Radiation Safety Short Course

Radiation Protection

Radiation Protection Philosophy

ALARA

As **L**ow **A**s **R**easonably **A**chievable

Radiation Protection Principles

For **External Radiation**

- Time
- Distance
- Shielding

Time

Reduce time in a radiation area, exposure will be reduced.

$$Dose = Dose\ Rate \times Time$$

$$Stay\ Time = \frac{Allowed\ Dose}{Dose\ Rate}$$

Example

A radiation worker needs to limit the dose he receives to 50 mrem. How long can he stay in a radiation field with a dose rate of 0.5 rem/hr?

$$\text{Stay Time} = \frac{\text{Allowed Dose}}{\text{Dose Rate}} = \frac{50\ \text{mrem}}{500\ \text{mrem/hr}}$$
$$= 0.1\ \text{hr}$$
$$= 6\ \text{minutes}$$

Distance

The amount of radiation an individual receives will also depend on how close the person is to the radioactive source.

- **Beta Particles**
  - Beta particles have a finite distance dependent on their energy. The higher the energy the further the particle will travel.
    - Tritium: 0.018 MeV: Maximum < 5 inches in air
    - Carbon-14: 0.15 MeV: Maximum 10 inches in air
    - Phosphorus-32: 1.710 MeV: Maximum 250 inches in air
  - Not all beta particles from the same isotope will have the same energy.

External Radiation

- Beta Energy Distribution
  - Because not all particles have equal energy from the same source, the average energy of a beta particle is approximately 1/3 of that isotope's maximum.

Isotope	Maximum Energy (MeV)	Average Energy (MeV)	Maximum Distance (in air)
Tritium (H3)	0.018	0.005	< 5 inches
Carbon-14	0.158	0.049	10 inches
P-32	1.709	0.694	250 inches

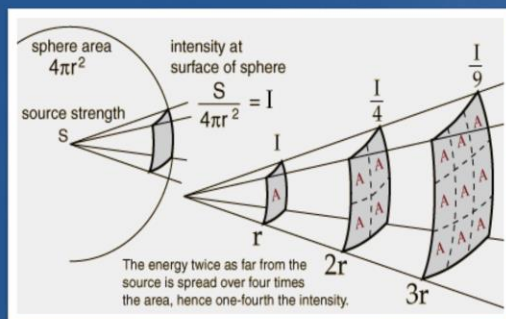
Inverse Square Law

Applies to Gamma and X-ray radiation:

- The intensity of the radiation (I) decreases in proportion to the square of the change in distance (d)
- The effect of a change in distance can be calculated using:

$$I_1 d_1^2 = I_2 d_2^2$$

Inverse Square Law



Example

The exposure rate 6 inches from a source is 200 mR/hr. What is the exposure rate 3 feet from the source?

$$I_1 = 200\,\text{mR/hr}$$
$$d_1 = 0.5\,\text{feet}$$
$$d_2 = 3\,\text{feet}$$
$$I_2 = \frac{I_1 d_1^2}{d_2^2} = \frac{(200\,\text{mR/hr})(0.5\,\text{ft})^2}{(3\,\text{ft})^2} = 5.56\,\text{mR/hr}$$

Gamma Constants

- What if you don't know the exposure rate?

- Gamma radiation levels (in R/hr) for one Curie of many radionuclides at a distance of one meter have been measured.
- These "gamma constants" (Γ) can be used to determine the expected exposure rate at any distance (using the inverse square law) provided you know the activity.
- You must divide the tabulated gamma constant by 10 to get:
  - Exposure in R/hr at 1 meter, for activity of 1 Ci

    OR

  - Exposure in mR/hr at 1 meter, for activity of 1 mCi

Example

You are using 50 mCi of Co-60. What is the exposure rate 2 meters from the source?

