ISE 112 Occupational Health for Engineers

Ionizing Radiation

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Ionizing Radiation

- Discovery of the properties of radioactive materials in 1896 when French physicist H. Becquerel observed that uranium can blacken a photographic plate.
- Marie Curie isolated radium and polonium, more radioactive than uranium in 1898.
- Lord Rutherford is accredited for adding the most to the scientific knowledge of radioactive materials in 1920.

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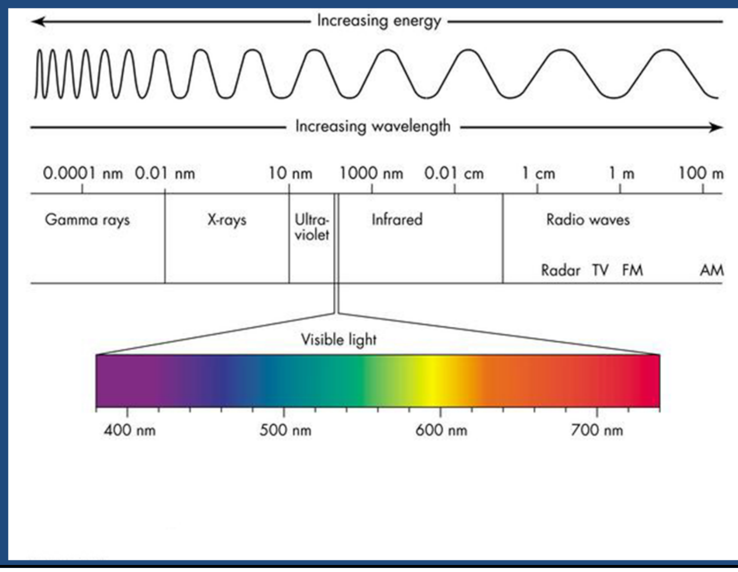
The Electromagnetic Spectrum and Ionizing Radiation.



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Rutherford discovered three distinctive types of rays.

- **Alpha rays** – slightly deflected by the magnetic field and consisting of positively charged particles.
- **Beta rays** – strongly deflected by the magnetic field in a direction opposite to that of the alpha particle deflection and consisting of negatively charged particles.
- **Gamma rays** – unaffected by the magnetic field and therefore electrically neutral.

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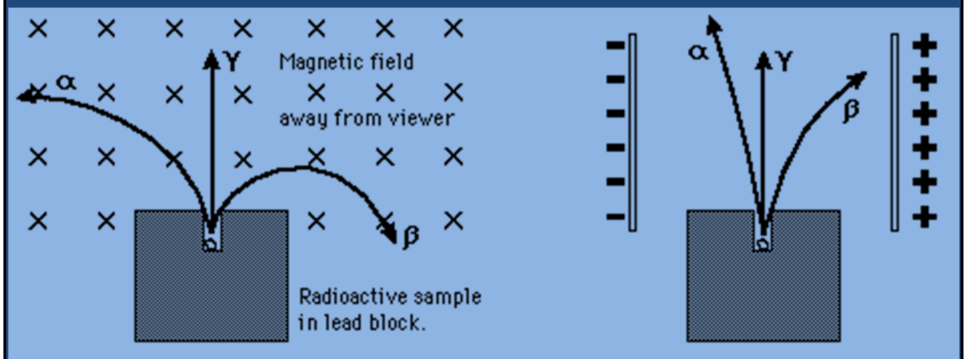
Magnetic Deflection of Radiation



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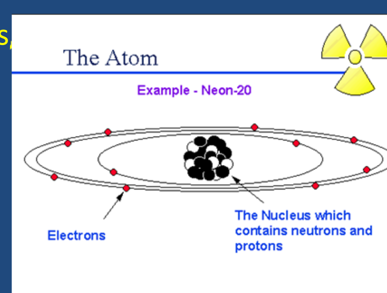
Methods of Radioactive Decay

When a nucleus disintegrates or decays, some type of radiation is emitted.



- **Alpha emission**.
  The nucleus emits an alpha particle, which consists of ***two protons and two neutrons.***
- **Beta emissions**:
  B+, B- particle, a positive or negative ***electron.***
- **Isomeric Transition**:
  Emits a ***gamma photon*** without losing electrons.

