Authorized User / Radiation Safety Officer Training for Veterinary Users

Module 6: Time, Distance, Shielding and Dosimetry

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Introduction

- This module introduces the radiation safety concepts of exposure time, distance and radiation shielding, basic facility shielding design, and applicable external and internal dosimetry and monitoring.
- The shielding considerations for charged particles and non-charged particles are illustrated using practical examples to help the reader understand and establish an intuitive sense on how to choose shielding material.
- The shielding design for a nuclear medicine facility is also described using practical examples.
- Common concepts and terms of external and internal dosimetry used in radiation practice are explained. Radiation professionals and radiation workers should understand their meanings when reading relative reports and articles.
- The shielding and monitoring of ^{131}I Radioiodine, ^{90}Y- IsoPet® and ^{117m}Sn Synovetin OA™ are discussed.

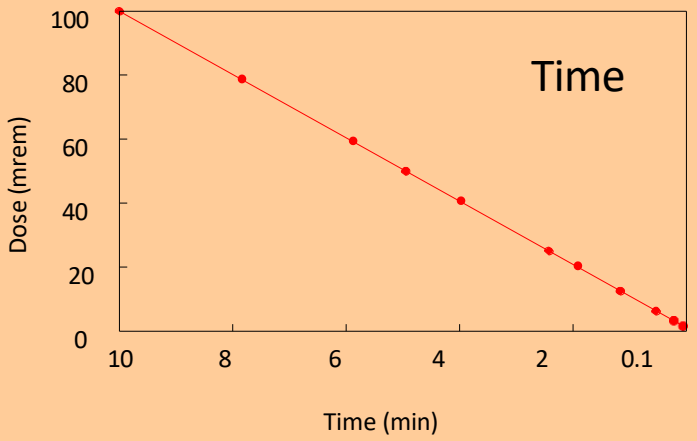
- Assigned reading:
  - 6.1. NRC Reg Guide 8.7, Instructions for recording and reporting occupational radiation dose data, 2018
  - 6.2. NRC Reg Guide 8.34, Monitoring criteria and methods to calculate occupational radiation doses, 1992
  - 6.3. NRC Reg Guide 8.20 Rev 2, Applications of bioassay for radioiodine, 2014

Outline

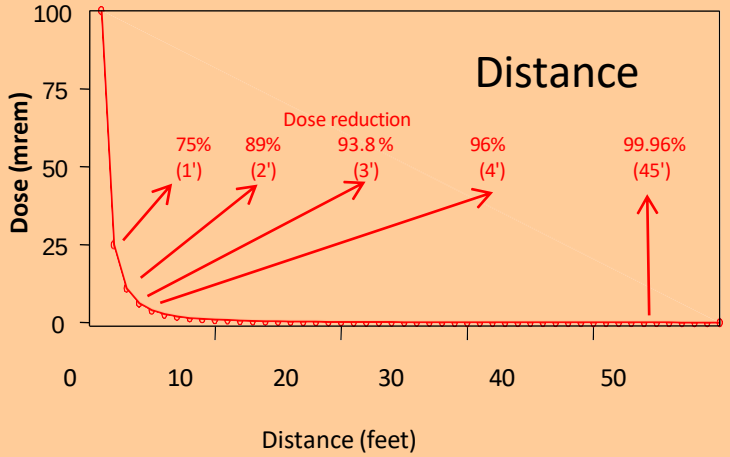
- **Part I – Radiation Protection Principles:**
  - Time
  - Distance, and inverse square law
  - Charged particle shielding, with specifics for ^{90}Y
  - Photon shielding, with specifics for ^{131}I
  - Facility design and shielding
  - Ideal hot lab setup
- **Part II – Dosimetry:**
  - External dosimetry
  - Occupational Dose Limits
  - Dosimeters for external monitoring
  - Internal dosimetry
  - Internal dose monitoring for bioassay
- **Specific Properties for External and Internal Monitoring of ^{131}I, ^{90}Y and ^{117m}Sn**
- **Quiz**

Part I: Radiation Protection Principles

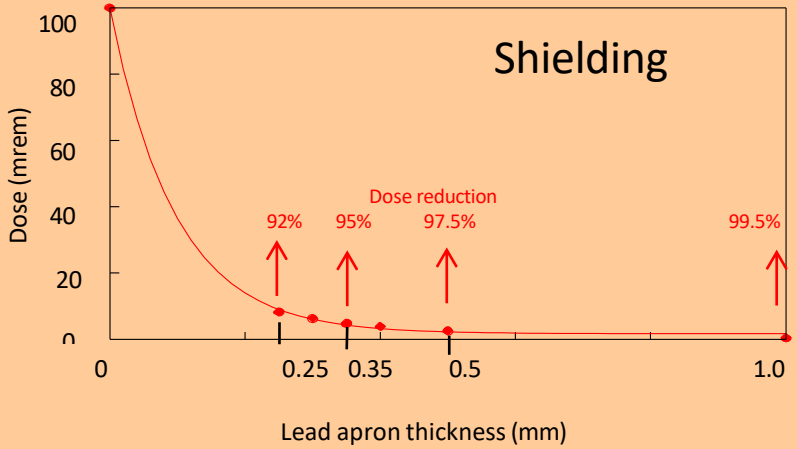
Plots showing the affects of time, distance and shielding on radiation dose or dose rate are shown below. These constitute the 'three pillars' of radiation safety.



Dose shows a simple, linear relationship with time. If time spend in the vicinity of radiation is decreased by a half, dose is also decreased by a half.



Dose has an inverse-square relationship with distance. Suppose a person receives 100 mrem at a distance of 1 foot: stepping away by one foot (doubling the distance) provides 75% dose reduction. Moving to 4 feet provides 96% reduction. At larger distances, dose reduction is minimal (*e.g.*, moving from 40 feet to 45 feet).



Shielding exhibits an exponential relationship with distance. In this example, for photons shielded with lead aprons, a 0.5 mm thickness provides 97.5% dose reduction. Doubling lead thickness, however, does not double the protection: At 1 mm, the additional dose reduction is a mere 2%.

Time

- Time is a straightforward principle. The less time one spends in the vicinity of a radioactive source, the less exposure one receives.

- Inherent in the time factor is the importance of working quickly and effectively while handling a dose, injecting it, and caring for animals once they have been injected.

- Performing dry runs of the entire treatment protocol with water or saline, with food coloring added to visualize the spread of ‘radioactivity’, will ensure that needles, pipettes and other paraphernalia are positioned ergonomically and the injection is carried out most efficiently.

- Performing trial runs on surrogate tissue (such as chicken breast) with a sample of the radioactive dose is an additional training tool when injecting methodologies are perfected, or when new personnel are trained.

Distance

- When distance from a point-source of radiation is doubled, dose is cut by $1/4^{th}$.
  When distance is tripled, the dose is $1/9^{th}$.
  When distance is halved, dose increases by 4 times. These are the result of an **inverse-square relationship**.

- The formula to perform an inverse-square calculation is: $\mathbf{R_1 \times D_1^2 = R_2 \times D_2^2}$
  where **R** is Radiation Dose or Dose Rate; and **D** is Distance.

- For any situation where an distance calculation is needed, one pair of information is always available (dose or dose rate at a particular distance, $\mathbf{R_1 \times D_1^2}$; note that the distance always has to be squared in the formula). The questions can only take two forms:
  a. What is the dose or dose rate at another distance? $\mathbf{R_2 = (R_1 \times D_1^2) / D_2^2}$

  b. What should the distance be, to achieve a particular dose or dose rate?

  Therefore, $\mathbf{D_2^2 = (R_1 \times D_1^2) / R_2}$

  $\mathbf{D_2 = \sqrt{(R_1 \times D_1^2) / R_2}}$

- **Example 1:** If dose rate at 3 feet = 12 mR/h. What is the dose rate at 23 feet?
  Dose rate = (12 mR/h x 3^2 feet) / 23^2 feet = **0.2 mR/h**

- **Example 2:** If dose at 4 feet = 240 mrem. At what distance is the dose going to be 3 mrem?
  Distance = sqrt [(240 mrem x 4^2 feet) / 3 mrem] = sqrt [1280 feet] = **36 feet**

Charged Particle Shielding

- Because many alpha and beta emitters are natural radioactive sources and are produced in radiation labs, the shielding of and protection from these two types of charged particles is important.
- Knowing the range of charged particles in a material provides guidance for radiation shielding and protection.
- The alpha particle interacts with matter primarily through electrical force between the positive charge of the alpha particle and the negative charge of an atomic electron in matter. Because of its heavy mass, the alpha travels slowly and creates dense ionization tracks along its path; thus, the range of penetration is short.
- Because of its small mass, the beta particle has a low energy transfer rate along the path and therefore a longer range of penetration.

Charged Particle Shielding: alphas *(continued)*

- The range of an alpha particle in air can be calculated by an empirical equation:[1]

$$R=(0.005xE+0.285)xE^{3/2}$$

  - R is the unit of cm; E is alpha energy in MeV.
  - The equation is valid for alpha particles in the energy range of 4<E<15MeV.
- The range of an alpha particle in other material can be calculated with the Bragg-Kleeman rule:

$$\frac{R_1}{R_2} = \frac{\rho_2 \cdot \sqrt{A_1}}{\rho_1 \cdot \sqrt{A_2}}$$

  - R_1 = range of alpha particle in reference material
  - ρ_1 = density of reference material
  - A_1 = effective atomic mass of reference material
  - R_2 = range of alpha particle in target material
  - ρ_2 = density of target material
  - A_2 = effective atomic mass of target material

Reference: 1. Lapp RE and Andrews HL. Nuclear Radiation Physics, 4th edition (1972). Prentice-Hall, Englewood Cliffs, NJ.

