Authorized User/Radiation Safety Officer Training for Synovetin OA™

Module 6: Shielding and Dosimetry

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Introduction

- This module introduces the concepts of 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 Synovetin OA™ (^{117m}Sn) is discussed.
- Assigned reading:
  1. NRC Reg Guide 8.7
  2. NRC Reg Guide 8.9
  3. NRC Reg Guide 8.34

Outline

- **Part I – Radiation Shielding:**
  - Charged particle shielding
  - Photon shielding
  - Facility design and shielding
  - Ideal hot lab setup
  - Specific shielding properties for Synovetin OA™ (^{117m}Sn)
- **Part II – Dosimetry:**
  - External dosimetry
  - Dosimeters for external monitoring
  - Internal dosimetry
  - Internal dose monitoring for bioassay
- **Specific Properties for External and Internal Monitoring of Synovetin OA™ (^{117m}Sn)**
- **Quiz**

Part I: Radiation Shielding

- External radiation protection procedures limit and prevent radiation workers or patients from receiving radiation doses from outside the human body.
- A dose received from being in the vicinity of an external radiation source can be reduced in three ways:
  - **Increasing the distance from the source** reduces radiation dose by a factor of distance squared. For example, the dose at one location is D(0), and the dose at another location "d" units away is $D(d)=D(0)/d^2$.
  - **Minimizing the duration of exposure** to a radiation source with certain activity can reduce total radiation dose.
  - **Shielding** is a reliable way of reducing radiation dose; it can be used to limit dose rate to a desired level.
- In nuclear medicine, photon shielding is the major concern. But understanding shielding techniques for charged particles and neutrons can be beneficial as well, because in nuclear medicine, you are typically handling radiation sources directly.

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 *(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 $4<E<15$MeV.
- 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 *(continued)*

Example 6-1: 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 0.00129g/cm^3 — A_{air} is 14.4
   - ρ_{tissue} is 1g/cm^3 — A_{tissue} is 13.1
   - ρ_{paper} is 1.5g/cm^3 — A_{paper} is 12.9
2. **Alpha particle range in air:**

$R_{air} = (0.005x5.5+0.285)x5.5^{3/2} = 4.03cm$

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

$=4.03cmx(0.00129x13.1^{1/2})/(1x14.4^{1/2})$

$=0.005cm$

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

$=4.03cmx(0.00129x12.9^{1/2})/(1.5x14.4^{1/2})$

$=0.0033cm$

Charged Particle Shielding *(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 it can be very harmful, since it creates dense ionization tracks in short ranges.

Charged Particle Shielding *(continued)*

- 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 *(continued)*

- **Example 6-2:** Calculate the maximum range of beta particle emitted from ^{90}Y in air, tissue, lead, and aluminum shielding. The maximum beta energy is 2.28 MeV.

1. Knowing that: ρ_{air} is $0.00129 g/cm^3$, ρ_{tissue} is $1 g/cm^3$, ρ_{lead} is $11.34 g/cm^3$, $\rho_{aluminum}$ is $2.7 g/cm^3$.
2. $R=0.412T^{1.27-0.0954\ln(T)}$

   $=0.412x(2.28)^{1.27-0.0954\ln(2.28)}$

   $=1.1 g/cm^2$

   $R_{air} = R/\rho_{air} = 1.1/0.00129 cm = 852 cm$

   $R_{tissue} = R/\rho_{tissue} = 1.1/1 cm = 1.1 cm$

   $R_{lead} = R/\rho_{lead} = 1.1/11.34 cm = 0.097 cm$

   $R_{aluminum} = R/\rho_{aluminum} = 1.1/2.7 cm = 0.407 cm$
3. Radiation yield in lead (Z=82):

   $Y_{lead} = (6x10^{-4} x82x2.28)/(1+6x10^{-4} x82x2.28)=0.1009$ (10.9%)

   Radiation yield in aluminum (Z=13):

   $Y_{aluminum} = (6x10^{-4} x13x2.28)/(1+6x10^{-4} x13x2.28)=0.0175$ (1.75%)

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Charged Particle Shielding *(continued)*

- The previous example shows that an energetic beta particle can travel a long distance in air before it stops, but the range in dense material is very short.
- Although a beta particle has a shorter range in lead, it yields a considerable amount of Bremsstrahlung photon radiation. On the other hand, an aluminum shield reduces Bremsstrahlung significantly ($y_{lead}/y_{aluminum}=5.76$).
- So an energetic beta particle can be shielded in aluminum, plastic, or another low-Z material (such as tissue as with Synovetin OA™).