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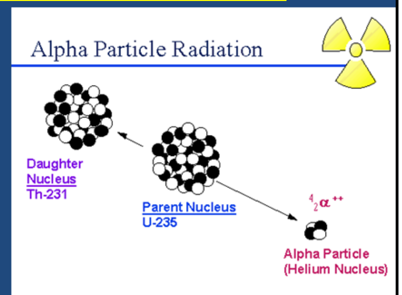

Alpha particles:

- As an alpha particle travels through an absorbing material,
  - it dissipates its kinetic energy [displaces orbital electrons into higher energy levels] or by
  - ionization complete removal of orbital electrons from atoms.
- When all energy has been dissipated, the particle comes to rest and becomes a **helium atom**.
- **Because of their high electric charge, alpha particles are powerful ionizers.**
- **Dangerous if inside the body, seeks out the bone, liver, kidney, spleen, lung.**

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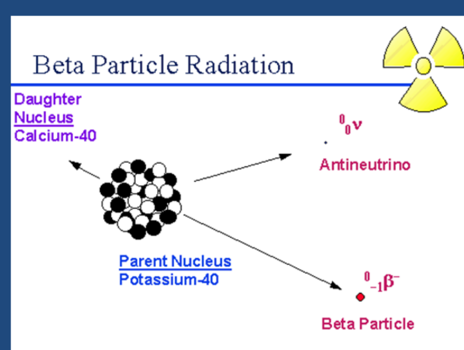
Beta emissions: B+, B- particle, a positive or negative ***electron.***

Beta Particles:

Beta particles are **electrons** ejected by unstable atomic nuclei during radioactive disintegration.



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Beta Interactions with Matter:

Beta Particles interact with matter in three ways.

- **Rutherford Scattering**:
  Deflected from its path.
- **Bremsstrahlung**:
  Collision with an atomic nucleus; the energy lost by the particle is converted to a photon of electromagnetic radiation, similar to an X ray, gamma ray.
  [German for "braking radiation"]
- **Ionization:** Beta particle collides with an electron, ejects the orbital electron. The atom is now an **ION**.

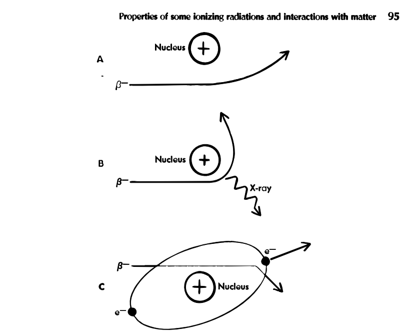
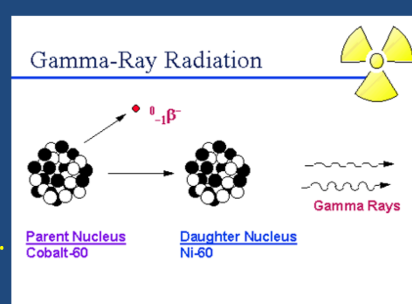


Fig. 6-5. Interactions of beta particles with matter. A, Rutherford scattering. B, Bremsstrahlung. C, Ionization.

Gamma Ray Interactions with Matter:

Gamma Rays:

- Gamma Rays are **electromagnetic radiations** .
- **They have the same photon energies as X-rays.**
  X-rays are of extra nuclear origin.



- [Outside of the nucleus, created by electromagnetic devices, machines]

Gamma Interaction with Matter:

Gamma Rays:

- **Photoelectric Effect**: Electromagnetic radiations can eject electrons upon striking.
- **Compton Effect**: Gamma ray ejects an electron and scatters a photon of lesser energy. The ejected electron can go on and produce secondary **ion pairs.**
- **Pair Production**: Gamma ray passes by the nucleus. Its energy is entirely converted into two material particles, a negatron and a positron, hence pair production. Particles are created from energy.