Charged Particle Shielding: alphas *(continued)*

Example 3: An alpha particle emitted from ^{241}Am (used in smoke detectors) has energy of 5.5 MeV.
Calculate the range of this alpha particle in air, tissue (assuming tissue is water equivalent), and paper shielding.

1. **Knowing that:**

- ρ_{air} is $0.00129 g/cm^3$ — A_{air} is 14.4
- ρ_{tissue} is $1 g/cm^3$ — A_{tissue} is 13.1
- ρ_{paper} is $1.5 g/cm^3$ — A_{paper} is 12.9

2. **Alpha particle range in air:**

$R_{air} = (0.005 \times 5.5 + 0.285) \times 5.5^{3/2} = 4.03 cm$

$R_{tissue} = R_{air} \times (\rho_{air} \times A_{tissue}^{(1/2)}) / (A_{air}^{(1/2)} \times \rho_{tissue})$

$= 4.03 cm \times (0.00129 \times 13.1^{1/2}) / (1 \times 14.4^{1/2})$

$= 0.005 cm$

$R_{paper} = R_{air} \times (\rho_{air} \times A_{paper}^{(1/2)}) / (A_{air}^{(1/2)} \times \rho_{paper})$

$= 4.03 cm \times (0.00129 \times 12.9^{1/2}) / (1.5 \times 14.4^{1/2})$

$= 0.0033 cm$

Charged Particle Shielding: alphas *(continued)*

- The previous example shows that an alpha particle can only travel a very short distance in matter.
- The alpha particle emitted from ^{241}Am would not penetrate the epidermal layer, which is 0.007cm, to damage living tissue.
- An alpha particle is easy to stop by using a sheet of paper.
- An alpha particle does not pose a threat to the outside of the body. However, if ingested or inhaled, it can be very harmful, since it creates dense ionization tracks in short ranges.

Charged Particle Shielding: betas

- The range of a beta particle can be calculated by empirical equations:[2]

  $R = 0.412T^{1.27-0.0954\ln(T)}$

  or

  $R = 0.53xT-0.106$

- R has units of g/cm^2, T is kinetic energy of the beta particle in MeV.
  - 1. The first equation is valid for beta particles with energy lower than 2.5 MeV.
  - 2. The second equation is valid for beta particles energy greater than 2.5 MeV.
- Unlike alpha particles, the Bragg-Kleeman rule is not applicable to betas. However, the range calculated in the above equations are in the unit of g/cm^2, the range in the unit of cm can be converted by dividing the density of the material through which the beta travels.
- It is important to be aware that a betas can emit Bremsstrahlung photons in shielding material. The radiation yield can be calculated by equation:

$$Y = \frac{6\times10^{-4}\times ZT}{1+6\times10^{-4}\times ZT}$$

  - Where Z is atomic number of shielding material, T is the kinetic energy of a beta particle in MeV. Basically, the equation above means that Bremsstrahlung typically becomes a concern with higher energy beta emitters .

Reference: 2. Turner JE. Atoms, Radiation, and Radiation Protection, 2nd edition (1995). Wiley-VCH, Weinheim, Germany.

Charged Particle Shielding: betas, with ^{90}Y as example *(cont'd)*

Example 4:

(a) Calculate the maximum range of beta particles emitted from ^{90}Y in air at room temperature (72 °F), tissue, acrylic and lead.

(b) How much of its energy transforms into Bremsstrahlung, if it interacts with lead, acrylic and bone?

Knowing that: The maximum beta energy is 2.3 MeV.

ρ_{air} is 0.0011961g/cm^3 (at 72 °F or 22.2 °C), ρ_{tissue} is 1g/cm^3, $\rho_{acrylic}$ is 1.18 g/cm^3, ρ_{lead} is 11.34 g/cm^3

(a) $R = 0.412T^{1.27-0.0954\ln(T)} = 0.412 \times (2.3)^{1.27-0.0954\ln(2.3)} = 1.1 g/cm^2$

$R_{air} = R/\rho_{air} = 1.1/0.0011961 cm = 919 cm =$ 9.19 m, or 30 feet → maximum travel range of ^{90}Y beta particles in air

$R_{tissue} = R/\rho_{tissue} = 1.1/1 cm = 1.1 cm =$ 11 mm, or 0.43 inches → maximum travel range of ^{90}Y beta particles in tissue

$R_{acrylic} = R/\rho_{acrylic} = 1.1/1.18 cm = 0.93 cm =$ 9.3 mm, or 0.4 inches → This thickness of acrylic can stop the highest energy ^{90}Y beta particle

$R_{lead} = R/\rho_{lead} = 1.1/11.34 cm = 0.097 cm =$ 0.97 mm, or 0.04 inches → This thickness of lead can stop the highest energy ^{90}Y beta particle

Charged Particle Shielding: betas, with ^{90}Y as example *(cont'd)*

(b). Radiation yield with lead (Z = 82), acrylic (Z = 6.56) and bone (Z = 12.31):

$Y_{lead} = (6x10^{-4} \times 82 \times 2.3)/(1+6x10^{-4} \times 82 \times 2.3) = 0.1016$, or 10.2%

$Y_{acrylic} = (6x10^{-4} \times 6.56 \times 2.3)/(1+6x10^{-4} \times 6.56 \times 2.3) = 0.00968$, or 0.96%

$Y_{bone} = (6x10^{-4} \times 12.31 \times 2.3)/(1+6x10^{-4} \times 12.31 \times 2.3) = 0.0166$, or 1.7%

Percentage of Bremsstrahlung x-rays possible in the presence of lead

Percentage of Bremsstrahlung x-rays possible in the presence of acrylic

Percentage of Bremsstrahlung x-rays possible in the presence of bone.

Charged Particle Shielding: betas, with ^{90}Y as example *(continued)*

- The previous example shows that an energetic beta particle can travel a long distance in air before it stops, but the range in denser material is very short. A 0.5 inch - thick acrylic shield offers sufficient shielding against the energetic betas from ^{90}Y.
- Although a beta particle has a shorter range in lead than acrylic, it yields a considerable amount of Bremsstrahlung photon radiation (about 10% for ^{90}Y). The corresponding value with acrylic is less than 1%. *In vivo* interaction with bone is expected to yield no more than 1.7% as Bremsstrahlung x-rays.
- Therefore, an energetic beta emitter like ^{90}Y-IsoPet® is best shielded with low-Z material such as tissue, or plastics like acrylic or lucite, with negligible yields of bremsstrahlung x-rays. If multi-millicurie quantities of the isotope are handled, a thin covering of lead outside the acrylic shield will stop any measurable bremsstrahlung x-rays generated within the acrylic shield.
- A 10 mm thick PVC pipe, about 6 inches long, forms a very effective shield when placed over a vial of ^{90}Y IsoPet®.

Photon (gamma and x-ray) Shielding

- Photons can be shielded or absorbed in matter through the (see module 3 for definitions):
  - Photoelectric effect
  - Compton scattering effect
  - Pair production effect
- When a photon penetrates matter, the probability of interaction per unit distance is called the linear attenuation coefficient, denoted by **μ**, in the unit of cm^{-1}.
- The linear attenuation coefficient depends on photon energy and shielding material. It comprises the individual contributions from photoelectric, Compton, and pair production effects.
- Attenuation of a stream of gamma or x-ray photons when they pass through a shielding material of thickness ***x*** is :

$$I_{(x)} = I_{(0)} e^{-\mu x}$$

- Where $I_{(0)}$ is the initial intensity of the beam, $I_{(x)}$ is the final intensity, and the value of **μ** is given. Note that this equation is identical to the radioactive decay equation (module 2). If the **Half Value Layer** (**HVL**) of the shielding material for a particular photon energy is known, **μ** can be calculated as **ln(2)/HVL,** i.e., **0.693 / HVL.**

- **HVL** is the thickness (in cm) of the material that decreases a beam's intensity in half. This is very similar to **Half Life**, the amount of time it takes to decrease the activity of a radioisotope by half.

Photon Shielding, with ^{131}I as example

Example 5: A cat injected with 3 mCi of ^{131}I measures 0.46 mR/h at 4 feet. You place a 1/8" lead sheet between the measurement point and the cat. What will the new exposure rate be?

We will assume that the cat is a point source of radiation.
1/8" = 0.3175 cm
HVL of lead for gamma emissions of ^{131}I = **0.23 cm** *[this is a useful conversion to remember]*
Therefore, Linear attenuation coefficient μ = 0.693 / 0.23 cm = 3.01 cm $^{-1}$

$$I_{(x)} = I_{(0)} e^{-\mu x}$$

= 0.46 mR/h x $e^{(-3.01\ cm^{-1} \times 0.3175\ cm)}$ = 0.46 x 0.3845 = **0.18 mR/h**

The shielded exposure rate of 0.18 mR/h over the unshielded dose rate of 0.46 mR/h represents a **61% decrease.**

Photon Shielding, with ^{131}I as example *(continued)*

Example 6: A syringe containing a ^{131}I dose measures 350 mR/h at a distance of 10 cm. What thickness of lead is required to bring this reading down to 2 mR/h ?