Photon 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.
- The number of photons in the primary beam that reach a depth x in the matter without having interacted is calculated by:

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

N(0) is the initial number of monoenergetic photon incident normally on matter. This is the standard attenuation equation. The distance travelled is energy-specific and material-specific. For instance, a photon will not travel very far in tungsten, but it can travel much further in air.

Photon Shielding *(continued)*

- **Example 6-3:** What thickness of lead is needed to reduce the number of 150 keV (max energy in X-ray machine) photons in a primary beam to 5%? What about 1.25 MeV (max energy of ^{60}Co is 1.17 MeV) photons?

  Knowing μ_{lead}=22.7 cm^{-1} for 150 keV photon. μ_{lead}=0.662 cm^{-1} for 1.5 MeV photon.

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

  $N(x)/N(0)=e^{-\mu x}=0.05$

  $-\mu x=\ln(0.05)$

  $x=-\ln(0.05)/\mu$

  1. for 150 keV photon

     $x=-\ln(0.05)/22.7cm^{-1}=0.132cm$

  2. for 1.25 MeV photon

     $x=-\ln(0.05)/0.662cm^{-1}=4.52\ cm$

Photon Shielding *(continued)*

- The previous example shows that 0.132 cm and 4.52 cm material would reduce a primary photon beam to 5% of its initial intensity for 150 keV and 1.25 MeV respectively.
- The maximum photon energy of an X-ray machine is 125 keV, so a layer of 0.132 cm lead would protect the X-ray technologist or patient by eliminating approximately 95% of the primary beam.
- The maximum photon energy of ^{60}Co used in nuclear medicine is 1.17 MeV, so a 4.52 cm lead window would protect the nuclear medicine technologist by eliminating more than 95% of the primary photons.
- For low-energy photons, the photoelectric effect dominates the interaction. A thin lead layer is sufficient to absorb most low-energy photons.
- For photon energy in the range of several MeV, most of the attenuation is due to the Compton scattering effect, thus it needs a thicker lead layer to block a more energetic photon beam.

Neutron Shielding

- The basic idea of neutron shielding is a two-step process:
  - First, to slow down or moderate fast neutrons to thermal energies
  - Second, to absorb the slow neutron.
- Neutrons are slowed down by interacting with light elements through scattering. Hydrogen (^{1}H) is the most effective element to slow down neutrons. Since the mass of protons and neutrons are similar, the neutron transfers almost all of its energy. Hydrogenous materials make efficient neutron shields, but in practice, concrete is the choice in most applications.
- Thermal neutrons can be absorbed through the neutron capture reaction with several materials. Hydrogen (^{1}H) as moderator can capture thermal neutrons through the $^{1}H(n,\gamma)^{2}H$ reaction.
- The disadvantage of hydrogen-containing shielding material (concrete) is that high-energy gamma rays are created. Thus, the shield is designed with an added layer of lead outside the concrete well.