- Look up Γ and divide it by 10:

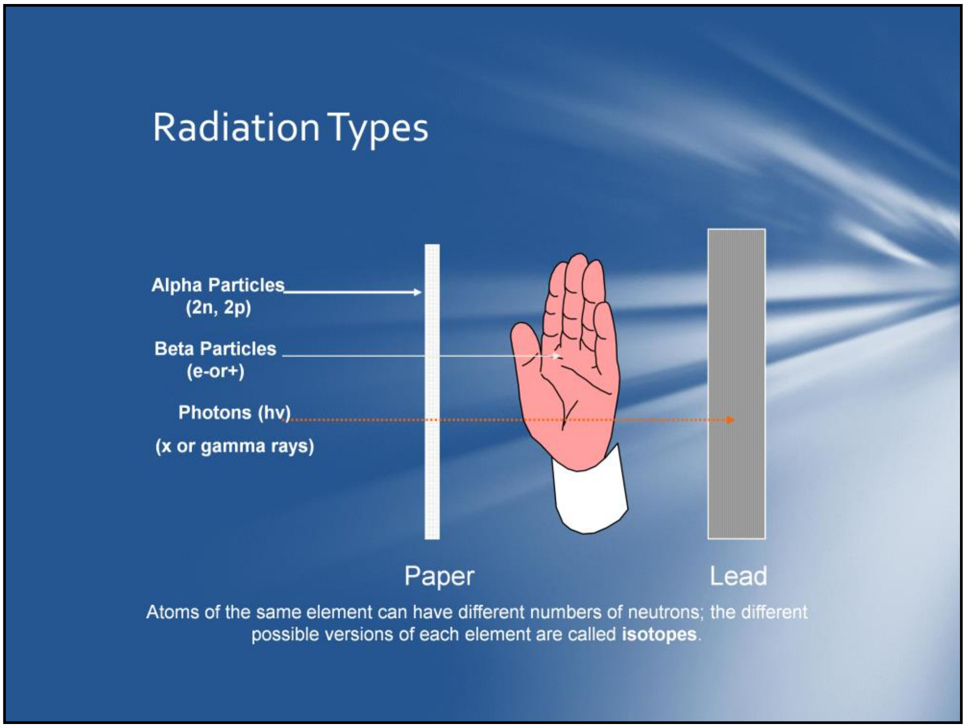
  Γ = 1.32 mR/hr at 1 m for 1 mCi

$$I_1 = 1.32\ \text{mR/hr} \times 50\ \text{mCi} = 66\ \text{mR/hr}$$
$$d_1 = 1\ \text{m}$$
$$d_2 = 2\ \text{m}$$
$$I_2 = \frac{I_1 d_1^2}{d_2^2} = \frac{(66\ \text{mR/hr})(1\ \text{m})^2}{(2\ \text{m})^2} = 16.5\ \text{mR/hr}$$

Shielding

Shielding material placed between the radiation source and personnel will reduce the radiation intensity by attenuation, and thus reduce the exposure received.

- Attenuation: process by which a beam of radiation is reduced in intensity by absorption or scatter in the medium.



Describe different types of radiation and their ability to penetrate different materials.
Neutrons (not shown on this slide) usually occur from fission (nuclear reactor) mechanisms. They are best shielded by materials like water. Water and other materials containing constituents of low atomic mass, especially hydrogen, have a higher probability that the neutron will hit the nucleus and slow the neutron down.

Shielding - Photons

- Mean Free Path:
  - Average distance a photon can travel before colliding with an atom within the shielding material.
- The linear attenuation coefficient (μ) is the inverse of the mean free path.
  - It is the sum of the probabilities of interaction, per unit path length, for photoelectric effect, Compton scattering, and pair production
    - The shorter the distance between photon interactions, the higher the μ (so the denser the shielding material, the better the shield!)
    - μ is dependent on photon energy

Attenuation Coefficients

- Mass attenuation coefficient μ_m
  - Because linear attenuation coefficients are proportional to the absorber density (ρ), which usually does not have a unique value but depends somewhat on the physical state of the material, it is customary to use "mass attenuation coefficients" which removes density dependence
  - Therefore, the linear attenuation coefficient equals mass attenuation coefficient times the density of the material.

    $\mu = \mu_m \times \rho$

Shielding - Photons

- Shielding equation for gamma and x-ray radiation:

  I = intensity after passing through shield

  I_0= initial intensity of source

  μ = linear attenuation coefficient of shielding material

  x = thickness of shielding material

$$I = I_o e^{-\mu x}$$

OR

$$I = I_o e^{-\mu_m \rho x}$$

Half-Value Layer

Another way of determining shielding efficiency is by using the Half-Value Layer (HVL)

- HVL: The thickness of a shielding material required to reduce the intensity of the radiation by one half.
- This is commonly used for x-ray sources in which the photons have a range of energies
- Is related to μ by: HVL = 0.693/μ
- HVL equation:

$$I = \frac{I_0}{2^n}$$

where n = number of half-value layers

Example

How much lead shielding must be used to reduce the exposure rate from an I-131 source from 32 mR/hr to 2 mR/hr?

