**Atomic Notation**

*Atomic Mass Number*

\[ A = \# \text{ protons} + \# \text{ neutrons} \]

*Atomic Number*

\[ Z = \# \text{ protons} \]

*Neutron Number N*

\[ N = \# \text{ neutrons} = A - Z \]

\[ ^1_1 H, \quad ^3_1 H, \quad ^{238}_{92} U \]
All Elements Have Isotopes

Same # of protons - different # of neutrons

Atomic Mass of an Element is an average of all Isotopes

Isotopes have the same chemistry as the atom. This is why radioactive isotopes can be so dangerous.

The body doesn’t see the difference between water made with hydrogen and water made with tritium.

<table>
<thead>
<tr>
<th>Isotope</th>
<th>Protons</th>
<th>Neutrons</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hydrogen-1</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>Hydrogen-2</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Hydrogen-3</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>Iron-56</td>
<td>26</td>
<td>30</td>
</tr>
<tr>
<td>Iron-55</td>
<td>26</td>
<td>29</td>
</tr>
</tbody>
</table>

[Diagram of isotopes shown]
Activity (Decay Rate) Units

• The unit of activity, $R$, is the **curie (Ci)**
  – $1 \text{ Ci} \equiv 3.7 \times 10^{10} \text{ decays/s}$
• The SI unit of activity is the **becquerel (Bq)**
  – $1 \text{ Bq} \equiv 1 \text{ decay/s}$
  • Therefore, $1 \text{ Ci} = 3.7 \times 10^{10} \text{ Bq}$
• The most commonly used units of activity are the **millicurie and the microcurie**
• There have been around 2,000 nuclear test explosions
• Atomic Tests released approximately 9 MCi of Sr-90
• At equilibrium with the atmosphere, a gram of carbon shows an activity of about 15 decays per minute.
Ionizing Radiation Effects on Cells

Ionization Energy ~ few eV ~ $10^{-18}$ J

$\alpha,\beta,\gamma$ radiation can ionize atoms which break chemical bonds and damage molecules in cells:

1. Interferes with cell reproduction
2. Destruction of cell’s function or destruction of cell itself.

It has the greatest effect on cells that are rapidly reproducing because they do not have time to repair the damage:

1. Fetus, infants, children (also in animals and plants)
2. Cancerous cells

Ionizing Radiation can cause cancer or kill cancer!
**Radiation Dose**

"Dose" the amount of radioactive energy that is actually absorbed by tissues in the body either internally or externally.

Radiation dose unit (rad) : \( 1 \text{ r} = 0.01 \text{ J/kg} \)

The biological effect depends on the type of radiation and body part:

RBE: Relative biological effectiveness

**Roentgen Equivalent Man:** \( \text{rem} = \text{rad} \times \text{RBE} \)

<table>
<thead>
<tr>
<th>Type of energy of radiation</th>
<th>RBE</th>
</tr>
</thead>
<tbody>
<tr>
<td>X rays</td>
<td>1</td>
</tr>
<tr>
<td>Gamma rays</td>
<td>1</td>
</tr>
<tr>
<td>Beta rays &gt; 30KeV</td>
<td>1</td>
</tr>
<tr>
<td>Beta rays &lt; 30 KeV</td>
<td>1.7</td>
</tr>
<tr>
<td>Neutrons, slow</td>
<td>2-5</td>
</tr>
<tr>
<td>Neutrons, fast</td>
<td>10 (body) 30 (eyes)</td>
</tr>
<tr>
<td>Alpha Rays</td>
<td>10-20</td>
</tr>
</tbody>
</table>
### Table 30.3: Dose delivered in less than one day

<table>
<thead>
<tr>
<th>Dose in rem</th>
<th>Effect</th>
</tr>
</thead>
<tbody>
<tr>
<td>0–10</td>
<td>No observable effect. Possible latent effects (cancer)</td>
</tr>
<tr>
<td>10–100</td>
<td>Slight to moderate decrease in white blood cell counts.</td>
</tr>
<tr>
<td>35, 50</td>
<td>Temporary sterility; 35 for women, 50 for men.</td>
</tr>
<tr>
<td>100–200</td>
<td>Significant reduction in blood cell counts, brief nausea and vomiting. Rarely fatal.</td>
</tr>
<tr>
<td>200–500</td>
<td>Nausea, vomiting, hair loss, severe blood damage, hemorrhage, fatalities.</td>
</tr>
<tr>
<td>450</td>
<td>LD50/30. Lethal to 50% so exposed in 30 days if untreated.</td>
</tr>
<tr>
<td>500–2000</td>
<td>Worst effects due to malfunction of small intestine and blood systems. Limited survival.</td>
</tr>
<tr>
<td>&gt;2000</td>
<td>Fatal within hours due to collapse of central nervous system.</td>
</tr>
</tbody>
</table>

*^Divide by 100 to obtain dose in Sv.*

**Total Average US Background Level Radiation:** 382 mrem

**Other Units**

1 Gray (Gy) = 1 J/kg = 100 rad

1 sievert (Sv) = 100 rem
Dose: Acute vs Chronic Dose

An acute radiation dose is defined as a large dose (10 rad or greater, to the whole body) delivered during a short period of time (on the order of a few days at the most). If large enough, it may result in effects which are observable within a period of hours to weeks.