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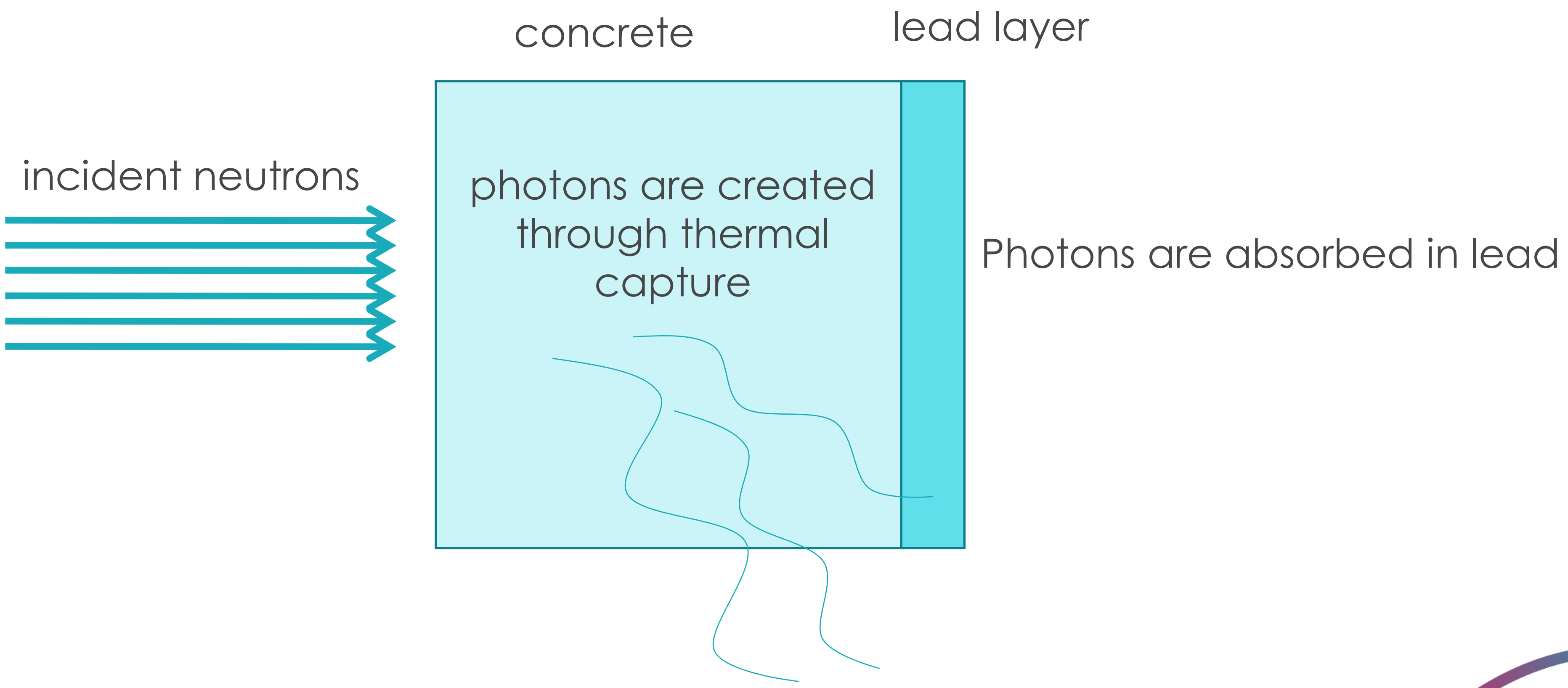
Neutron Shielding *(continued)*

Neutrons are thermalized and absorbed in concrete, emitting gamma rays, which are blocked by lead.



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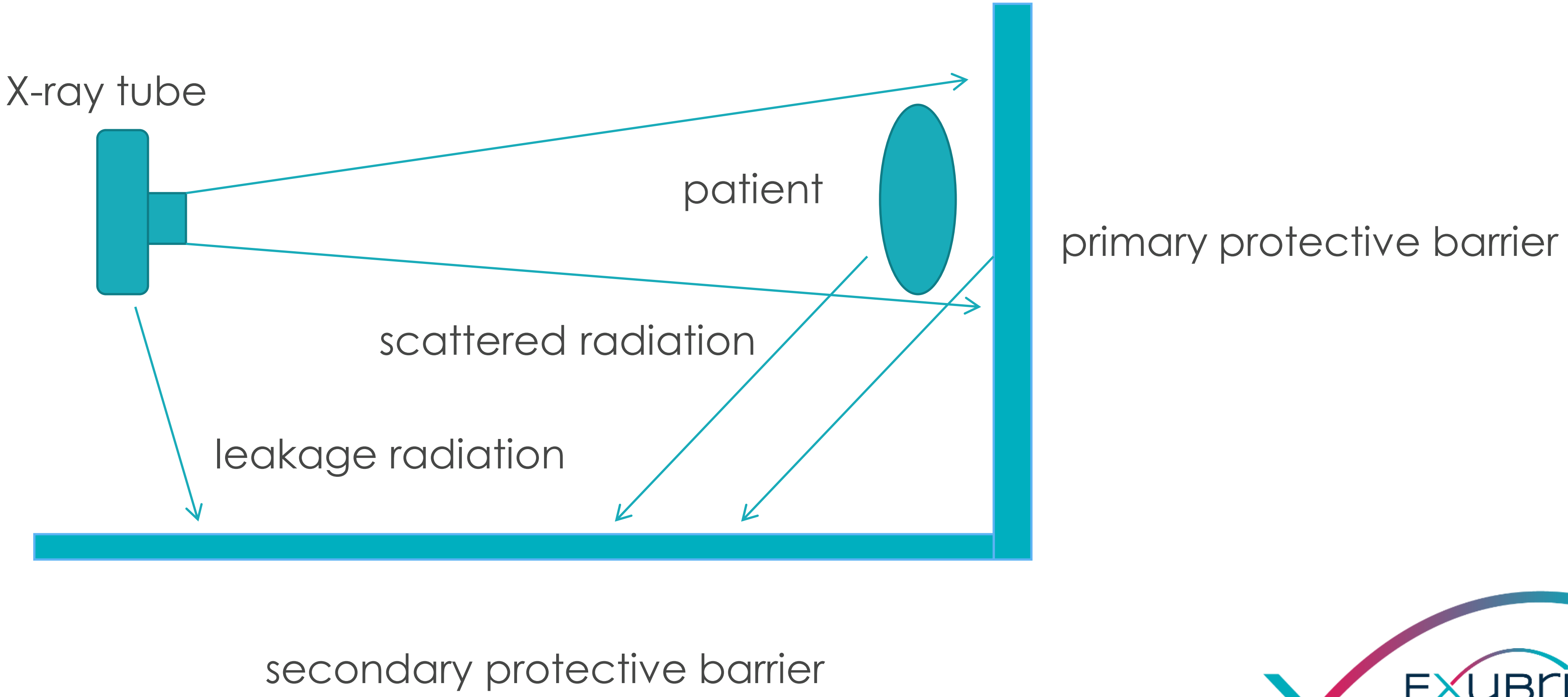
Facility Design and Shielding

