Lecture 14, Exposure to Ionizing Radiation

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The Electromagnetic Spectrum
1. Background

Wilhelm Conrad Roentgen

- November 8, 1895 – Discovers “a new kind of ray”
- He names them X-rays; X representing the unknown.
- December, 1895 – First radiograph of a living object (His wife’s hand).
- January 23, 1896 – First medical use of x-rays reported in the *Lancet*. 
1. Radiation Basics

Uses of High-Dose Radiation in U.S.

- Industrial radiography
- Power production
- Research-Tagging
- Processing food and medicines
- Medical diagnostic studies
- Medical cancer therapy
- Atomic Weapons Production
Radiation vs Radioactive Material

• **Radioactive Material**
  – Any substance that spontaneously gives off radiation
  – Can be in various chemical forms
  – If not contained (sealed source) can lead to contamination - External, Internal or Both

• **Radiation**
  – The energetic emissions of radioactive material
  – Can be subatomic particles (α, β, n), photons (X-ray, γ) or combinations
  – Results in ionization of the absorbing material (if living tissue ➔ radiation injury)
Common Radioactive Material Terms

• **Radioisotope** - a generic name for a radioactive element

• **Radionuclide** - a specific radioisotope such as Uranium-235

• These terms are often used interchangeably
Simply stated, Ionizing Radiation carries sufficient energy to eject electrons from their atomic orbits.

- Atom $\rightarrow$ Ion
- Molecule $\rightarrow$ Bond Breakage
- DNA $\rightarrow$ Chromosomal Aberration

Cell Death  Mutation
Standards:
0.1 Rem / yr
( general public)
5 Rem / YR,
occupational
Half-Life

• The time required for a radioactive substance to lose 1/2 of its radioactivity
• Each radionuclide has a unique half-life
• Half-lives range from extremely short (fraction of a second) to billions of years
1. Ionizing radiation is radiation with enough energy to produce ions in atoms that it strikes.
1. Radiation Basics

Alpha Particle
Alpha Particle Radiation

Daughter Nucleus
Np-237

Parent Nucleus
Am-241

\( ^{4}_{2} \alpha^{++} \)

Alpha Particle (Helium Nucleus)
## Selective Alpha Emitters

<table>
<thead>
<tr>
<th>Radioisotope</th>
<th>Alpha Energies (MeV)</th>
<th>Half-Life</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ra-226</td>
<td>4.7 to 7.7</td>
<td>1620 years</td>
</tr>
<tr>
<td>Pb-210</td>
<td>5.3</td>
<td>22 years</td>
</tr>
<tr>
<td>Po-210</td>
<td>5.3</td>
<td>138 days</td>
</tr>
<tr>
<td>Ac-227</td>
<td>4.9 to 7.4</td>
<td>22 years</td>
</tr>
<tr>
<td>Pu-238</td>
<td>5.3 to 5.5</td>
<td>88 years</td>
</tr>
<tr>
<td>Pu-239</td>
<td>5.1</td>
<td>24131 years</td>
</tr>
<tr>
<td>Am-241</td>
<td>5.3 to 5.5</td>
<td>432 years</td>
</tr>
</tbody>
</table>

*Fig. 86 - Alpha emitters commonly used for neutron sources*
1. Radiation Basics

Beta Particle
\( \gamma \) rays may be emitted from an excited nucleus following \( \beta^- \) or \( \alpha \)-decay.
1. Radiation Basics

X-Ray
1. Radiation Basics

**Neutron**

Uncharged, heavy

**Critical Mass and a Chain Reaction!**
Penetrating Power of the Various Types of Radiation

Types of radiation and their penetrating powers:

- Alpha
- Beta
- Gamma, X-Rays
- Neutrons

Materials:
- Aluminum
- Lead
- Concrete
Ways to Decrease Exposure to Radiation
1. Radiation Basics

Dose

- **Roentgen (R)** - X, γ-ray exposure, ions in air
- **Rad (R)** -- traditional unit, absorbed dose (Radiation Absorbed Dose) (= 100 ergs/g)
- **Gray (Gy)** -- SI unit of absorbed dose
  \[ 1 \text{ Gy} = 100 \text{ rad} = 100 \text{ cGy} = 1 \text{ J/Kg} \]
- **Rem (R)** -- effective dose (Rad x weighting factors: tissue, radiation type)
- **Sievert (Sv)** -- SI unit effective dose, 100 Rem
Energy Deposited

Dose is the energy imparted to matter per unit mass of irradiated material.

