body by drinking water, eating food, or breathing air.

$^{3}$H : Hydrogen has three isotopes known as protium, H-1, with a single proton, deuterium, H-2, with one proton and one neutron and tritium, H-3, with one proton to two neutrons. The first of these are not radioactive, but tritium is with two neutrons that take it out of its stable state. Hydrogen's positive charge draws it to electrically negative polar Oxygen molecules to make water. However, in the case of tritium, "heavy water" is made due to the hydrogen's extra neutron. Natural heavy water comprises less than 1% of water on earth and is made when cosmic rays interact with the atmosphere which is composed in part of Hydrogen.
Food ingestion also represents the major source of naturally occurring Po-210 intake at 77%, while 5% is taken in via water and 1% from the air. Additionally, 17% is added by cigarettes. Po-210 is a daughter of Pb-210 and enters the food chain via plant uptake from soil and water and particle deposition from the decay of Rn-222 in the atmosphere as we already learned about, with greater preference on the latter deposited during rainfall. Po-210 is mostly found in leafy vegetables and grains.

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Similar to Po-210, Ra-226 is part of the Radium decay series and is released into the atmosphere and deposited in and on vegetation via soil and water uptake and precipitation. Radium is chemically similar to calcium and, when ingested, a small fraction is transferred across the small intestine and most is deposited in bone, which contains 75-95% of the total ingested body radium.

Another source of background radiation is Cosmic Radiation. This form of radiation is delivered via “cosmic rays,” or energetic charged subatomic particles that originate from outer space and produce secondary charged particles that can penetrate the Earth’s atmosphere and surface. Most cosmic radiation is composed of familiar stable subatomic particles that normally occur on Earth, such as protons, atomic nuclei, or electrons and photons, as well as some positrons. Such radiation is primarily comprised of low-energy photons that are remnants from the creation of the universe and from active stars, such as the Sun. This radiation is of more consequence at higher altitudes. Therefore, cosmic radiation has a heightened effect, delivering more dose when flying on a plane or living in the mountains versus sea level.
Background Radiation

Cosmic Radiation: 5% Background Radiation

In flight there are two principal sources of natural radiation to consider:
- Galactic Cosmic Rays (GCR) which are always present
- Solar Energetic Particle (SEP) or Solar Cosmic Ray (SCR) events which occur sporadically

GCR provides an inescapable radiation background which varies over the solar cycle of about 11 years. GCR are maximum when solar activity is minimum and vice-versa. The resulting dose equivalent at aircraft also varies quite strongly with altitude and latitude. The following table provides estimates of the radiation dose equivalent at the times of a recent solar minimum (10/86) and solar maximum (7/89) for representative high and low latitude (values obtained by use of the CARI-6 program developed by the Civil Aeromedical Institute of the Federal Aviation Administration (FAA)).

<table>
<thead>
<tr>
<th>Dose Equivalent Rate (mrem/h)</th>
<th>Altitude (x1000 ft)</th>
<th>North Latitude 70 degrees</th>
<th>North Latitude 35 degrees</th>
</tr>
</thead>
<tbody>
<tr>
<td>Solar Minimum (10/86)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td>10</td>
<td>1.99</td>
<td>2.07</td>
<td>1.73</td>
</tr>
<tr>
<td>20</td>
<td>9.85</td>
<td>11.4</td>
<td>8.75</td>
</tr>
<tr>
<td>30</td>
<td>32.5</td>
<td>40.6</td>
<td>28.5</td>
</tr>
<tr>
<td>40</td>
<td>67.8</td>
<td>90.2</td>
<td>58.8</td>
</tr>
<tr>
<td>50</td>
<td>97.1</td>
<td>138</td>
<td>83.6</td>
</tr>
<tr>
<td>60</td>
<td>110</td>
<td>171</td>
<td>94.9</td>
</tr>
<tr>
<td>70</td>
<td>114</td>
<td>192</td>
<td>96.8</td>
</tr>
<tr>
<td>80</td>
<td>112</td>
<td>206</td>
<td>94.4</td>
</tr>
</tbody>
</table>

Solar Maximum (7/89)            |                     |                          |                          |
| 0                             | 0.00                | 0.00                     | 0.00                     |
| 10                            | 0.40                | 0.41                     | 0.37                     |
| 20                            | 1.30                | 1.32                     | 1.26                     |
| 30                            | 4.00                | 4.14                     | 3.70                     |
| 40                            | 9.73                | 10.0                     | 9.42                     |
| 50                            | 19.0                | 20.3                     | 18.7                     |
| 60                            | 32.1                | 34.0                     | 30.2                     |
| 70                            | 46.6                | 49.2                     | 43.8                     |
| 80                            | 62.4                | 65.6                     | 57.9                     |

Terrestrial Radiation: 3% Background Radiation

The last main source of background radiation is Terrestrial Radiation. This radiation arises as a result of naturally occurring radioactive materials in the Earth such as Uranium, Radium, Radium and Thoron, serving as a source of external exposure.
Background Radiation