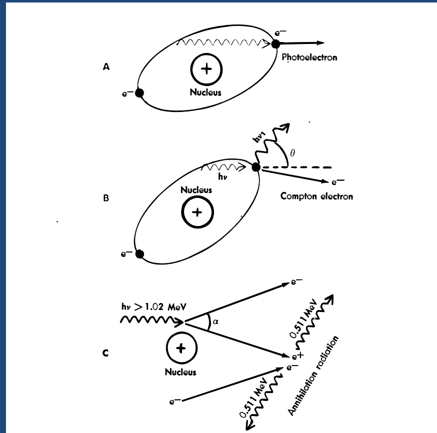


Fig. 6-10. Interaction of gamma rays with matter. A, Photoelectric effect. B, Compton scattering. C, Pair production.

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Table 11.1. Reactions Resulting from Ion Pair Formation in Water Due to Radiation.[a]

$H_2O \xrightarrow{\text{energy (34 eV)}} H_2O^+ + e^{-1}$		(Ion Pair Formation)
$H_2O + e^{-1}$ ----------> H_2O^-		(Electron Capture)
H_2O^+ ---------------> $H^+ + OH\cdot$		(Free Radical Formation)
H_2O^- ---------------> $H\cdot + OH^-$		
$H\cdot + O_2$ ------------> $HO_2\cdot$		(Free Radical Interactions)
$HO_2\cdot + H_2O$ ---------> $H_2O_2 + OH\cdot$		
$H\cdot + H\cdot$ ------------> H_2		(Loss of Free Radicals by Collision)
$H\cdot + OH\cdot$-----------> H_2O		
$OH\cdot + OH\cdot$----------> H_2O_2		

[a]The first step (Ion Pair Formation) is the direct result of the radiation; the rest of the steps result from this initial reaction. As a result of electron capture in water, there are both positively and negatively charged water molecules, which form free radicals as they react to form more stable structures. Free radicals stabilize by extracting atoms from other molecules, but the source molecule in turn is left as a free radical. This "chain reaction" of the free radicals causes miscellaneous damage to important biological molecules in the cell. This terminates by chance collision of two free radicals to form stable molecules.

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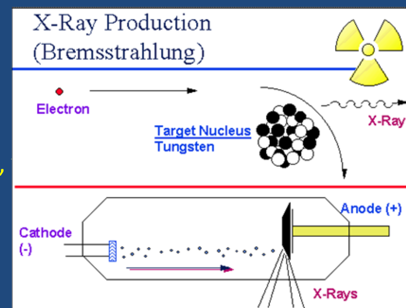
X-ray Production.



Over a century ago in 1895, Roentgen discovered x-rays.

- The key to Roentgens discovery was a device called a Crooke's tube, which was a glass envelope under high vacuum, forming the cathode, and a heavy copper target at the other end forming the anode.
- When a high voltage was applied to the electrodes, electrons formed at the cathode would be pulled towards the anode and strike the copper with very high energy.
- Roentgen discovered that very penetrating radiations were produced from the anode, which he called x rays.

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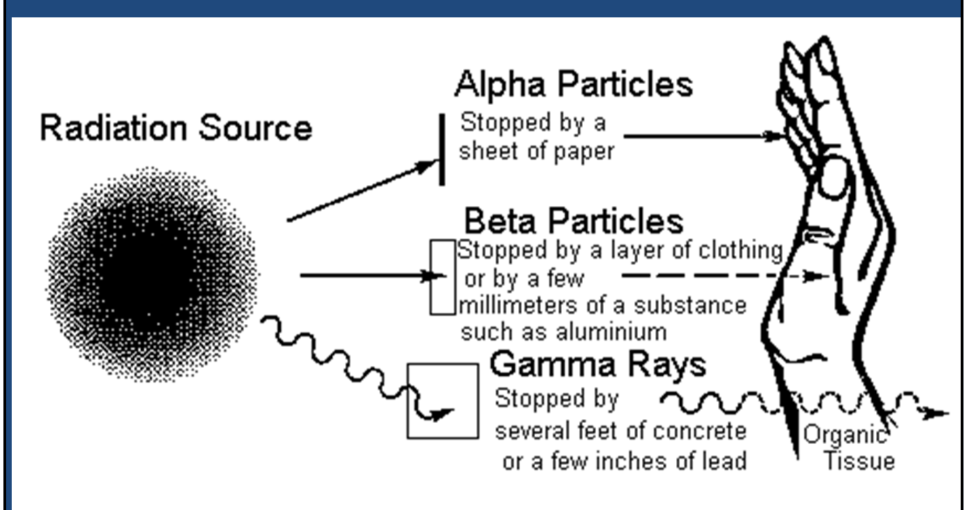
Relative Penetrations of Ionizing Radiation.