- The HVL of lead for I-131 is 0.178 cm.

$$2^n = \frac{I_0}{I} = \frac{32\text{ mR/hr}}{2\text{ mR/hr}}$$

$$2^n = 16$$

$$n = 4$$

$$4\text{ HVL} \times 0.178\text{ cm/HVL} = 0.71\text{ cm}$$

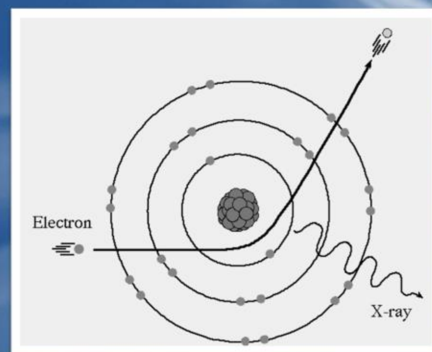
Shielding - Betas

Bremsstrahlung x-rays

Bremsstrahlung x-rays form when beta particles are slowed down quick enough that spontaneous energy is released to compensate for the change in velocity. This is also called 'braking radiation'.

The energy released is an x ray.

In labs, the most common cause of Bremsstrahlung x rays are shielding high energy beta emitters with lead shields, when plastic, aluminum, or brass should be used instead.



Shielding – Betas and Photons

- What if a radiation source emits both beta particles and photons?
- You need to use a double shield:
  - Plastic shield closest to source to stop betas
  - Then a lead shield to stop the photons
- DO NOT reverse the order of the shields or you will have x-ray production!

External Radiation

	Alpha	Beta	X and Gamma
Absorption:	Very short range	Short range	Long range
Hazard:	Internal	Mostly internal, small external for high energies	Mainly external, internal for lower energies.
Shielding:	Sheet of paper	Aluminum plate Plastic	Lead bricks Lead glass

External Radiation

- Exposure Monitoring
- External radiation exposure is measured by personal monitoring devices. Personal monitoring is required when it is likely that an individual will receive in 1 year, a dose that is in excess of 10% of the allowed dose.
- Not used for H-3, C-14, or S-35

External Radiation

At the University of Florida, whole body doses are determined using an optically stimulated luminescence dosimeter (Luxel).

- This badge shall be worn on the front part of the body somewhere between the waist and the collar.

External Radiation

Luxel Dosimeter:

External Radiation

Extremity Badges:

- Shall be worn when working with beta emitters where the energy is 1MeV or higher and the quantity used is greater than 1 millicurie in any month.
- Shall be worn underneath the gloves to prevent contamination of the dosimetric device.
- At the University of Florida, thermo luminescent dosimeters (TLD) are used

External Radiation

Finger Ring:

Dose Limits

Maximum Permissible Exposure for Occupational Workers

Whole Body:	5.0 REM /year
Eye:	15 REM /year
Skin or Extremity:	50 REM /year
50 REM committed dose equivalent to any individual organ or tissue /year	

Dose Limits

Occupational Dose limits for Minors:

- Minor – any individual under 18 years of age
- Dose Limit: 0.1 rem per year

Occupational Dose limits for Embryo or Fetus:

- The dose to an embryo or fetus during the entire pregnancy from occupational exposure of a **declared** pregnant woman shall not exceed 0.5 rem.
- Declared Pregnant Woman – a person who has declared her pregnancy in writing via her supervisor to the Radiation Control Department.

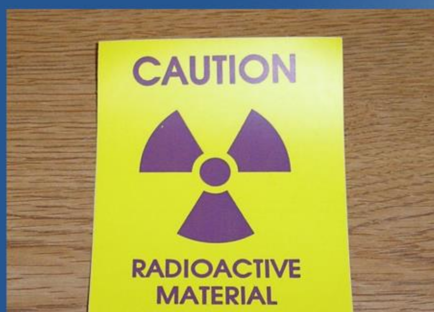
Dose Limits

Occupational Dose limit for individual members of the public:

- Total effective dose equivalent to individual members of the public shall not exceed 0.1 rem in a year.