This problem requires a bit of math jugglery

$$I_{(x)} = I_{(0)} e^{-\mu x}$$

$$I_{(x)} / I_{(0)} = e^{-\mu x}$$

$$\ln (I_{(x)} / I_{(0)}) = -\mu x$$

$$\frac{\ln (I_{(x)} / I_{(0)})}{-\mu} = x$$

2 mR/h = 350 mR/h x $e^{(-3.01\ \text{cm}^{-1} \times x\ \text{cm})}$.

note: the value of μ was calculated in the previous example

ln (2 mR/h / 350 mR/h) = -3.01 x

-5.1647 = -3.01 cm^{-1} x

x = -5.1647 / -3.01 cm^{-1} = **1.72 cm**

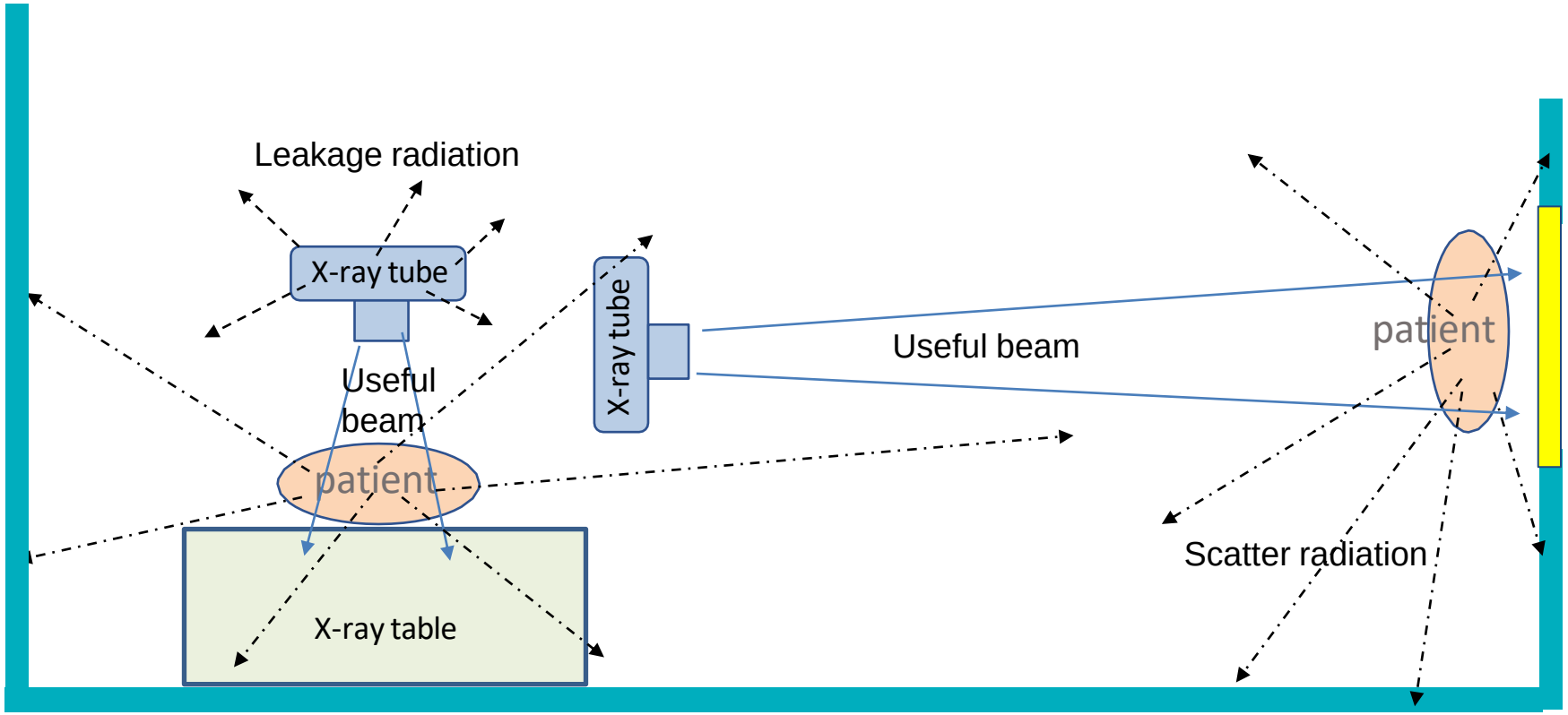
That's a little more than half an inch of lead!

Facility Design and Shielding for x-ray units

- Rooms containing X-ray machines must be shielded to protect medical staff, patients, and visitors outside the room from radiation that penetrates through the wall.
- The basic components of shielding construction are the **primary protective barrier** and the **secondary protective barrier**.
- A primary protective barrier is fixed in place in any direction in which the useful beam can be pointed. For units meant for human use, a typical example is a chest bucky mounted on the wall. This generally does not apply to veterinary uses. When the beam is pointed downwards, components of the x-ray table, floor construction, and distance to occupied spaces below, all combine to make additional primary shielding unnecessary.
- The secondary protective barrier is designed to protect areas which are not in the line of the primary beam to reduce radiation exposure outside the X-ray room from leakage and scatter radiation. Scatter radiation occurs when photons of the primary radiation beam enter the patient, and a certain percentage undergo compton scattering, exiting the patient at various angles and with reduced energy. Leakage radiation is the radiation that escapes from the sides of the x-ray tube housing, and has to meet regulatory limits. For veterinary operations, almost all barriers are secondary.

Facility Design and Shielding *(continued)*

Components of X-ray facility shielding construction



primary protective barrier (yellow)

secondary protective barrier (green)

Primary Protective Barrier

- The measurement of radiation exposure on the other side of the shielding wall is referred to as a distance of 1 m from the target of the tube and it is denoted by K.
- K values from X-rays operating at peak voltages have been experimentally measured for various materials and thicknesses.
- In order to calculate the thicknesses of shielding walls, first compute K value at maximum tube peak voltage, then look up wall thickness from experimental values.
- K value can be computed from the formula:

$$K = \frac{Pd^2}{WUT}$$

Primary Protective Barrier *(continued)*

- K is in the unit of [R mA^{-1} min^{-1}] at 1 meter.
- P is the maximum permissible exposure rate, expressed in the units of [R wk^{-1}].
  P=0.1 R wk^{-1} for controlled areas, P=0.01 R wk^{-1} for un-controlled areas.
- W is workload. Workload is the amount of use of an X-ray machine expressed in the unit of [mA min wk^{-1}].
- U is the use factor, which is the fraction of the workload during which the useful beam is pointed in a direction under consideration.
- T is occupancy factor that takes into account the fraction of the time that an area outside the barrier is likely to be occupied by a given individual.
- d is the distance from the target of the tube to the location under consideration, expressed in m (meters).

Primary Protective Barrier *(continued)*

- **Example 7:** A diagnostic X-ray machine is operated at 125 kVp and 100mA for an average of 100 min wk^{-1}. Calculate the primary protective barrier thickness if lead was to be used to protect a hallway area 5 meters from the tube target.
  - The maximum permissible exposure rate at the hallway is 0.01R wk^{-1}.
  - The useful beam is directed horizontally toward the barrier 1/3 of the time and vertically into the ground the rest of the time.
  - Assume the occupancy factor at this location is 1/4.

Answer: knowing: P=0.01[R wk^{-1}], d=5m, W= 100[mA] x 100 [min wk^{-1}] =10000 [mA min wk^{-1}], U=1/3 , and T=1/4.

$K=Pd^2/(UWT)=(0.01x5^2)/(10000 \times 1/3 \times 1/4)$

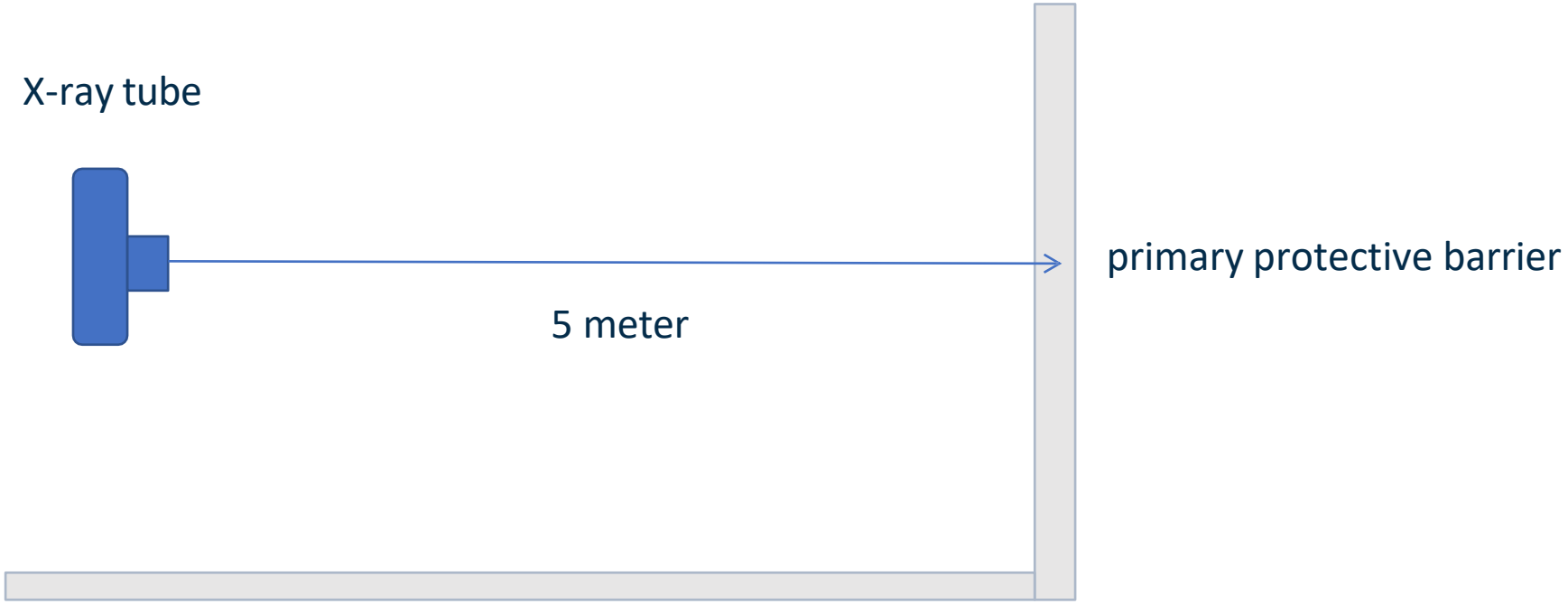
$= 0.00003$ [R mA^{-1} min^{-1}] at 1 meter

From data chart of lead thickness vs K value for operating voltages from 50 kVp to 150 kVp, the required thickness of a lead shield for 125 kVp is about 3 mm.