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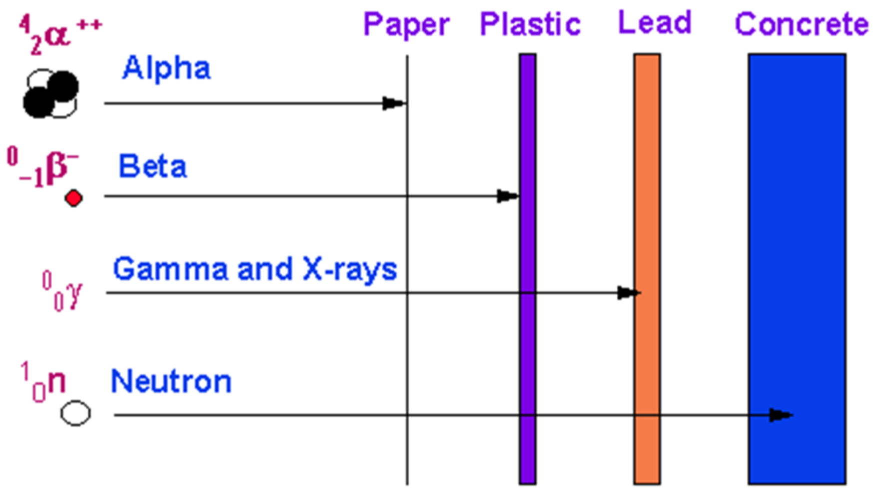
Penetrating Distances



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Three Radiation Dose Units

- **Roentgen**, R, is a unit of exposure and is defined in terms of ***ionizations produced in air by X and gamma rays.***
- **RAD**, is a unit of ***absorbed dose*** and is defined in terms of energy deposited in any material by ionizing radiation of any type.
- **REM**, may be considered as a unit of *biologic dose* and takes into account the ***relative biologic effectiveness***, damage, of any radiation absorbed by a biologic system.

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The Roentgen: "R"

Is a unit of ***exposure dose***, defined in terns of number of ionizations produced in air by ***X and Gamma radiation***.

- Other types of radiation [alpha, beta] cannot be measured in ROENTGEN.

- One Roentgen is an exposure of *X or Gamma* radiation such that the associated corpuscular (particle) emission per 0.001293 grams of air produces, in air, ions carrying ***1 esu*** of electricity of either sign.
  - 1 cubic centimeter of air at 760 mm Hg and 0*C weighs 0.001293 grams
  - The actual number of ion pairs produced equals 2.082 X 10^9
  - The amount of energy absorbed is 86.9 ergs.

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RAD: Radiation Absorbed Dose

Is defined as the ***absorbed dose*** of any type of ionizing radiation that is accompanied by the liberation of **100 ergs of energy per gram of any absorbing material**

Materials do not absorb energy the same.

- Bone, tissue, absorbs energy in different rates.
  - Bone absorbs 175 ergs of energy per gram.
  - Tissue absorbs 95.1 ergs of energy per gram.

- ***From a health view point, we should be more interested in the dose absorbed and not the exposure dose, R.***

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REM: Roentgen Equivalent Man

Absorption of equal doses of different types of radiation by the same biologic system does not produce the same effect to the same degree.

- **REM:** Defined as the ***absorbed dose*** of any type of radiation that **produces the same biologic effect as 1 RAD of therapy X-rays.**

Concept of RBE: Relative Biological Effect

RBE = The ratio of the biologic efficiency of the radiation used relative to the biologic efficiency of therapy X-rays in producing the same effect.

$$RBE = \frac{\text{Dose in RADs to produce a given effect with therapy X rays}}{\text{Dose in RADs to produce the same effect with the radiation under investigation.}}$$

If the unit of absorbed dose [RAD] is multiplied by the RBE, another unit of dose is obtained. = REM

REM = RBE x RAD

RBE: Relative Biological Effect

Type of Radiation	RBE Values:
• X-rays	1.0
• 4 MeV gamma rays	0.7
• Beta Particles of E< 30 keV	1.7
• Alpha Particles	10 – 20

(Relative biological effect compared to X-rays.)