- 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.
- 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 scattered radiation.

Facility Design and Shielding *(continued)*

Components of X-ray facility shielding construction



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 6-4:** 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.

$$K=Pd^2/(UWT)=(0.01 \times 5^2)/(10000 \times 1/3 \times 1/4)$$

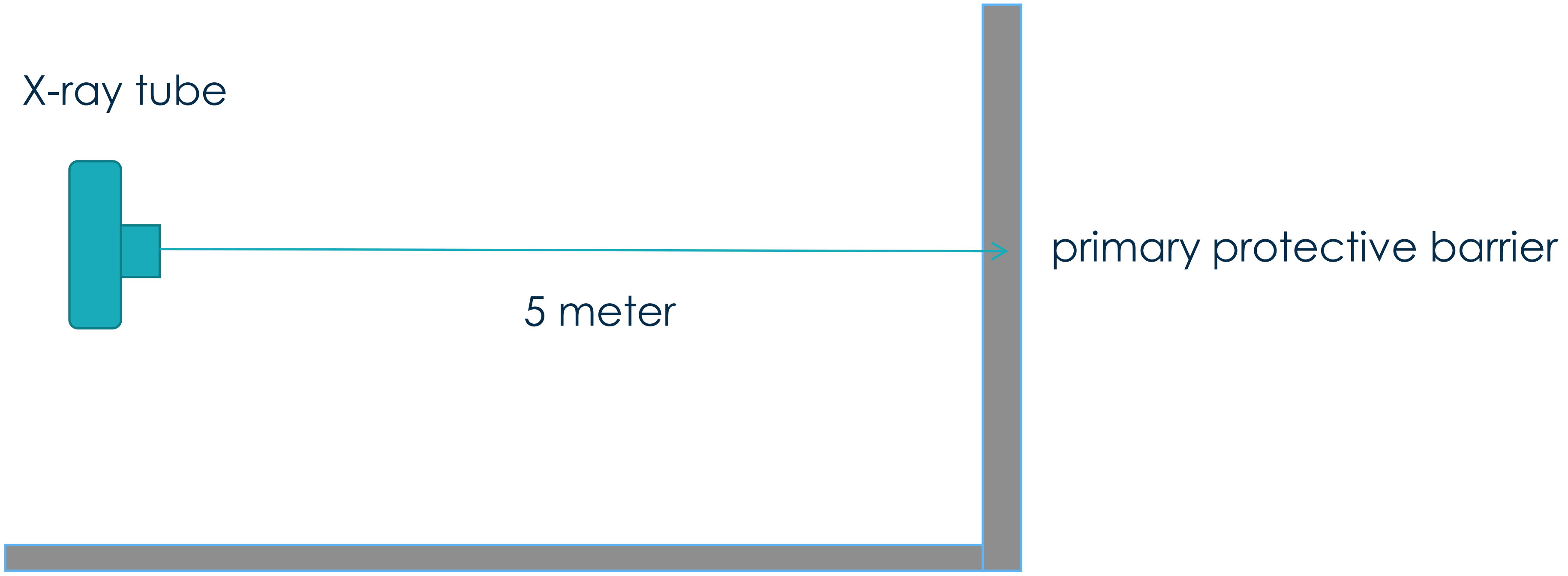
$$= 0.00003\ [R\ mA^{-1}\ min^{-1}] \text{ at 1 meter}$$

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.