Note that kVp = kilovolt potential specifically for X-ray units.

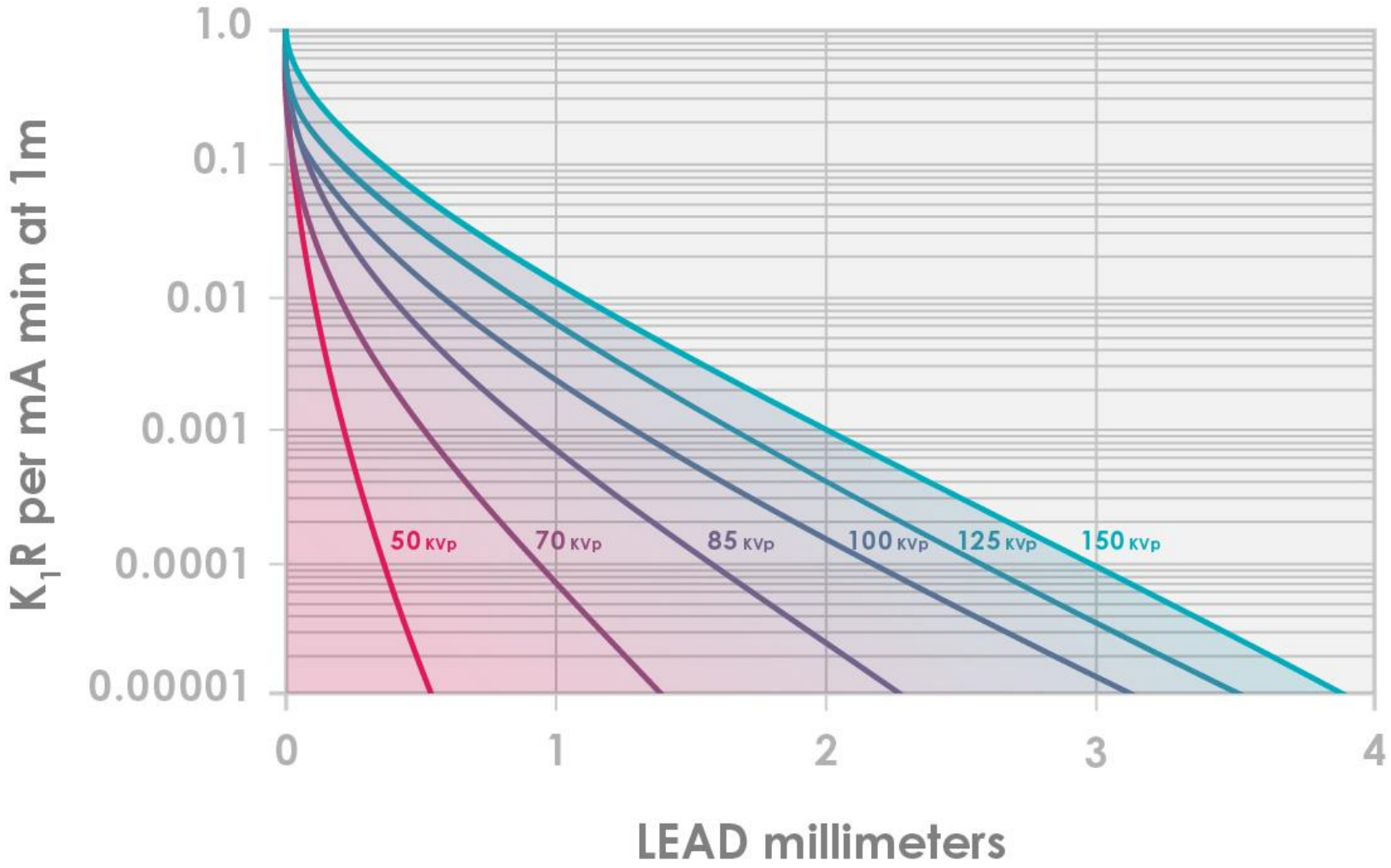
Primary Protective Barrier *(continued)*

primary protective barrier thickness construction geometry



Primary Protective Barrier *(continued)*

Data chart of lead thickness vs K value for operating voltages from 50 kVp to 150 kVp



Reference: National Bureau of Standards Handbook 76, 1961, Washington, DC.

Secondary Protective Barrier

- The secondary protective barrier is designed to protect areas from leakage and scattered radiation. The shielding requirements are calculated separately, and the final barrier thickness is chosen at a value that is adequate for both.
- Thickness of shielding for leakage radiation is computed by formula:

$$B = \frac{60IPd^2}{YWT}$$

  - B is the reduction factor, which is used to calculate the (N) number of "half-value layers" needed for shielding. The true thickness of the required "half-value layer" (HVL) can be looked up from data table from previous slide.

$$N = -\frac{\ln B}{\ln 2}$$

  - I is the average beam current in [mA].
  - P is maximum permissible exposure rate, expressed in the unit of [R wk^{-1}].
  - d is the distance from the target of the tube to the location under consideration, expressed in meters.
  - Y is the desired exposure rate limit at 1m. Y is 0.1 R h^{-1} for diagnostic machines.
  - W is the workload in [mA min wk^{-1}].
  - T is the occupation factor.
- Note: Because shielding conditions varies greatly, many methods satisfy the calculation of shield design. The calculation presented in this section is used as a guide.

Secondary Protective Barrier *(continued)*

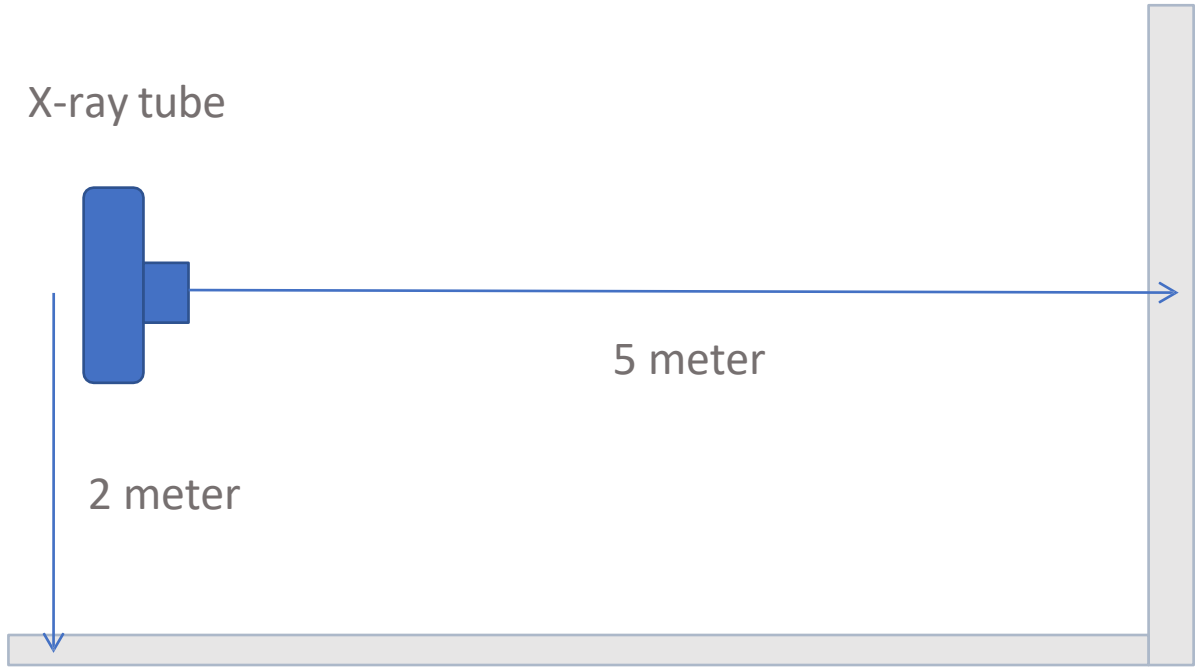
- Thickness of shield for scattered radiation is computed by formula:

$$K = \frac{1000\,Pd^2}{fWT}$$

- Like primary shielding design, K value is calculated in the unit of [R mA^{-1} min^{-1}] at 1 meter.
- P is maximum permissible exposure rate expressed, in the unit of [R wk^{-1}].
- d is the distance from the target of the tube to the location under consideration, expressed in meters.
- W is the workload in [mA min wk^{-1}].
- T is the occupation factor.
- f value depends on operating voltage.

Secondary Protective Barrier *(continued)*

secondary protective barrier thickness construction geometry



Secondary Protective Barrier *(continued)*

- **Example 8:** Calculate secondary shielding thickness in lead used in the design in the previous example. Use:
  - P=0.01 s wk^{-1} d=2m
  - Y=0.1 R h^{-1} f factor is one for operating voltage less than 500 kVp

- Answer: Knowing: p=0.1[R wk^{-1}], d=5m, W= 10000[mA min wk^{-1}], I=100 [mA].