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Summary: Three Radiation Dose Units

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Dose is Dependant on Six Factors

1. **Activity of the Material**, expressed in disintegrations per unit of time. - ***More disintegrations, the greater the dose.***
2. **Number of particles or photons produced per disintegration.**
   Not all radioactive materials behave the same.
   Ex. Cobalt 60 produces two (2) gamma photons per disintegration.
3. **Dose is dependent on the distance from the source.**
   Exposure dose is inversely proportional to the square of the distance of the object from the source.
4. **Dose depends on the objects surface area exposed.**
   The larger the area, the larger the dose.
5. **Dose depends on the nature of an absorber between the source and the object.**
   Shielding by lead. Air is not a good absorber.
6. **Dose is directly proportional to the time of exposure.**

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Actions of Ionizing Radiation on Molecules:

DNA:

Single strand breaks and intermolecular cross linking, leading to genetic mutations.

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Actions of ionizing radiation on cell types:

The Law of Bergonie' and Tribondeau

- Cells of different organisms, or of different tissues and organs of the same organism do not have equally radio sensitivity.
  - 1906 J. Bergonie' and L. Tribondeau observed that X rays may discriminate not only between healthy and cancerous tissues, but also between different healthy tissues of the same organ or organism.

X-rays are more effective on cells that are in dividing activity.

- Rat testis only **germinal cells** are destroyed, whereas the interstitial tissue remains unimpaired.
- **Germinal cells** are more radiosensitive than interstitial cells are because they have a **greater reproductive activity**.
- **Cancerous cells** **have a greater reproductive activity** and are less differentiated than are the surrounding healthy tissues; **they are more vulnerable to the killing action of X - Rays.**
  - ***Interstitial tissues include the more fibrous types of tissues.***

Organs, Structures more Radiosensitive:

- **Reproduction Systems:**
  - Ovulation, ovary production
  - Testis, spermatogenesis
  - Fetus, first 3 months critical
- **Hemopoietic Systems** (hemo poi et ic)
  - [blood forming, bone marrow]
- **Digestive Tract**
  - Intestinal epithelium
- **Skin and Hair**

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Effects of High Whole Body Dosage

Dose Level RADs	Health Effect
1	No health effects detected in short term
10	Developmental effects in very you embryos
100	White blood cell count decreases
1,000	Damage to the GI tract causes vomiting, diarrhea, nausea. Depressed blood cell production. Death in 1 to 2 weeks.
10,000	Nervous system damage. Coma and death in 1 to 2 days.
1,000,000	Massive cell death. Death is immediate.

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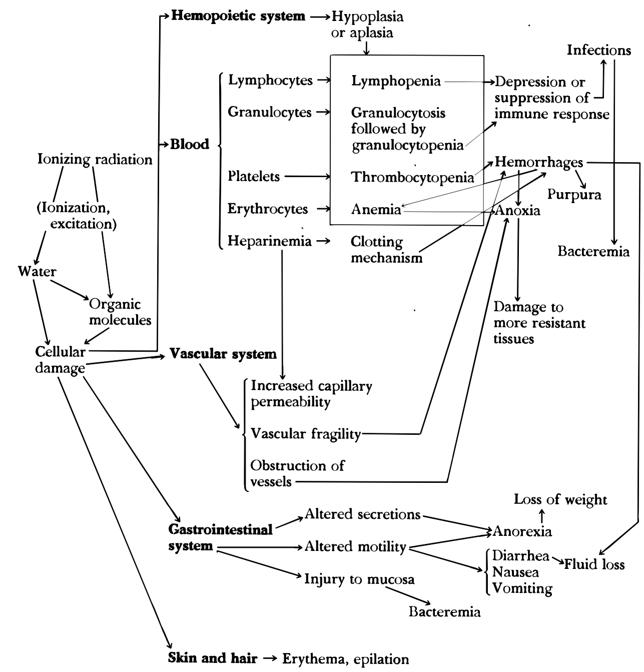
Acute Radiation Sickness:

Hemopoietic -
Vascular -
Gastrointestinal -
Skin and Hair -



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How much will radiation exposure increase my chances of cancer death over my lifetime?