Postings and Labels

Postings found in laboratories:



Postings and Labels

Postings found in laboratories:

Postings and Labels

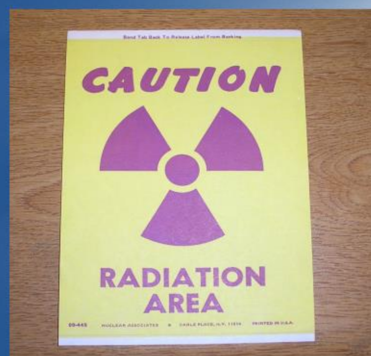
Postings found on packages:

Yellow = special precautions necessary!

Labels	Dose Rate Limits	
	At Any Point on Accessible Surface of Package	At Three Feet From External Surface of Package (Transport Index)
"RADIOACTIVE-WHITE I"	0.5 mR/hr	N/A
"RADIOACTIVE-YELLOW II"	50 mR/hr	1.0 mR/hr
"RADIOACTIVE-YELLOW III"	200 mR/hr	10 mR/hr

Postings and Labels

Radiation Area: An area where the whole body can receive 5 millirem in any one hour.



Postings and Labels

High Radiation Area: An area where the whole body could receive greater than 100 millirem in any one hour.

Internal Radiation

Internal Radiation

- Internal radiation exposure results when the body is contaminated internally with a radionuclide.
- When radioactive materials enter into the body they are metabolized and distributed to the tissues according to the chemical properties of the elements.

Internal Radiation

Examples of target tissues of internal contaminants:

- Tritium (H-3) – Extra-cellular Fluids
- Iodine – Thyroid
- P-32 – Bone

Internal Radiation

Radiation can enter the body via:

- Ingestion
  - GI System
- Inhalation
  - Pulmonary System
- Absorption
  - Skin
- Injection
  - Puncture of skin

Effective Half-Life

How long a radioactive substance stays in the body is a combination of the radiological half-life (T_r) and the biological half-life (T_b)

- Biological half-life: the time required for half of the substance to be eliminated from the body by biological means

Effective half-life: $$T_{eff} = \frac{T_r \times T_b}{T_r + T_b}$$

Example

You accidently ingest an isotope that has a radiological half-life of 14 days and a biological half-life of 8 days. How long will it take for half of it to be eliminated from your body?

$$T_{eff} = \frac{T_r \times T_b}{T_r + T_b} = \frac{14 \times 8}{14 + 8} = 5 \text{ days}$$

Precautions

To reduce and/or eliminate internal hazards you should do the following:

1. Control contamination by wearing protective clothing as a primary barrier against radioactive materials (universal precautions) – gloves and lab coats!

2. No smoking, eating or drinking in areas where radioactive materials are used or stored.

Annual Limits of Intake

- Limits pertaining to internal emitters are set up for particular radionuclides. These limits are called Annual Limits of Intake (ALI's).
- An ALI will deliver a committed effective dose equivalent (CEDE) of 50 rem per year to any individual organ or tissue, or 5.0 rem per year if the whole body is the critical organ.

Derived Air Concentrations

Derived Air Concentrations (DAC's):

- The concentration of radionuclides in air required to yield an ALI.
- DAC's are based on breathing the contaminated air for 2000 hours. (40 hr weeks / 50 weeks a year)

Where They Come From

Factors which are considered in the calculation of ALI's and DAC's are:

- Type and energy of radiation emitted
- It's distribution in the body
- Solubility/Volatility of the compound containing the isotope
- Effective Half-Life of the Isotope.

Bioassays

Internally deposited radioactive material can be monitored by measuring the radiation emitted from the body or by measuring the amount of radioactive material contained in a biological sample, such as urine, feces, and hair. Such monitoring techniques are called "bioassays".

Types of Bioassay

The determination of the kind, quantity, concentration and location of radionuclides in the human body is done by one of two methods.

- IN VIVO: External measurement or detection of gamma or X-rays emitted from radionuclides in the body for the purpose of estimating the amount of radioactivity present.
- IN VITRO: Measurement of the amount of radioactivity in samples (i.e. urine, etc) from the human body.

Requirements

- Bioassays are required whenever a person handles more than 1 millicurie of iodine in a month or more than 25 millicuries of tritium in a month.
- Laboratories will be notified of required bioassays when they receive more than the above limits.
- Personnel working with tritium or iodine will receive a questionnaire each month regarding their use of these radionuclide.
- Analysis for other radionuclides can also be performed by request.
- Bioassays may also be required whenever personnel are involved in a contamination incident