A chronic dose is a relatively small amount of radiation received over a long period of time. The body is better equipped to tolerate a chronic dose than an acute dose. The body has time to repair damage because a smaller percentage of the cells need repair at any given time. The body also has time to replace dead or non-functioning cells with new, healthy cells. This is the type of dose received as occupational exposure.
Immediate vs Delayed FX

**Immediate effects** are due to an acute (short term) exposure: a large exposure that takes place over a short period of time.

**Delayed effects** are due to latency period of cancer and disease where a health effect of radiation exposure may not become apparent for months, years or several decades after the exposure occurs. Leukemia has a latency period of 2 years, other cancers, 15 or more. If a sperm or egg are damaged then the latency period can be generations.
Background Radiation: ~300 mrem/year

• Sources are UV radiation and cosmic particles, radium, radon, potassium 40, carbon 12 present in rocks, air, and our own body cells.

• Exposure to Natural Radiation induced mutations may have contributed to our evolutionary process. Most geneticists believe that humanity has reached an evolutionary peak in beneficial mutations caused by natural radiation that the species can undergo. Thus any further mutations are detrimental, causing disease and deformity.

• Although the exact percent is unknown, background radiation is thought to be responsible for a portion of all cancers and genetic disorders.
Increasing the Background
Nuclear Fallout:
Bombs, Tests & Accidents
Cs-137, Sr-90, I-131

Fallout is the descent of airborne particles of dust, debris, and radioactive substances. About 200 different substances are formed from a nuclear bomb explosion. Millions of curies of radioactivity in the form of dust and debris get carried into the upper atmosphere by the mushroom cloud. Jet stream winds can carry fallout from bomb blasts around the world within a few months.

There have been around 2,000 nuclear test explosions
Atomic Tests released approximately 9 MCi of Sr-90
U-235 Fission Fragments
Nuclear Power and Weapons
Cesium 137 & Strontium 90, and Pu-239

In a reactor chain reaction:

1. $^{235}_{92}U + ^1n \rightarrow ^{236}_{92}U$
   - This isotope highly unstable and breaks down in the presence of slow neutrons

2. $^{236}_{92}U \rightarrow ^{95}_{39}Y + ^{139}_{53}I + 2^1n + 3.2\times10^{-11}J$
   - Yttrium
Iodine-131

- Half Life of 8 days
- Decay Mode: BETA (0.364 MeV)
- Organ most effected: Thyroid
- Pathways: Inhalation, food chain (milk, vegetables)
- Most serious fallout product from nuclear testing. Average American alive at the time received a thyroid radiation exposure of 2 – 300 rads.
- Chernobyl released 83 million curies of I-131
- Iodine-131 is produced by the fission of uranium atoms during operation of nuclear reactors and by plutonium (or uranium) in the detonation of nuclear weapons.
Cesium-137

- Half Life of 30 years
- Decay Mode: BETA (0.19 MeV)
- Decay to Barium-137 that radiates gamma (0.6 MeV)
- Behaves like Potassium and is taken up by living organisms as part of fluid electrolytes.
- Both internal and external hazard from cancer
- Ingested, it is absorbed in the intestine, settles in muscles, excreted after a few months.
- Radioactive cesium is present in soil around the world largely as a result of fallout from past atmospheric nuclear weapons test.
Strontium-90

• Half Life of 28 years.
• Does not occur naturally. It is a by product of fission.
• Beta emitter. Decays to Yttrium-90, also a beta emitter.
• Behaves like Calcium and concentrates in bone where it damages stem cells of the bone marrow critical to reproduction of cells that mediate immune function. Causes leukemia and auto-immune illnesses.
• Interferes with neuron communication leading to brain damage of developing frontal cortex (dyslexia, autism)
• Y-90 concentrates in the glands which controls hormonal function – interferes with estrogen and testosterone which contributes to breast and prostrate cancer, sexual organs.
Strontium-90

• Large amounts of Sr-90 were produced during atmospheric nuclear weapons tests in the 1950’s and 1960’s.
• Large amounts of Sr-90 was released by Chernobyl.

Worldwide:

• Trace levels of Sr-90 in food especially dairy products and leafy vegetables which are major sources of dietary calcium.

• Every person alive today has ingested some strontium-90.
Plutonium 239

- Half Life of 24,000 years.
- Does not occur naturally. It is a by product of fission.
- Alpha emitter (5.15 MeV)
- Acts like iron and can cross the placental barrier to reach fetus.
- Concentrates in testicles and ovaries.
- 1 pound, if uniformly distributed, could hypothetically induce lung cancer in every person on Earth.
- 5 metric tons of plutonium are dispersed around the Earth due to nuclear tests, bombs, satellite burn ups, fires, accidents, spill and leakages.
Uranium U-238

- Half Life of 4.5 billion years.
- Alpha emitter (5 MeV)
- Wherever you find U-238 you will find all the 14 radioactive daughters of U 238 which emit all types of radiation up to 100 MeV in energy.
- Concentrates in bone and kidneys.
- Chemically behaves like Calcium.
- A severe exposure (of the order of one milligram in the kidneys) causes lesions of the tubular cells and deterioration of the kidney function.
Depleted Uranium

- After isotope separation, the remaining $^{238}\text{U}$ is said to be “depleted” as it is missing $^{235}\text{U}$ – however, $^{238}\text{U}$ is highly radioactive
- Uranium is a very dense metal (1.7 x Pb), making it ideal for use in armor and shell casings