  1. Leakage radiation shielding

     B= (60 x 100 x 0.01 x 2^2)/(0.1 x 10000 x 1)=0.24

     N=-ln(0.24)/ln(2)=2.05 HVL of lead

  2. Scattered radiation shield

     K=(1000 x 0.01 x 2^2)/(1 x 10000 x 1)=0.004

  Using "Data chart" on slide 23 of lead thickness vs K value for operating voltages from 50 kvp to 150 kvp", the required thickness of lead shield for 125 kvp is about 1.2 mm, about 1.2 mm/0.28 mm = 4.3 HVL

  3. To determine the total thickness of the secondary, one must compare the thickness difference between leakage and scattered radiation:
     - If the difference in less than 3 HVL, then 1 HVL is added to the larger one.
     - If the difference is greater than 3 HVL, then the thicker one is chosen.
     - In the above example, the required secondary lead barrier is 1.2mm (4.3 HVL).

Secondary Protective Barrier *(continued)*

Table: Half-value layer thickness of lead at X-ray operating voltage

Peak voltage (kvp)	Half-value layer lead thickness (mm)
50	0.06
70	0.17
100	0.27
125	0.28
150	0.3
200	0.52
250	0.88

Reference: Atoms, Radiation, and Radiation Protection. 2nd edition. J.E. Turner

Ideal Hot Lab Setup

- A radiation “hot lab” is where radioactive materials are prepared for diagnosis and therapy.
- A hot lab that handles gamma emitters (^{131}I and ^{117m}Sn) should include the following equipment:
  - ‘L” Block shield made of lead with leaded glass window
  - Syringe shield – Lead or Tungsten, with leaded window
  - Shielded waste storage container (lead lined)
  - Appropriate survey meters:

    For ^{131}I: Two Ludlum Model 3 meters with 44-3 NaI probe and 44-9 pancake probe with energy flattening filters.

    For ^{117m}Sn: Two Ludlum 26-1DOSE ratemeters.

  One meter will serve as a backup in case the primary meter becomes non-functional, needs repair, or is taken for annual calibration.
  - Plastic or steel tray(s) to contain potential radioactive spills
  - Spill Kit to clean up radioactive spills
  - Dose calibrator (optional for Veterinary use)
  - Sealed radioactive calibration sources (if using a dose calibrator)
- For the most part, localized shielding is used for radioactivity in a hot lab; therefore, the use of leaded dose containers and syringe shields are critical to shielding. For ^{131}I treatment, the walls or floors likely need added lead shielding, the thickness of which will exceed the 1/16th inch typically used in x-ray rooms.
- A technician working in hot lab should always wear two pairs of disposable gloves, a lab coat, a ring dosimeter, and a whole-body dosimeter to monitor any occupational radiation dose received while working with radioactivity. Personnel dosimetry will be covered in more detail later in the module.

Ideal Hot Lab Setup *(continued)*

- A hot lab that handles pure beta emitters (^{90}Y) should include the following equipment:
  - Peltier Chiller: a custom built device that stores up to two glass vials containing IsoPet® doses at low temperature, and is quipped with a magnetic stirrer and four chilling ports in which filled syringes can be held during the procedure.
  - Acrylic or Lucite L-block shield
  - Syringe shield (acrylic or similar)
  - Shielded waste storage container (acrylic or similar)
  - Appropriate survey meter: Two Ludlum 26-1 ratemeters. One meter will serve as a backup in case the primary meter becomes non-functional, needs repair, or is taken for annual calibration.
  - Plastic or steel tray(s) to contain potential radioactive spills
  - Spill Kit to clean up radioactive spills
  - Dose calibrator (optional for Veterinary use)
  - Sealed radioactive calibration sources (if using a dose calibrator)

  - Note that localized shielding is used for radioactivity in a hot lab therefore, the walls of the room do not need to be shielded Unit doses of ^{90}Y prepared for injection can be locally shielded in the bulk container, behind the L shield, within a 10 mm thick PCV pipe, or in a shielded carrier

Use of Hot Lab Equipment, and Procedure Overview: ^{131}I and ^{117m}Sn

- ^{131}I NaI is generally supplied as a unit dose, customized for a patient, and generally does not need additional preparation. The dose must be maintained at room temperature. Freezing the dose increase volatility, creating airborne radioactive contamination. Opening the syringe pig* and placing the dose in a syringe shield is done behind the lead L-shield. The dose is transported to the injection table in a leaded container.

- A ^{117m}Sn dose is prepared and drawn into a syringe behind an L-shield. An L-block shield is made of lead and lead-equivalent glass to protect the preparer's body from unnecessary radiation exposure.

- A dose calibrator is used to measure the reading of syringe activity (if applicable).

- A syringe holder is a small lead container which temporarily holds a prepared syringe. The technologist carries the syringe in the syringe holder to the patient for injection to avoid unnecessary radiation exposure during the process.

- After the radioactive medicine is injected into the patient, the syringe is transferred into a shielded waste storage container to "decay in storage" until the radioactivity decays to background level, when it can be disposed of as regular trash.

- After the procedure, a GM survey meter is used to check whether there is any radioactive contamination in the facility.

The term **pig for lead shielded containers of radioactive materials comes from pig lead, which is unrefined, cast lead, similar to pig iron. Groups of moulds laid out in sand, to be fed from a common runner, to be filled with molten lead, resembled suckling pigs, with the runner being called a sow.*

Use of Hot Lab Equipment, and Procedure Overview: ^{90}Y

- Each unit dose of IsoPet® is supplied in a 20 ml glass vial containing pre-mixed hydrogel and the ^{90}Y particle suspension with a blue dye, and a magnetic stirrer bar. Please save the SoftBox because it is reusable, and must be returned to Vivos. The product will be calibrated at the time of shipment to ensure accuracy and to allow precision on achieving the prescribed dose, allowing for decay with the 2.7-day half-life. Typically, the product will be shipped to arrive one day prior to the scheduled therapy. This allows an extra day for delivery in case a shipment is delayed for unforeseen reasons.

- During preparation for injections, the vial is stored a Peltier Chiller that maintains the dose at 4 °C, and has a built in magnetic stirrer to keep the microspheres in suspension.
- A dose calibrator can be used to measure the starting ^{90}Y activity. Alternate methods can be used to determine the pre-therapy mass or volume of IsoPet®.
- The IsoPet® is withdrawn from the vial into small (e.g. 1 cc) syringes with 22 or 25 gauge needles. Luer-lock syringes and needles are recommended to minimize potential for contamination. An acrylic shield should be used for additional protection of the user's extremities, both while the syringes are being filled, and during IsoPet® injections. Up to four filled syringes can be held in chilling ports located on the side of the Chiller. The syringe filling and IsoPet® injection process is repeated until sufficient product has been administered to treat the tumor and applicable margins..
- After the IsoPet® administration is complete, any unused product and all waste materials are removed from the therapy room and transferred back to the hot lab. A GM survey meter is used to check whether there is any radioactive contamination in the facility. This includes the hot lab, dose preparation area, injection area, equipment and paraphernalia, furniture, floors, door handles, etc.

Hot Lab Signage and Documentation Requirements

The following signage is required to be posted in a hot lab:

1. Notice to Workers: post on the wall or bulletin board [(1)]
2. A notice card indicating where your printed hard-copy of current license, license conditions and regulations (10CFR35 or state-equivalent) is kept
3. Contact information for the Authorized User and Radiation Safety Officer (post in a conspicuous location)
4. "Caution Radioactive Material" signs on the door of the hot lab, on the sealed source container, and on the shielded waste container. . The universal sign for radioactivity is the **trefoil symbol**

Caution Signs and their meanings:

CAUTION RADIOACTIVE MATERIALS - dose rate less than 5 mrem in 1 h @ 30 cm from shielded source
CAUTION RADIATION AREA - dose rate greater than 5 mrem in 1 h @ 30 cm from shielded source
CAUTION HIGH RADIATION AREA - dose rate greater than 100 mrem in 1 h @ 30 cm from shielded source
VERY HIGH RADIATION AREA - dose rate greater than 100 rad in 1 h @ 100 cm from shielded source

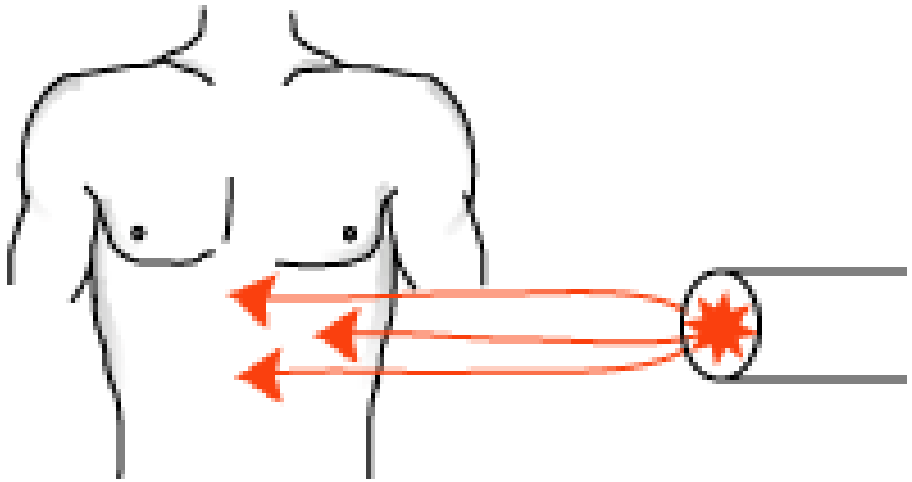
- For veterinary nuclear medicine, the following information must be documented and kept on file:
  - Patient name and ID, name of drug , prescribed dose, determined dose, date and time of dose determination, and name of the technician.
  - Regulatory records such as daily closeout surveys, weekly wipe tests, annual training records, individual patient records, and dosimetry results (see Module 8).