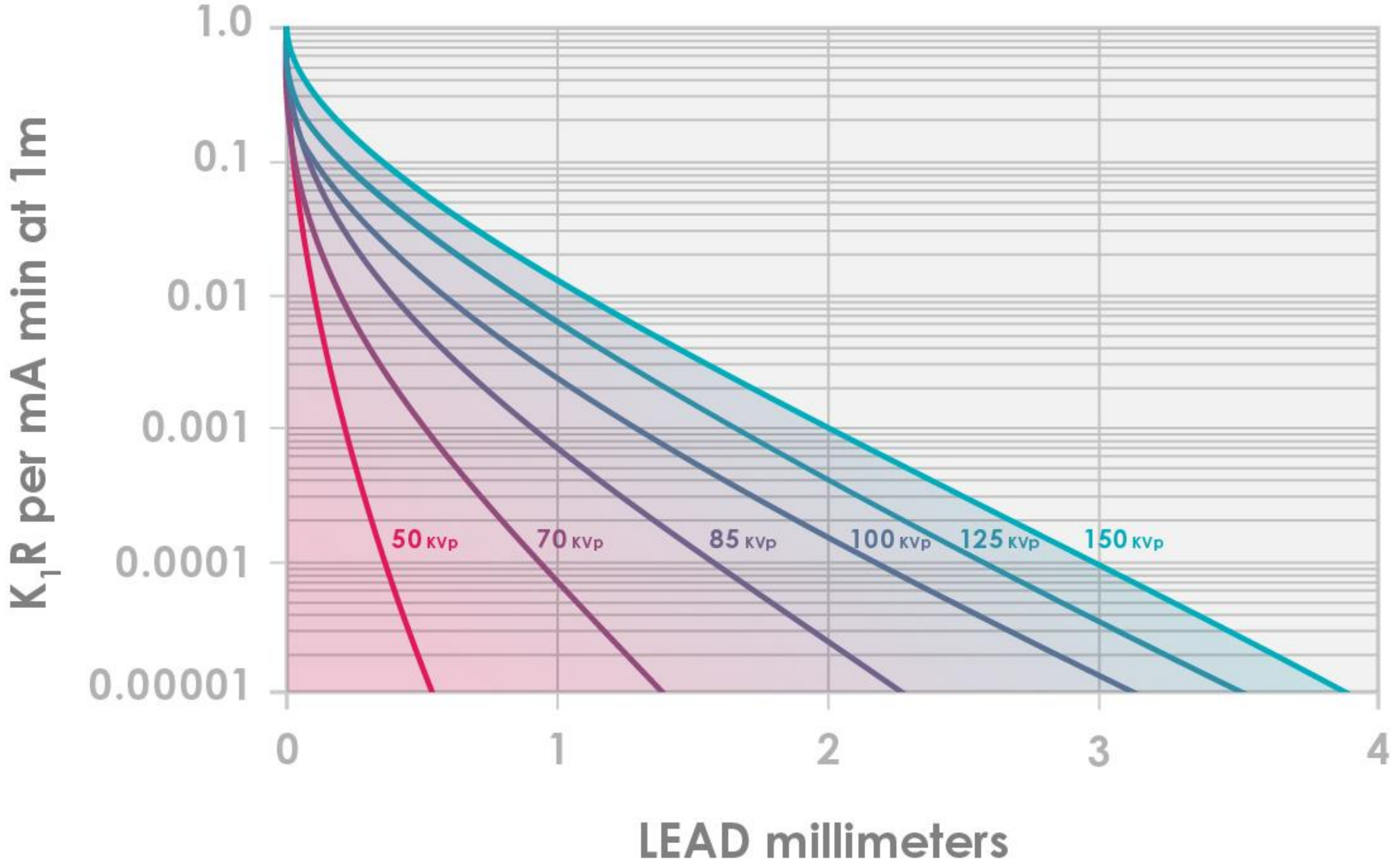
Primary Protective Barrier *(continued)*

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 so as to be 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)*

