BIOLOGICAL EFFECTS OF RADIATION

Natural Sources of Radiation

- Natural background radiation comes from three sources:
  - Cosmic Radiation
  - Terrestrial Radiation
  - Internal Radiation

Natural Sources of Radiation

- Cosmic Radiation
  - Sun and stars send constant stream of cosmic radiation to Earth
    - Like steady drizzle of rain
  - Differences in certain variables can change the amount (or dose) of cosmic radiation that we receive.
    - Elevation
    - Atmospheric conditions
    - Earth's magnetic field

Natural Sources of Radiation

- Terrestrial Radiation
  - The Earth itself is a source of terrestrial radiation
  - Radioactive materials exist naturally in soil and rock
    - Uranium
    - Thorium
    - Radium
  - Water contains small amounts of dissolved uranium and thorium
  - All organic matter (both plant and animal) contains radioactive carbon and potassium.

Natural Sources of Radiation

- Internal Radiation
  - All animals (including people) have internal radiation
  - Comes from radioactive potassium-40 and carbon-14 inside their bodies
    - Present from birth
    - Very minor sources of exposure to others

Man-Made Sources of Radiation

- All living things are exposed to natural background radiation
- Exposure to man-made radiation sources differs by group:
  1. Members of the Public (Diagnostic Xray, Nuclear Medicine Procedures)
  2. Occupationally Exposed Individuals (Workers)

Radiation Measurement Units

- Radioactive Material Quantity
  - Curie :: the amount of radioactive material decaying at 2.22 X 10^{12} atoms per minute or 3.7 X 10^{10} atoms per second
    - 1 ci = 3.7 X10^{10} decays per second (dps)
  - Becquerel :: the amount of radioactive material decaying at 1 decay per second
    - 1 ci = 3.7 × 10^{10} Bq
    - 1Bq = 1 dps

Radiation Measurement Units

- Biological Effects
  - Not fully described by decay rate of radioactive material
  - Additional factors must considered
    - Radiation type
    - Radiation energy

Radiation Measurement Units: Roentgen (R)

- Relates to gamma or x-ray interactions in air
- Relates to energy deposition in air
- Qty of x-ray or gamma radiation producing 1 esu of charge (positive or negative) in 1 cc (cm^3) of dry air
  - esu = electrostatic unit of charge
  - 1 ionizing event = addition or removal of 1 electron = $\pm 4.8 \times 10^{-10}$ esu
  - 1 R = 2.08×10^{9} ion pairs
  - 1 R = 88 erg/gram energy deposition in air
    - erg = unit of work or energy

- Problem: Doesn't relate to biological damage.

Radiation Measurement Units: Radiation Absorbed Dose (RAD)

- Dose = Total amount of energy delivered to a specific area or organ by radiation.
- Dose rate = dose units per unit of time

- 1 RAD is an amount of any type of ionizing radiation that deposits 100 ergs/gram in tissue.

- 1 RAD = 100 ergs/gram energy deposition (tissue)

- Problem: Different types of ionizing radiation might have the same energy, but have totally different effects on tissue.

Radiation Measurement Units: Roentgen Equivalent Man (REM)

- The amount of ionizing radiation required to produce the same biological effect as one rad of high-penetration x-rays.
- Radiation dose in rem is referred to as the dose equivalent (DE)

  DE (rem) = Dose (rad) x QF

- Quality Factor (QF)
  - Accounts for differences in biological effect for different types of radiation

Quality Factor

- Gamma, X-Rays, and High-Energy Beta
  - 1 rad = 1 rem
- Alpha, Proton, Neutron, and Low-Energy Beta
  - 1 rad ≠ 1 rem
  - 1 rem = 1 rad * QF

RADIATION	QUALITY FACTOR
GAMMA	1
X	1
BETA, ELECTRON>0.03 MeV	1
BETA, ELECTRON < 0.03 MeV	1.7
THERMAL NEUTRONS	3
FAST NEUTRONS	10
PROTONS	10
ALPHA	10
HEAVY IONS	20

Different Radiation Types

- Biological effect of any radiation is related to rate at which radiation transfers energy to tissue
- Linear Energy Transfer (LET)
  - Measure of the interaction density along radiation travel path
  - Equivalent to ionization potential or stopping power of body tissue
  - Inversely proportional to radiation range
    - Short range particles like alphas have a high LET
- Most damaging types of radiation to a biological system are those with a high LET.
- High LET radiation deposits all of its energy in a short distance of travel.

Different Radiation Types

- LET increases with:
  - Increasing mass of incident radiation
  - Increasing charge of incident radiation
  - Decreasing energy of incident radiation
- In order of decreasing LET:
  - Fission fragments
  - Low mass number nuclei
  - Alpha particles
  - Protons
  - Neutrons
  - Low energy Beta, x-ray and gamma
  - High energy beta, x-ray and gamma

Cellular Effects of Radiation: Free Radical Formation

- Radical
  - An atom (either neutral or charged) with unpaired electrons that wants to join with another atom to stabilize itself
- Free radicals
  - Radicals that have not yet bonded with other atoms
  - Highly reactive atoms or chemical compounds that can alter existing state of cells
- Changes in cellular chemistry are the root causes of all the harmful effects of radiation.

Cellular Effects of Radiation: Free Radical Formation

- Direct Effect of Radiation on Cells
  - Ionization and excitation of intracellular water molecules produces free radicals

- Indirect Effect of Radiation on Cells
  - Subsequent interference of free radicals with cells not direct affected by radiation

Effects of Radiation by Biological Organization

- Molecular
  - Damage to enzymes, DNA etc. and interference with biological pathways
- Subcellular
  - Damage to cell membranes, nucleus, chromosomes etc.
- Cellular Inhibition of cell division, cell death, transformation to a malignant state

Effects of Radiation by Biological Organization

- Tissue, Organ
  - Disruption to central nervous system, bone marrow, intestinal tract
  - Induction of cancer
- Whole Animal
  - Death
  - Life shortening
- Populations
  - Changes in the genetic characteristics of individual members

Radiosensitivity

- Different cells within the body have different structures and functions

- Vary in their **radiosensitivity**
  - Susceptibility to radiation-induced damage

4 Factors Affecting Radiosensitivity

1. Cellular division rate
   - Rapidly dividing cells are more sensitivity to radiation damage
2. Cellular metabolism rate
   - Cells with high metabolism rate are more susceptible to radiation damage
3. Developmental stage
   - Cells in division stage are more susceptible to radiation damage
4. Blood / nourishment to cell
   - Normally undernourished cells reproduce less
   - Faster reproduction = more mutations

Radiation Effects on Humans: Rate of Exposure

- Biological damage decreases with decreasing dose rate
- Acute Exposure
  - High dose
  - Short exposure time
- Chronic Exposure
  - Low dose
  - Long exposure time
  - Occupational radiation exposure
  - Exposure from natural background radiation

Acute Radiation Effects: Whole Body Exposure

Dose (Rads*)	Effects
25-50	First sign of physical effects (drop in white blood cell count)
100	Threshold for vomiting (within a few hours of exposure)
320 - 360	~ 50% die within 30 days (with minimal supportive care)
480 - 540	~50 % die within 30 days (with supportive medical care)
1,000	~ 100% die within 30 days

Acute Radiation Effects: Localized Exposure

- Dermal Necrosis
  - Cell/tissue death due to insufficient blood flow
- Acute Epidermal Necrosis
  - Severe tissue loss
  - High-dose, low-energy beta irradiation