It is important to maintain the required documentation in a concise, organized manner to make your regulatory inspections as transparent and easy as possible.

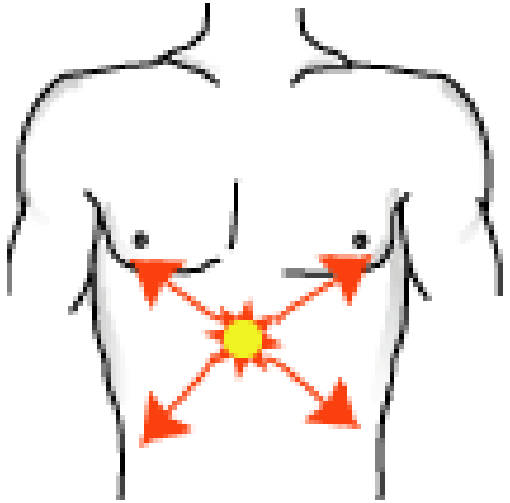
(1): This is the NRC form for non-agreement states: https://www.nrc.gov/reading-rm/doc-collections/forms/nrc3info.html
Agreement states have their own versions of the Notice to Workers posting.

Part II: Dosimetry

- When radioactive materials are outside the body, various kinds of radiation may contact the skin and penetrate the body, depositing energy into internal organ(s). The bioeffects resulting from external radiation sources are evaluated and calculated by external dosimetry.
  - External dosimetry can be calculated and measured with radiation detectors.
- When radionuclides are taken into the body by inhalation, injection, or ingestion, the radioactivity enters various parts of the body through typical metabolic pathways as with any other molecule. The bioeffects resulting from internal exposure to radioactive materials are assessed by internal dosimetry.
  - Internal dosimetry is measured by bioassay.



vs.



External Dosimetry

- Targets of radiation emitted by external radioactive sources are the ‘whole body’, skin, lens of the eye, extremities, and internal organs.
- Alpha particles have a very short range traveling in material. As calculated in Example 3, a 5.5 MeV alpha particle has a range of 0.005 cm. In general, alpha particles cannot penetrate the 0.007 cm dead skin layer.
- Beta particles have a higher probability of external dose deposition, depending on particle energy. A 2.3 MeV beta has range of 1.1 cm in tissue, which means that beta particles can cause skin damage or damage to the lens of the eye.
- Photons and neutrons are highly penetrating radiations and are the primary sources of external radiation dose deposition.

External Dosimetry *(continued)*

Definition of body parts used for external dosimetry:

- Whole body: Head, neck, trunk, arms above the elbows and legs above the knees
- Extremities: Arms below the elbows and legs below the knees
- Shallow dose or Skin dose: Dose to skin over the entire body. The same standard applies to any other individual organ of the body, except for lens of the eye.
- Lens of the eye: Special consideration is given to this organ, because of the occupational risk of developing radiation-induced cataracts.

Depth of external dose measurement:

- Deep Dose, or whole-body dose, is measured at 1 cm beneath skin surface
- Lens of eye dose is measured at 0.3 cm behind cornea
- Shallow dose is measured at 0.007 cm beneath skin surface

External Dosimetry *(continued)*

Terms used in external dosimetry:

- **Deep Dose Equivalent (DDE)** is the total effective dose equivalent to organs or tissue from external sources. It is also referred to “whole body dose”.
- **Lens Dose Equivalent (LDE)** is the equivalent dose to the lens of the eye. There is no weighting factor assigned to the lens of the eye, and the lens dose is not counted as a contribution to the whole body.
- **Shallow Dose Equivalent (SDE)** is the equivalent dose to the skin, or any other organ except for lens of the eye.

The ALARA (As Low As Reasonably Achievable) concept is used to ensure that occupational dose levels are maintained well below occupational dose limits (ODLs). For most licensees, the ALARA goal is set at **10%** of ODLs.

- Occupational Dose Limits and ALARA goals, all values are **annual:**

	Occupational Dose Limit			**ALARA goal, not to exceed:**		
	rem	mrem	mSv	rem	mrem	mSv
DDE (Deep Dose Equivalent)	5	5,000	50	0.5	500	5
LDE (Lens Dose Equivalent)	15	15,000	150	1.5	1,500	15
SDE (Shallow Dose Equivalent)	50	50,000	500	5.0	5,000	50

- DDE is meant to protect from stochastic effects.
- LDE and SDE protect from deterministic effects.

External Dosimetry *(continued)*

- Aside from limits to occupational users of radiation, there are standards for (a) members of the general public, and (b) for uncontrolled areas of a licensed facility.

- Members of the general public include anyone working at or present in a licensed facility other than radiation users, for instance, physician staff, office workers, secretaries, receptionists, technicians, aides, housekeeping staff, cafeteria staff, pet owners, per caretakers, bystanders, and visitors.

- The annual dose limit for a member of the general public is **100 mrem**, over and above natural background radiation.

- The same limit also applies to the dose received by pet owners and their family, from exposure to a pet that has undergone treatment with radioisotopes (such as ^{90}Y, ^{131}I and ^{117m}Sn).

- The infrequent exposure standard for family and caregivers exposed to *human patients* treated with radioactive materials is different: in these cases, the annual dose to bystanders must not exceed 500 mrem. The *veterinary patient* standard just happens to be more stringent, at 100 mrem.

- Although dose to the public should be kept ALARA, there are no additional numerical ALARA goals (*e.g,* 10% of 100 mrem) applicable to this regulatory standard.

- Dose rate in any uncontrolled area (*i.e*, an area of the facility with restricted access) cannot exceed **2 mrem in any 1 hour**. For practical purposes, this can be measured in mR/h, but the standard strictly refers to the *integrated dose in 1 hour*. The hot lab is considered a controlled area, and therefore, higher ambient dose rates are allowable (typically as high as 5 mrem/h). A room dedicated for storing radioactive waste is also a controlled area. All other areas at the facility are uncontrolled, and therefore must meet this standard.

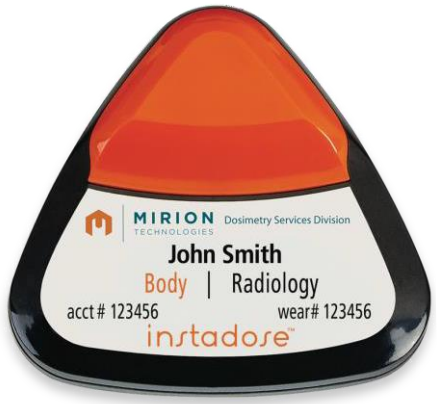
External Dosimetry *(continued)*

- External doses are monitored using dosimetry badges and rings.
- Two popular suppliers of dosimeters in the US are Landauer Inc., and Mirion Technologies. There are several other dosimetry vendors as well. All dosimeters must by NVLAP accredited.
- A dosimetry badge is typically worn at the chest level and designated as a 'whole body / chest badge'.
- A ring badge is worn on the finger of the hand dominantly used to handle radioactive material, and oriented inward to the palm of the hand. Ring badges are generally made of Thermo Luminescent Detectors (TLDs).
- After the wear period, dosimeters are returned to the badge company for processing. Wear periods can be monthly, bi-monthly, or quarterly, depending on the level of radioisotope usage at the facility.
- A single dosimetry badge captures all three occupational doses that require monitoring: DDE, LDE and SDE. Ring badges only report SDE for the extremity.
- Landauer currently uses Luxel+® badges that employ OSL (Optically Stimulated Luminescence) technology. These badges are read using lasers. Prior to 2000, dosimetry badges used x-ray film, and commonly referred to as 'film badges'. More details at: https://www.landauer.com/faq
- Mirion currently uses Instadose+™ badges based on Direct Ion Storage (DIS) technology, that do not require return to the company for processing: they can be read off a smartphone app, or via an installed hub. More details at: https://www.mirion.com/
- All dosimeters are stored in a central location when not in use, along with a 'control badge'. The control badge accompanies user badges when shipped back for processing (to Glenwood Illinois, for Landauer badges)
- The licensee's Radiation Safety Officer decides on the type of badges and their wear frequency