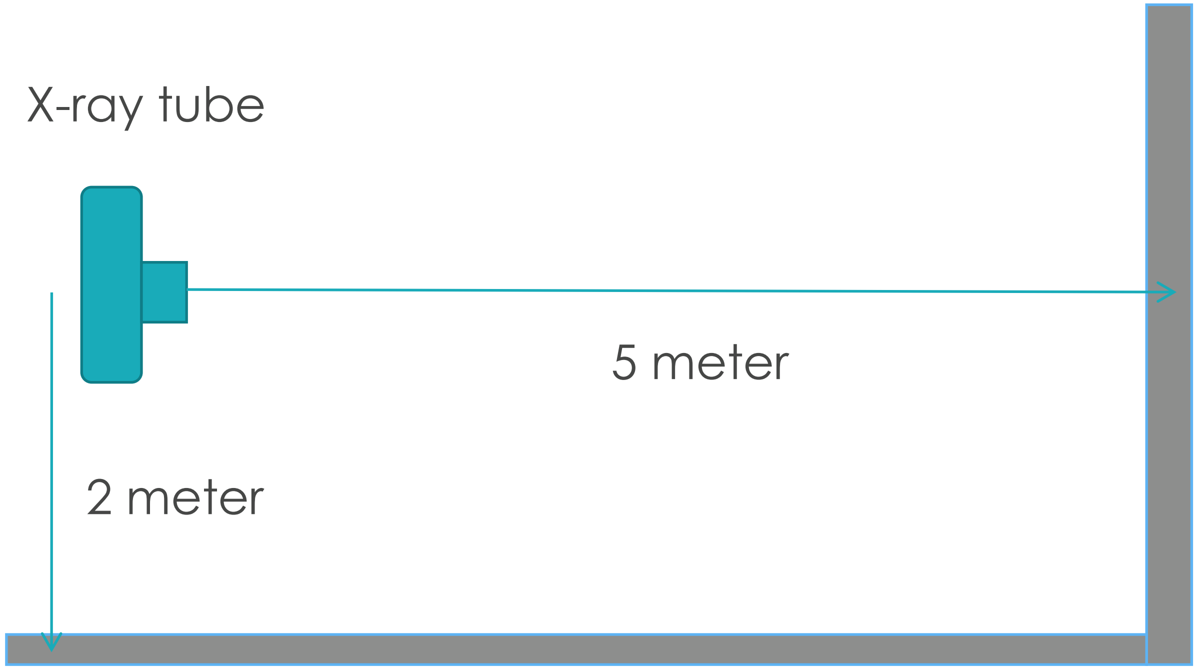
- Thickness of shield for scattered radiation is computed by formula:

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

- Similar to 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

Secondary Protective Barrier *(continued)*

- **Example 6-5:** 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

   $B= (60 \times 100 \times 0.01 \times 2^2)/(0.1 \times 10000 \times 1)=0.24$

   $N=-\ln(0.54)/\ln(2)=2.05$ HVL of lead

2. Scattered radiation shield

   $K=(1000 \times 0.01 \times 2^2)/(1 \times 10000 \times 1)=0.004$

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

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Ideal Hot Lab Setup

- A radiation "hot lab" is where radioactive materials are prepared for diagnosis and therapy.
- A hot lab should include the following equipment:
  - Dose calibrator (optional for Synovetin OA™)
  - L-block shield
  - Syringe shield
  - Shielded waste storage container
  - Sealed calibration sources (if using a dose calibrator)
  - Appropriate survey meter
  - A fume hood is required if working with volatile or gaseous radioactive material such as ^{131}I or ^{133}X.
- Note that localized shielding is used for radioactivity in a hot lab; therefore, the walls do not need to be shielded. Unit doses of radioactivity prepared for injection can be locally shielded in the bulk container, behind the L-shield, or in a shielded carrier.
- A nuclear medicine technician working in hot lab should always wear 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.

Use of Hot Lab Equipment

1. Radioactive medicine is prepared and drawn into a syringe behind an L-block shield. An L-block shield is made of lead and lead-equivalent glass to protect the preparer's body from unnecessary radiation exposure.
2. A dose calibrator is used to measure the reading of syringe activity (if applicable).
3. A syringe holder is a small lead container which temporarily holds a prepared syringe. The nuclear med tech carries the syringe in the syringe holder to the patient for injection to avoid unnecessary radiation exposure during the process.
4. 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.
5. After the procedure, a GM survey meter is used to check whether there is any radioactive contamination in the facility.

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. Where your copy of current regulations is kept (10CFR35 or equivalent)
  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
- 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.

https://www.nrc.gov/reading-rm/doc-collections/forms/nrc3info.html

EXUBRION THERAPEUTICS

Specific Shielding Properties for Synovetin OA™ (^{117m}Sn)

- ^{117m}Sn emits electrons with maximum energy of 158 keV; these low-energy electrons can be shielded effectively in a lead container. The range of electrons with the maximum energy is:

  $R_{lead} = 0.412x(0.158)^{1.27-0.0954\ln(0.158)} = 0.029 g/cm^2$

  $= 0.029[g/cm^2]/11.34[g/cm^3]$

  $= 0.0026cm$ (lead)

- The percentage of radiation yield at this maximum created by a lead shielding container is:

  $Y_{lead} = (6x10^{-4}\ x82x0.158)/(1+6x10^{-4}x82x0.158)$

  $=0.0077$ (~0.8%)

  Only 0.8% of 158 keV is irradiated as photons, while 99.2% of electron energy is dissipated in lead shielding by collision.

