Chapter 5

External Dose Calculations

Objectives

- Understand how radiation is affected by distance from a point source
- Using the inverse square law, calculate dose rates
- Understand how the specific gamma ray constant is used
- Explain how each photon-emitting radionuclide has a unique gamma constant associated with it

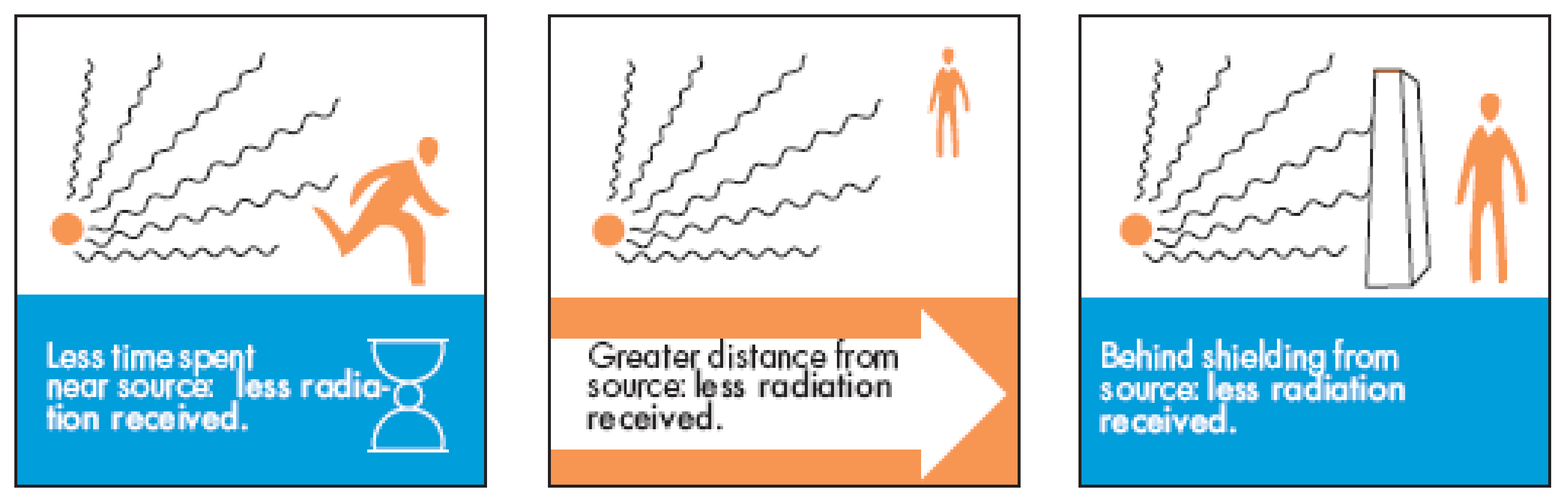
Objectives

- Use the gamma constant correctly in an exposure calculation
- Calculate exposure and dose rates from gamma point sources