Summarization of Background Radiation

- Cosmic Radiation
- Inhaled Radionuclides (e.g., Rn-222)
- Ingested Radionuclides (e.g., Cs-137)
- Terrestrial Radiation

Risk Benefit Analysis

- Balance between the risk of use (exposure) and the benefit of its use

<table>
<thead>
<tr>
<th>RISK</th>
<th>BENEFIT</th>
</tr>
</thead>
<tbody>
<tr>
<td>One is exposed to 800-1300mrem</td>
<td>Allows for diagnosis and lifesaving of the patient</td>
</tr>
</tbody>
</table>

Risk in Perspective

<table>
<thead>
<tr>
<th>Health risk</th>
<th>Days of life lost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Smoking 1 pack of cigarettes a day</td>
<td>2370</td>
</tr>
<tr>
<td>20% overweight</td>
<td>985</td>
</tr>
<tr>
<td>Average US alcohol consumption</td>
<td>130</td>
</tr>
<tr>
<td>Home Accidents</td>
<td>95</td>
</tr>
<tr>
<td>Dose of 5000 mrem/hr</td>
<td>32</td>
</tr>
<tr>
<td>Dose of 500 mrem/hr</td>
<td>3</td>
</tr>
</tbody>
</table>
Medical uses of Radiation

• X-rays
  – Observe broken bones
  – Contrast material for x-ray, barium enema (not radioactive barium, angiogram for cardiology viewing)
  – Mammogram to view breast tissue looking for tumors
  – Computerized Tomography (CT) exam Xrays with computer processing to get 2-d slices of the body

Medical uses of Radiation

• Nuclear Medicine - Injecting or ingesting radioactive material short lived (biological or radioactive) material as
  – Check organ function, blood flow, respiration
  – PET (Positron emission tomography) scan Imaging

Medical uses of Radiation

• Radiation oncology
  – Brachytherapy seed treatments of all kinds of cancer
  – Linear accelerator and Intensity modulated Radiation therapy (high energy x-rays and electron beams)
  – Gamma stereotactic surgery (gamma knife) for treatment of muscle issues (face tics), reduce tumors, blood vessel defects, epilepsy and Parkinson’s disease.
Industrial uses of Radiation

• Power generation- use of fissionable material to heat water and spin a turbine generator that will produce power

Industrial uses of Radiation

• Industrial radiography- Iridium 192 to take images of welds, pipes, etc.

Industrial uses of Radiation

• Guaging devices- measure thickness of metals, determine content of an item (XRF) gamma and neutron emitters
**Industrial uses of Radiation**

- Well logging - gamma or neutron source sent in a well to determine viability for certain valuable mineral mining

**Industrial uses of Radiation**

- X-rays for security + inspection
  - Dual energy x-ray image
  - Backscatter x-ray image
  - [http://www.as-e.com/popups/zback_animation.WMV.asp](http://www.as-e.com/popups/zback_animation.WMV.asp)

**Industrial uses of Radiation**

- Food irradiation – kills bacteria that cause food to rot quicker
  - USDA

<table>
<thead>
<tr>
<th>Product</th>
<th>Approved</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wheat</td>
<td>1963</td>
</tr>
<tr>
<td>Potatoes</td>
<td>1964</td>
</tr>
<tr>
<td>Seaweed</td>
<td>1983</td>
</tr>
<tr>
<td>Pork</td>
<td>1986</td>
</tr>
<tr>
<td>Fruit and vegetables</td>
<td>1986</td>
</tr>
<tr>
<td>Herbs + spices</td>
<td>1986</td>
</tr>
<tr>
<td>Enzymes</td>
<td>1986</td>
</tr>
<tr>
<td>Papaya</td>
<td>1987</td>
</tr>
<tr>
<td>Poultry</td>
<td>1992</td>
</tr>
<tr>
<td>Red Meat</td>
<td>1999</td>
</tr>
<tr>
<td>Eggs</td>
<td>2000</td>
</tr>
</tbody>
</table>
Industrial uses of Radiation

- Sterilization - hospital equipment, mail potentially containing biological compounds

Industrial uses of Radiation

- Static eliminating devices (po-210 alpha) to ionize the air

Radiation Exposure per Activity

- Flight from NY to LA 2.5 mrem/Trip
- Full Mouth X-Ray 9 mrem/scan
- Chest X-Ray 10 mrem/scan
- Ct Scan 800-1300 mrem/scan
- Radon Gas 200 mrem/yr
- Smoking 1300 mrem/yr
Radiation Exposure (non Rad workers)

- Medical personnel: 70 mrem/yr
- Grand central station workers: 120 mrem/yr
- Nuclear power plant: 160 mrem/yr
- Airline flight crew: 1000 mrem/yr

Household uses of Radiation

- Smoke detector: 0.001 mrem/year (NUREG 1717)
- Thoriated lenses (thorium impregnated): believed to capture light better
- Thorium lantern
- Old radium dial watches
- Fiesta ware dinnerware
- Old Glassware