- ^{117m}Sn also emits a 159 keV photon. The lead thickness to reduce 95% of the photon beam is: ($\mu=20.6cm^{-1}$ for 159 keV photon)

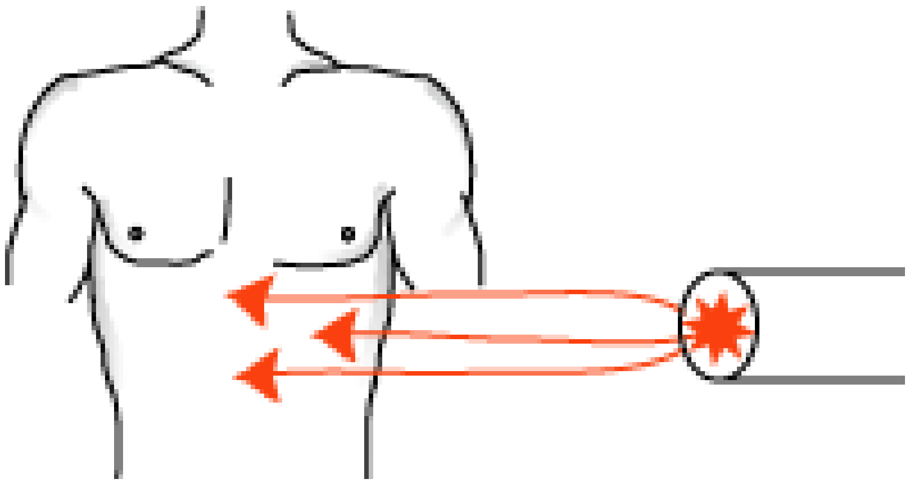
  $x=-\ln(0.05)/\mu=-\ln(0.05)/20.6=0.145cm \sim 1.5mm$ (lead)

- Theoretically, a 1.5mm thick lead container can be used to shield radioactive ^{117m}Sn.

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.

External and Internal Radiation Exposure



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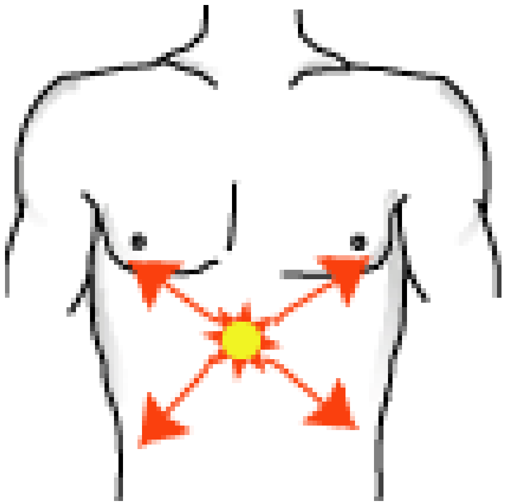

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External Dosimetry

- Targets of radiation emitted by external radioactive sources are skin, lens of the eye, extremities, and internal organs.
- Alpha particles have a very short range traveling in material. As calculated in Example 6-1 on Slide 7, 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 2.28 MeV electron has range of 1.1cm 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 and torso, but not extremities
  - Whole body skin: Skin that covers the body, except extremities
  - Extremities: Arms, legs
  - Depth of external dose measurement:
  - Deep whole-body dose is measured at 1 cm beneath skin surface
  - Lens of eye dose is measured at 0.3 cm behind cornea
  - Shallow skin dose is measured at 0.007 cm beneath skin surface