External Dosimetry *(continued)*

Sample dosimetry reports

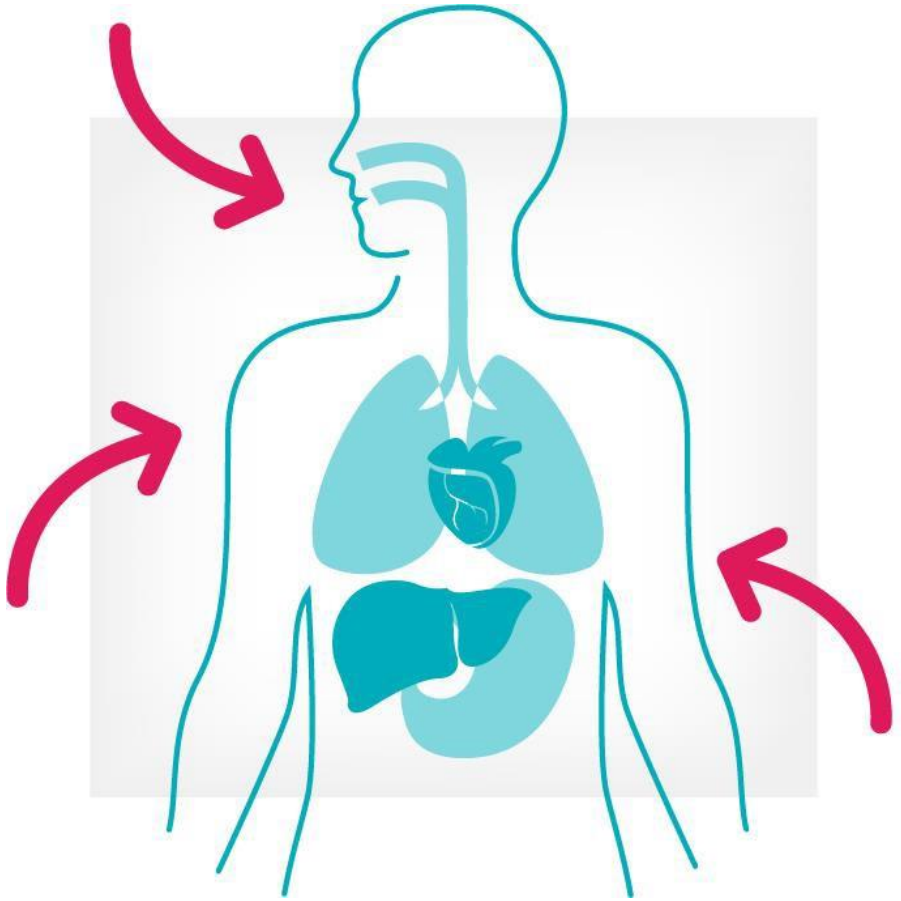
① PARTICIPANT NUMBER	② NAME / ID NUMBER / BIRTH DATE / SEX	③ DOSIMETER	④ USE	⑤ RADIATION QUALITY	⑥ DOSE EQUIVALENT (MREM) FOR PERIODS SHOWN BELOW: DEEP DDE / EYE LDE / SHALLOW SDE	QUARTERLY ACCUMULATED DOSE EQUIVALENT (MREM): DEEP DDE / EYE LDE / SHALLOW SDE	YEAR TO DATE DOSE EQUIVALENT (MREM): DEEP DDE / EYE LDE / SHALLOW SDE	LIFETIME DOSE EQUIVALENT (MREM): DEEP DDE / EYE LDE / SHALLOW SDE	⑦ RECORDS FOR YEAR	⑧ INCEPTION DATE (MM/YY)
FOR MONITORING PERIOD:					06/01/00 - 06/30/00	QTR 2	2000			
000CC	CONTROL	J	CNTRL		M M M				6	6/80
	CONTROL	P	CNTRL		M M M					6/80
	CONTROL	U	CNTRL		M					6/80
00191	ADDISON JOHN	J	WHBODY	PN	90 90 90	90 90 90	100 100 100	200 200 200	6	6/80
	336235619 08/31/1944 M			P	60 60 60	60 60 60	70 70 70	170 170 170		
				NF	30 30 30	30 30 30	30 30 30	30 30 30		
14839	JORGENSON MIKE	P	WHBODY		160 160 160	160 160 160	470 470 470	860 860 860	6	1/90
	471740095 10/04/1968 M		NOTE		DOSIMETER PARTIALLY SHIELDED, NO EVALUATION POSSIBLE					
16784	THOMAS LEE	P	COLLAR	P	62 62 57				6	2/86
	384846378 11/22/1964 M	P	WAIST		M M M					2/86
			ASSIGN		2 62 57	N/A N/A N/A	2 112 107	1072 3192 3327		
			NOTE	⑨	ASSIGNED DOSE BASED ON EDE 1 CALCULATION					
00901	WALKER JANE	P	WAIST				30 30 30	100 100 150	6	1/90
	587336640 06/09/1960 F		NOTE		ABSENT					
50601	ZERR ROBERT	P	WHBODY		40 40 40	160 160 160	200 200 200	240 240 240	6	6/80
	982446591 07/15/1945 M		NOTE	⑩	CALCULATED					
		U	UFINGR		50	50	80	620		6/80



WEARER NUMBER	SLOT NUMBER	PROCESS CONTROL NUMBER	NAME (LAST) OR OTHER DESIGNATION	F I	M I	ID TYPE	SSN / ID	BIRTH DATE	SEX	BADGE TYPE	BODY REGION	BODY PART	SERVICE	DOSE EQUIVALENT IN MILLIREMS FOR PERIODS INDICATED BELOW: MONITORING PERIOD FIRST DAY / LAST DAY	CURRENT: DEEP / EYE / SHALL. / NEUT. / PROC. NOTES	QUARTER TO DATE: DEEP / EYE / SHALL.	YEAR TO DATE: DEEP / EYE / SHALL. / NO. RPTS	LIFETIME TO DATE: DEEP / DOSE HISTORY ADJUSTMENTS / INCEPTION DATE LIFETIME TOTAL
		0226211	CONTROL							36			M	07/01/2015 07/31/2015				
1		0226211	ALDERMAN MD	J		1				36	WB		M	07/01/2015 07/31/2015	10 10 10	10 10 10	90 90 100 7	90 01/01/2015
1		0226211	ALDERMAN MD	J		1				36	WB	CL	M	07/01/2015 07/31/2015	70 70 80	70 70 80	640 700 730 7	640 01/01/2015
			EDE Calculation												18	18	163 7	163
2		0226211	BLOMBERG	P		1				36	WB		M	07/01/2015 07/31/2015	10 10 10	10 10 10	80 80 80 7	80 01/01/2015
2		0226211	BLOMBERG	P		1				36	WB	CL	M	07/01/2015 07/31/2015	30 40 40	30 40 40	340 350 350 7	340 01/01/2015
			EDE Calculation												17	17	137 7	137
3		0226211	BURMAN	E		1				36	WB		M	07/01/2015 07/31/2015	* * * *	0 0 0	20 20 20 7	20 01/01/2015
3		0226211	BURMAN	E		1				36	WB	CL	M	07/01/2015 07/31/2015	* * * *	0 0 0	20 20 20 6	20 01/01/2015
			EDE Calculation												*	0	32 6	32
4		0226211	DAVIDSON MD	E		1				36	WB		M	07/01/2015 07/31/2015	* * * *	0 0 0	20 20 20 6	20 01/01/2015
4		0226211	DAVIDSON MD	E		1				36	WB	CL	M	07/01/2015 07/31/2015	20 20 20	20 20 20	140 140 140 6	140 01/01/2015
			EDE Calculation												1	1	22 6	22
5		0226211	DESAI	V		1				36	WB		M	07/01/2015 07/31/2015	* * * *	0 0 0	10 10 10 7	10 01/01/2015
5		0226211	DESAI	V		1				36	WB	CL	M	07/01/2015 07/31/2015	* * * *	0 0 0	140 140 140 7	140 01/01/2015
			EDE Calculation												*	0	24 7	24
6		0226211	GANGE	C		1				36	WB		M	07/01/2015 07/31/2015	10 10 10	10 10 10	130 130 130 7	130 01/01/2015
6		0226211	GANGE	C		1				36	WB	CL	M	07/01/2015 07/31/2015	60 70 100	60 70 100	550 590 630 7	550 01/01/2015
			EDE Calculation												18	18	152 7	152
7		0226211	LOVE MD	D		1				36	WB		M	07/01/2015 07/31/2015				

How To Reduce Internal Radiation Exposure

- Ingestion
  - Refrain from eating, drinking, smoking, and applying cosmetics
- Inhalation
  - When using volatile material, work in fume hood (^{125}I is volatile)
- Injection
  - Beware of sharp objects
- Absorption
  - Wear appropriate personal protective equipment (PPE)



Internal Dosimetry

- Internal dose is calculated from radiation emitted by radioactive materials inside the human body.
- Radioactive materials may enter the body through inhalation, ingestion, wounds on skin, or general skin absorption.
- Once in the body, the radionuclide follows the metabolic pathway to distribute the dose into organs or tissue. For example, iodine tends to accumulate in the thyroid.
- Different tissues and organs respond differently to radiation, the probability of stochastic effects resulting from a certain equivalent dose depends on the organ or tissue which receives the radiation dose. Tissue weighting factors are assigned to differentiate the degree of radiation response of each organ. For example, low risk body part is skin (weighting factor 0.01, or 1%), high risk body part is red bone marrow (weighting factor 0.12, or 12%). The sum of all weighting factors of organs and tissues is 1.00.
    - The brain is one of the most radioresistant organs whereas blood forming organs are more radiosensitive.

Internal Dosimetry *(continued)*

- Definitions used for internal dosimetry:

  1. Committed dose equivalent (CDE): Although the dose delivered to organs or tissue inside the body decreases as time passes due to both natural radioactive decay and biological decay, it accumulates over time. CDE is thus defined as the accumulated equivalent dose in an organ over 50 years after initial intake and is assigned to the year of intake.

  2. Committed effective dose equivalent (CEDE): CEDE is the sum of the products of CDE and tissue weighting factors of the organ(s).

  3. Considering both external and internal dose, the total effective dose equivalent (TEDE) is the sum of effective dose equivalent (EDE, from external radiation) and committed effective dose equivalent (CEDE, from internal radiation). TEDE = EDE + CEDE

  4. Total organ dose equivalent (TODE) is the sum of deep dose equivalent (DDE, from external to one organ) and committed dose equivalent (CDE, from internal radiation to the same organ). TODE = DDE + CDE

Internal Dosimetry *(continued)*

5. Annual limit intake (ALI): Because different radionuclides emits different kinds of radiation with various energies, annual limits of intake (ALIs) for a specific radionuclide is the amount of that material taken into body which would result in a CEDE of 5000 mrem (stochastic ALI) or CDE of 50,000 mrem (non stochastic ALI). ALIs are exclusively internal dose.