Health Risk	Est. life expectancy lost
Smoking 20 cigs a day	6 years
Overweight (15%)	2 years
Alcohol (US Ave)	1 year
All Accidents	207 days
All Natural Hazards	7 days
Occupational dose (300 mrem/yr)	15 days
Occupational dose (1 rem/yr)	51 days

http://www.umich.edu/~radinfo/introduction/risk.htm

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You can also use the same approach to looking at risks on the job:

Industry type	Est. life expectancy lost
All Industries	60 days
Agriculture	320 days
Construction	227 days
Mining and quarrying	167 days
Manufacturing	40 days
Occupational dose (300 mrem/yr)	15 days
Occupational dose (1 rem/yr)	51 days

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Radiation Control Methods: Six Factors.

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4. **Dose depends on the objects surface area exposed.** The larger the area, the larger the dose.
5. **Dose depends on the nature of an absorber between the source and the object.** Shielding by lead. Air is not a good absorber.
6. **Dose is directly proportional to the time of exposure.**

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The Effect of Distance from the Source.

$$I_r = 1/n^2$$

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#1. What is level of radiation at 10 feet away?

Initial design has operator at 2 ft away.

- What is level of radiation at 10 feet away?

- Two feet equals 1 unit of distance.
- Ten feet equals 5 units of distance.

Radiation level = $1/5^2$

= 1/25th (4%) of the initial level.

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#2. Distance from Source

$$\frac{I_A}{I_B} = \frac{D^2_B}{D^2_A}$$

Where:

I_A = radiation intensity at distance A

I_B = radiation intensity at distance B

D_A = distance A

D_B = distance B

Problem:

A radiation point source measured at 3 feet produced 50 mRem/hr.

- At what distance will the exposure reach 5 mRem/hr?

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- At what distance will the exposure reach 5 mRem/hr?

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Where:

I_A = radiation intensity at distance A

I_B = radiation intensity at distance B

D_A = distance A

D_B = distance B

I_A = radiation intensity at distance A = 50 mREM

I_B = radiation intensity at distance B = 5 mREM

D_A = distance A = 3 ft

D_B = distance B = ?

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#2. Solution

$$\frac{50}{5} = \frac{D^2_B}{3^2}$$

$$90 = D^2_B$$

$$D_B = 9.49 \text{ ft}$$

Answer:

If at a distance of 3 feet the point source of radiation produces 50 mRem/hr, at a distance of 9.5 feet, the radiation intensity will be reduced to 5 mRem/hr.

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Shielding: Half-Value Layer

- Gamma radiation can be attenuated by the use of shielding. The amount of shielding required to reach a desired level of safety depends on the emission rate of the source and the energy spectrum of the gamma radiation.
- Using the concept of Half-Value Layers (HVL) in determining the amount of shielding material is the most common and straightforward method for calculating the thickness of a specific material for attenuating the gamma radiation.

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#3 Half Value Layer

Formula:

$$x = \frac{\log\left(\frac{ER_o}{ER_d}\right) HVL}{\log 2}$$

Where:

x = thickness of shielding in cm.
ER_o = emission rate – observed
ER_d = emission rate – desired
HVL = Half-Value Layer

Half-Value Layers for Select Materials:

Radionuclide	Lead (cm)	Concrete (cm)
Cobalt – 60	1.20	6.2
Cesium – 137	0.65	4.8
Iridium – 192	0.60	4.3
Radium – 226	1.70	6.9

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#3. Shielding Problem

What thickness of lead (cm), would reduce a 5 Rad/hr Cobalt-60 source to 1 Rad/hr?

- HVL Cobalt-60 = 1.20 cm.

$$x = \frac{\log\left(\frac{ER_o}{ER_d}\right) HVL}{\log 2}$$

$$x = \frac{\log(5/1)\ 1.2\ \text{cm}}{0.30103}$$

Answer:

- Using the HVL method, a 2.79 cm lead barrier will be necessary to reduce the amount of radiation from a Cobalt-60 source by a factor of 5.

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The End

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