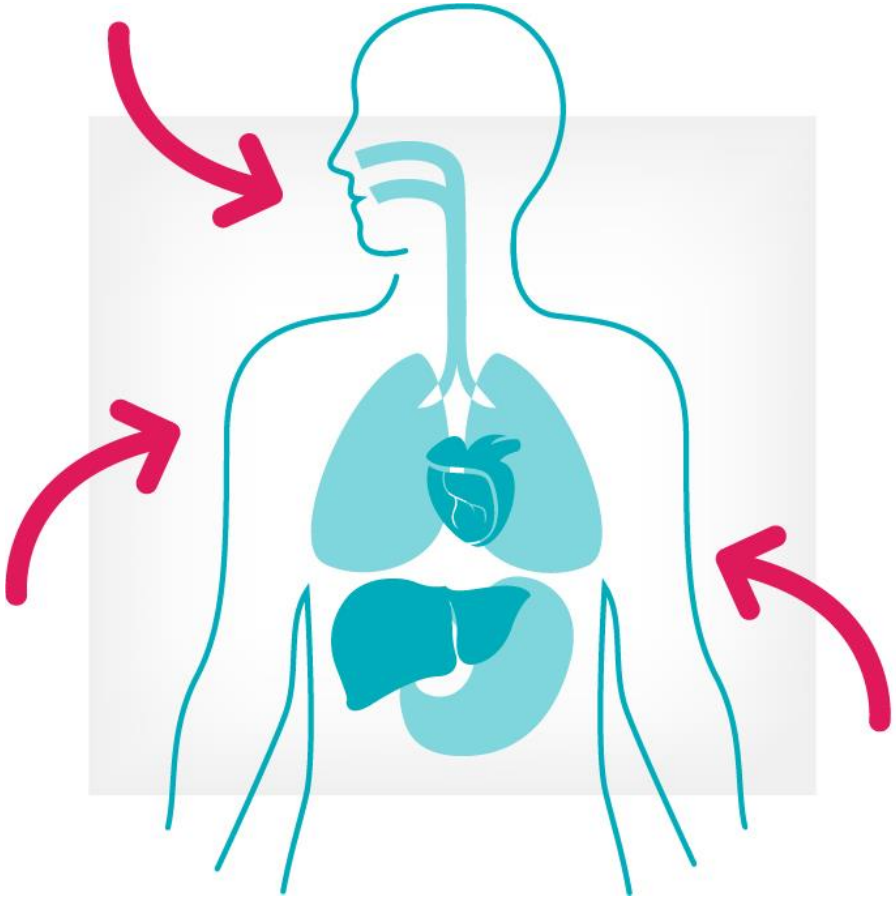
External Dosimetry *(continued)*

Terms used in external dosimetry:

- **Effective Dose Equivalent (EDE)** is the total effective dose to organs or tissue from external sources. It is also referred to "whole body dose" or "deep dose equivalent" (DDE) if tissue weighting factors are not considered.
- **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 (effective dose is not used here) to skin or extremity skin.
- Occupational Dose Limits:
  - DDE = 5000 mrem/y
  - LDE = 15,000 mrem/y
  - SDE = 50,000 mrem/y

How To Reduce Internal Radiation Exposure

- Ingestion
  - Refrain from eating, drinking, smoking, and applying cosmetics
- Inhalation
  - When using volatile material, work in fume hood (^{131}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, or wounds on skin.
- 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), high risk body part is gonad (weighting factor 0.2). The sum of weighting factors of organs and tissue is 1.
  - 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 product of CDE and tissue weighting factors of the organ(s).

  3. Taking into account 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 5 rem (stochastic ALI) or EDE of 50 rem (non stochastic ALI). ALIs are exclusively internal dose.

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).

Internal Dosimetry *(continued)*

Example 6-6: Calculate the CDE of thyroid and CEDE, if a radiation worker inhales 10 μCi of ^{131}I. Knowing that sALI for ^{131}I is 200 μCi , nALI is 50 μCi .

Answer: CEDE= (10μCi/200 μCi) x 5rem=0.25rem

CDE= (10 μCi /50 μCi) x 50rem=10rem

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 (^{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.

Specific Properties for External and Internal Monitoring of Synovetin OA™ (^{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.

EXUBRION THERAPEUTICS

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 hydrogenous material (plastic) or thin high Z material (copper). It should be noticed that 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.
- ^{117m}Sn emits low energy electrons and photons, it can be effectively shielded by lead. Lead has a high attenuation factor for ^{117m}Sn photon. Since emitted electron energy is low, Bremsstrahlung radiation does not significantly contribute to external radiation dose.
- Dose created from external radiation is monitored by radiation dosimeters. Commonly used dosimeters are luminescent dosimeter from companies such as Landauer or Mirion.

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

- When radioactivity is taken into human body, it deposits energy to living organs and tissue. Radioactivity can enter the body through inhalation, ingestion, or injection. Internal dose is measured through a bioassay. External radiation is monitored by using external whole body radiation counters or personnel dosimetry.
- Synovetin OA™ is a non-volatile colloid containing radioactive ^{117m}Sn, thus internal dose is not a concern. However, ^{117m}Sn emits both electrons and photons and can therefore cause skin and body dose to personnel. Staff handling Synovetin OA™ should be provided with a whole body and ring dosimeter to ensure that occupational dose limits are maintained.
  - Always follow your local state or federal regulations for occupational dose.

EXUBRION THERAPEUTICS

Supplemental Reading Material

Assigned reading material for Module 6:

1. NRC Reg Guide 8.7
2. NRC Reg Guide 8.9
3. NRC Reg Guide 8.34

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

EXUBRION THERAPEUTICS