The stochastic ALI of ^{131}I is 90 µCi for oral ingestion, and 200 µCi for inhalation

The non-stochastic ALI of ^{131}I is 30 µCi, with Thyroid as critical organ

The stochastic ALI of ^{90}Y is 500 µCi for oral ingestion, and 700 µCi for inhalation

The non-stochastic ALI of ^{90}Y is 400 µCi, with Lower Large Intestine (LLI) wall as critical organ

The stochastic ALI of ^{117m}Sn is 2000 µCi for oral ingestion and inhalation

The non-stochastic ALI of ^{117m}Sn is 2000 µCi for oral ingestion, with Lower Large Intestine (LLI) wall as critical organ, and 1000 µCi for inhalation, with bone surfaces as critical organ

What these numbers mean is that if a radiation worker ingests or inhales one stochastic ALI or one non-stochastic ALI's worth of activity, they receive the annual ODL from that contamination: 5000 or 50,000 mrem, respectively.

6. Derived air concentration (DAC): The concentration of a certain radionuclide in air which, if inhaled by a radiation worker in a working year would result in an intake of one ALI (5 rem).

The DAC value for ^{131}I is 2×10^{-8} µCi/ml, ^{90}Y is 3×10^{-7} µCi/ml, and 117mSn is 5×10^{-7} µCi/ml

Internal Dosimetry *(continued)*

Example 9: Calculate the CEDE, and CDE to the LLI wall of a radiation worker who accidentally ingests 10 µCi of ^{90}Y.

Knowing that SALI for ^{90}Y is 500 µCi , NALI is 400 µCi

Answer: CEDE= (10 µCi / 500 µCi) x 5 rem = 0.1 rem

CDE= (10 µCi /400 µCi) x 50 rem = 1.25 rem

Internal Dose Monitoring for Bioassay

- Bioassay measurement is performed to estimate an intake/uptake received by a radiation worker and to monitor the compliance with occupational limits.
- There are two types of bioassay tests: In-vitro bioassay and in-vivo bioassay.
- An In-vitro test is performed outside a living organism. Radioactivity is usually measured for urine, feces, or blood.
- In-vivo test is performed in a living organism. An external radiation counter is used to measure radiation emitted from human body. For example, a whole body counter is used at a nuclear power plant where the radiation worker needs to be scanned before exiting the facility to check for contamination.
- Bioassay tests are conducted when there is a suspected intake from working near a volatile material (^{125}I) or high-risk liquid (^{131}I). Or a bioassay can be conducted at a regular frequency if the occupational worker works routinely with airborne or volatile radioactivity. The frequency is dependent on the license, quantity of material, and likelihood of uptake.
- A bioassay is routinely not required for ^{90}Y and ^{117m}Sn applications.

Bioassay for ^{131}I handlers

- Bioassay for ^{131}I was introduced in Module 4, with details on how to use a 44-3 NaI probe to make measurements.

- Thyroid bioassays are required for anyone who handles a ^{131}I dose, or cares for a treated cat (with potential for skin injury from being scratched) , or cleans up a spill: in short, for anyone who has potential contact with liquid ^{131}I.

- The guidance document for radioiodine bioassays is **NRC Reg Guide 8.20**, Rev 2, 2014, APPLICATIONS OF BIOASSAY FOR RADIOIODINE, which supersedes Revision 1, 1979, APPLICATIONS OF BIOASSAY FOR I-125 AND I-131. The 2014 version is included in supplementary material. [Note that on Table 1 of that document, the non-stochastic ALI for ^{131}I is quoted wrongly as 50 µCi instead of 90 µCi.]

- RG 8.20 quotes handling 1 mCi of volatile ^{131}I as the level that requires a bioassay. A baseline bioassay is recommended before starting work with ^{131}I. Guidance on medical consultation is provided in NCRP Report 161

- The **PAL** (Predetermined Action Levels) for ^{131}I are:
  If the activity exceeds **1 µCi** (1000 nCi): Investigate the operations involved; repeat the bioassay within 24 hours.
  If the activity exceeds **5 µCi** (5000 nCi): In addition to the above actions, seek medical attention.

- For a NaI probe with a calibration factor of 25 cpm/nCi (for example), the net cpm on the thyroid would have to be 25,000 cpm to hit PAL-1, and 125,000 cpm to hit PAL-2

Specific Properties for External and Internal Monitoring of ^{131}I

- ^{131}I emits a large number of beta, gamma and conversion electrons, prominent among which are high energy 0.606, 0.334 and 0.248 MeV betas, and 0.364, 0.637 and 0.723 MeV gammas.

- These emissions present a significant external and internal hazard. Anyone coming in contact with liquid ^{131}NaI will receive a substantial radiation dose, the gamma component alone delivers 2200 mR/h at 1 cm from 1 mCi.

- Anyone who handles a cat treated with ^{131}I will only be exposed to the gamma emissions from ^{131}I, its betas will be stopped by the cat's tissues.

- Anyone who is internally contaminated and accumulates ^{131}I in their thyroid will be exposed to both its betas and gammas, and will require a bioassay.

- Any personnel who handles a dose of ^{131}I (including opening the syringe pig, handling the syringe, injecting the dose), or cares for treated cats, or handles contaminated kitty litter or other wastes, must wear a whole body dosimetry badge and a ring. The typical wear period is monthly.

- Proper PPE (personal protective equipment) must be worn, including gloves (double gloves when injecting), button-down lab coats, and closed-toe footwear.

Specific Properties for External and Internal Monitoring of ^{90}Y - IsoPet®

- The ^{90}Y dose of IsoPet is supplied in a sterile glass vial, shielded with acrylic or equivalent material.
- ^{90}Y emits high energy beta particles of average energy 0.93 MeV, with a maximum of 2.3 MeV. These emissions can present a substantial skin and eye dose hazard. All personnel who handle the material shall (*i.e.*, **must**) wear a whole body dosimeter and ring dosimeter while handling IsoPet®, to monitor radiation dose received from ^{90}Y.
- After the use of IsoPet®, a GM survey meter should be used to check if there is any contamination from radioactivity in the area where the unsealed ^{90}Y® was used and injected. The user's hands should be monitored periodically, as well as soles of footwear to ensure any spilled radioactivity is not carried out of the room (More on this in Module 9).
- Appropriate PPE should be worn at all times when handling unsealed radioactivity: this incudes button-down lab coats, gloves, and closed-toe footwear.

Specific Properties for External and Internal Monitoring of ^{117m}Sn

- Synovetin OA™, Tin (^{117m}Sn) stannic colloid ammonium salt, is a radioactive suspension. The radioactive material is placed in lead shield all times except when using for injection.

- ^{117m}Sn emits conversion and auger electrons and photons with a maximum energy of 159 keV. The personnel handling the material shall wear a whole body dosimeter and ring dosimeter when handling Synovetin OA™, to monitor radiation dose received from ^{117m}Sn.

- After the use of Synovetin OA™, a GM counter should be used to check if there is any contamination from radioactivity in the area where the unsealed Synovetin OA™ was used and injected (More on this in Module 8).

- Since Synovetin OA™ is liquid, internal monitoring of radiation due to ^{117m}Sn is not necessary. However, the hands should be monitored with a GM counter after each use of Synovetin OA™. Also, appropriate PPE should be used at all times when handling unsealed radioactivity.

Summary of Module 6: Shielding and Dosimetry

- Charged particles do not travel a significant distance/depth in matter. Alpha and beta particles are commonly seen in radiation labs or facilities. Alpha particles do not have the ability to penetrate the dead layer human skin, and therefore alphas do not pose any kind of hazard to external radiation. As a rule of thumb, an alpha particle can be shielded by a sheet of paper. Beta particles can be harmful to the human body because of the ability for higher energy betas to penetrate tissue and organs. However, beta particles can be shielded by low-Z material (plastic). Low Z metal is chosen for beta shielding to avoid or minimize Bremsstrahlung radiation.
- Photons and neutrons are neutral, they can travel a very long distance in matter. Photons and neutrons are the primary sources of external radiation dose to humans. Photons are shielded by high Z materials. Lead is the most commonly used for photon shielding. Neutrons are heavier particles and can be stopped by material with equivalent atomic mass such as water, plastic, or concrete. In practice, concrete is most commonly used for neutron shielding design.

Summary of Module 6: Shielding and Dosimetry *(continued)*

- Primary and secondary radiation are the concerns for X-ray shielding design. The primary beam shielding thickness shall reduce the exposure rate to a certain level (0.1 R wk^{-1} or 0.01 R wk^{-1}) at a publicly accessible location. Secondary radiation shield shall be designed to protect areas, which are not in the direction of primary beam, from scattered radiation and X-ray tube leakage radiation.
- Dose created from external radiation is monitored by radiation dosimeters. Commonly used dosimeters are from companies such as Landauer or Mirion.
    - When radioactivity is taken into human body, it deposits energy to living organs and tissue. Radioactivity can enter the body through inhalation, ingestion, injection or absorption. Internal dose is measured through a bioassay. External radiation is monitored by using external whole body radiation counters or personnel dosimetry.
    - Any personnel who handle unsealed radioactive material, including doses of ^{131}I, ^{90}Y and ^{117m}Sn, must wear external dosimeters (badges and rings) to monitor their doses, and check for compliance with regulations. Additional internal dosimetry requirements exist for handlers of ^{131}I doses.

Supplemental Reading Material

Assigned reading material for Module 6:

6.1. NRC Reg Guide 8.7, Instructions for recording and reporting occupational radiation dose data, 2018
6.2. NRC Reg Guide 8.34, Monitoring criteria and methods to calculate occupational radiation doses, 1992
6.3. NRC Reg Guide 8.20 Rev 2, Applications of bioassay for radioiodine, 2014

Upon successful completion of the Module 6 quiz, you may continue to Module 7.