The unit of absorbed dose is the Gray (Gy) or centigray (cGy).

One Gy equals 10,000 ergs deposited per gram of tissue.

1 Gy = 100 rads or 1 cGy = 1 rad

3. Effective Dose
Types of Ionizing Radiation in Decreasing Order of Weighting Factor

1. Alpha
2. Neutron
3. Proton
4. Beta
5. Gamma
6. X-ray
Effect of Radiation Weighting per Unit of Absorbed Dose

A tissue absorbing 1 cGy of proton radiation sustains five times (5X) as much biological damage as a tissue absorbing the same quantity of X-rays.
Radiation Effects Depend Upon

- Energy deposited.
- Radiation type
- Distribution of deposited energy:
  - Whole-body/external
  - Local
  - Internal contamination
Classification of Radiation Induced Health Concerns

- Acute Radiation Syndrome
- Local Radiation Injury
- External Radionuclide Contamination
- Local Trauma with Radionuclide Contamination
- Internal Radionuclide Contamination
Atomic Veterans

- New proposal – August 2001
- Expansion of “radiation-risk activities” to include:
  - Service at gaseous diffusion plants in Paducah, KY., Portsmouth, OH., and Oak Ridge, TN (area K25).

- List of illnesses to include
  - Cancer
    - Bone
    - Brain
    - Colon
    - Lung
    - Ovary

6. Summary
### Excess Cancer Mortality Estimates

**Excess Lifetime Cancer Deaths per 100,000 Persons Exposed to 100 mSv**

<table>
<thead>
<tr>
<th>Cancer Type</th>
<th>Excess Risk (males)</th>
<th>Excess Risk (females)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Leukemia, adult</td>
<td>110</td>
<td>80</td>
</tr>
<tr>
<td>Respiratory system</td>
<td>190</td>
<td>150</td>
</tr>
<tr>
<td>Digestive system</td>
<td>170</td>
<td>290</td>
</tr>
<tr>
<td>Breast, female</td>
<td>---</td>
<td>70</td>
</tr>
<tr>
<td>All other sites</td>
<td>300</td>
<td>220</td>
</tr>
<tr>
<td><strong>TOTAL</strong></td>
<td><strong>770</strong></td>
<td><strong>810</strong></td>
</tr>
</tbody>
</table>

Note: Predicted approximately 20% lifetime cancer deaths U.S. (without added radiation dose)
Radiosensitivity (most to least):

- Lymphocytes
- Erythroblasts
- Myeloblasts
- Epithelial Cells
  - Intestinal crypts
  - Testis
  - Ovary
  - Skin
  - Secretory glands
  - Lungs and bile ducts
- Endothelial Cells
- Connective Tissue Cells
- Tubular Cells of Kidneys
- Bone Cells
- Nerve Cells
- Brain Cells
- Muscle Cells
Mental Retardation and Fetal Doses
[Combined A-bomb Data (BEIR V)]
# Recommended Dose Limits

<table>
<thead>
<tr>
<th>Application</th>
<th>Occupational Dose Limit</th>
<th>Public Dose Limit</th>
</tr>
</thead>
<tbody>
<tr>
<td>TEDE (whole body)</td>
<td>5 Rem or cSv</td>
<td>100 mrem or .1 cSv</td>
</tr>
<tr>
<td>Annual equiv. dose</td>
<td></td>
<td></td>
</tr>
<tr>
<td>- Lens of the eye</td>
<td>15 Rem or cSv</td>
<td>1.5 Rem or cSv</td>
</tr>
<tr>
<td>- Skin</td>
<td>50 Rem or cSv</td>
<td>5 rem or cSv</td>
</tr>
<tr>
<td>- Hands and feet</td>
<td>50 Rem or cSv</td>
<td>-</td>
</tr>
</tbody>
</table>