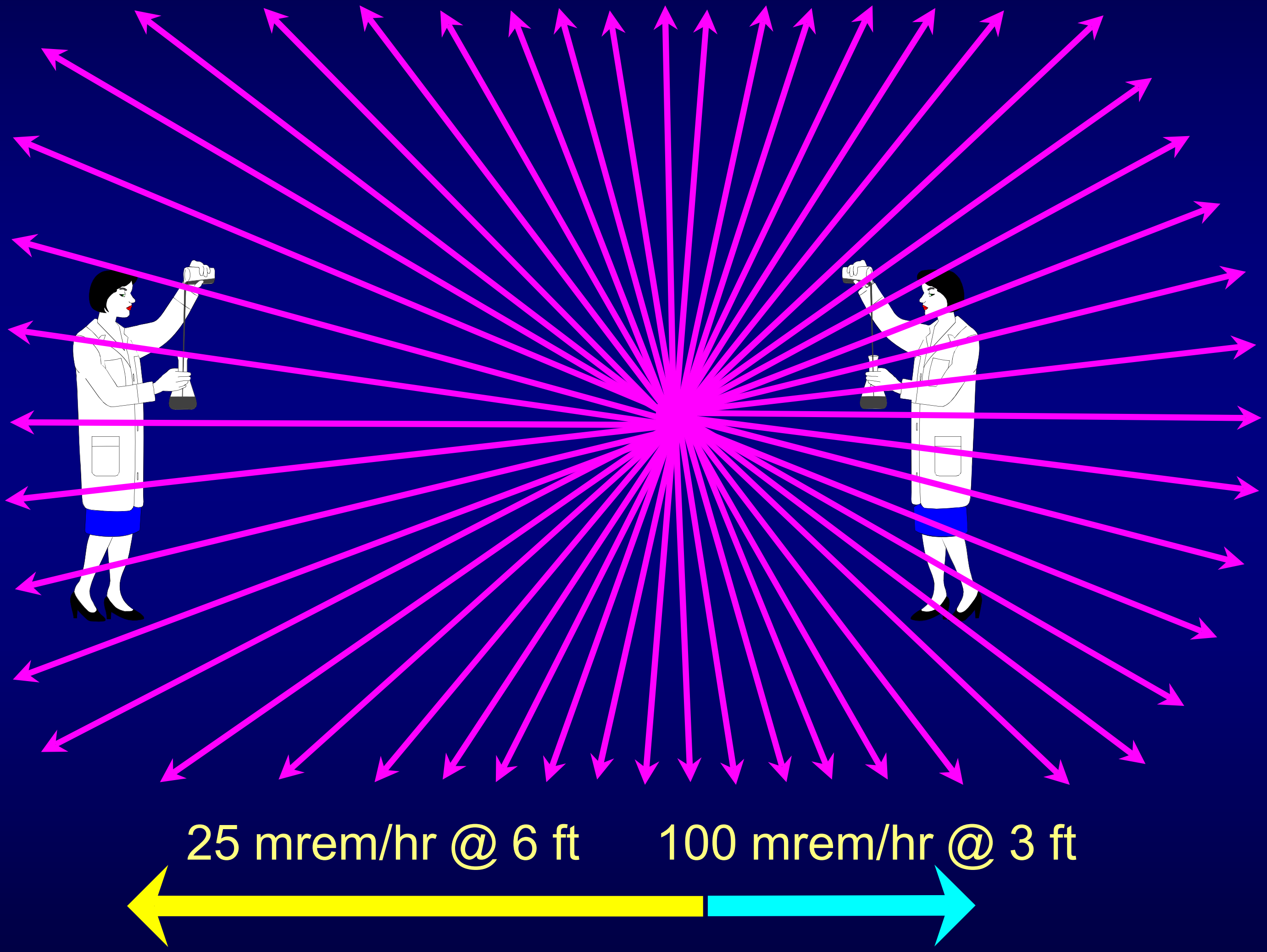
Time, Distance and Shielding

"Although exposure to ionizing radiation carries a risk, it is impossible to completely avoid exposure. Radiation has always been present in the environment and in our bodies. We can, however, avoid undue exposure through the following protection principles:"

http://www.nrc.gov/about-nrc/radiation/protects-you/protection-principles.html



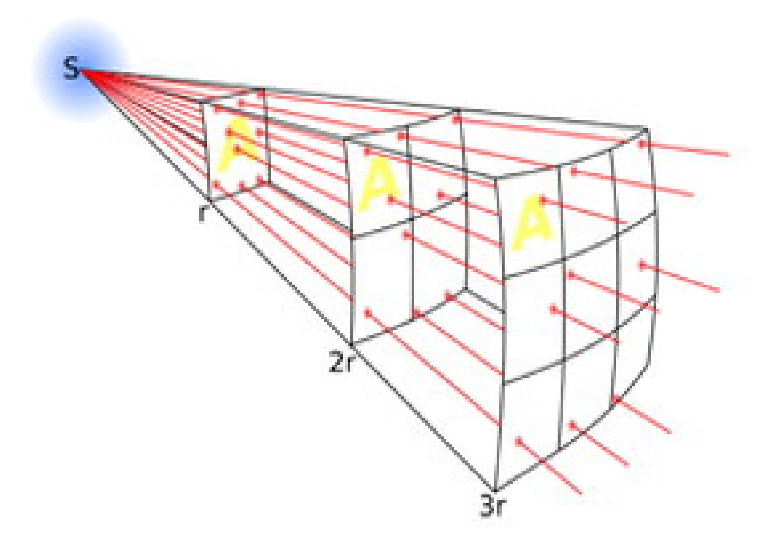
Effect of Distance on Dose Rate



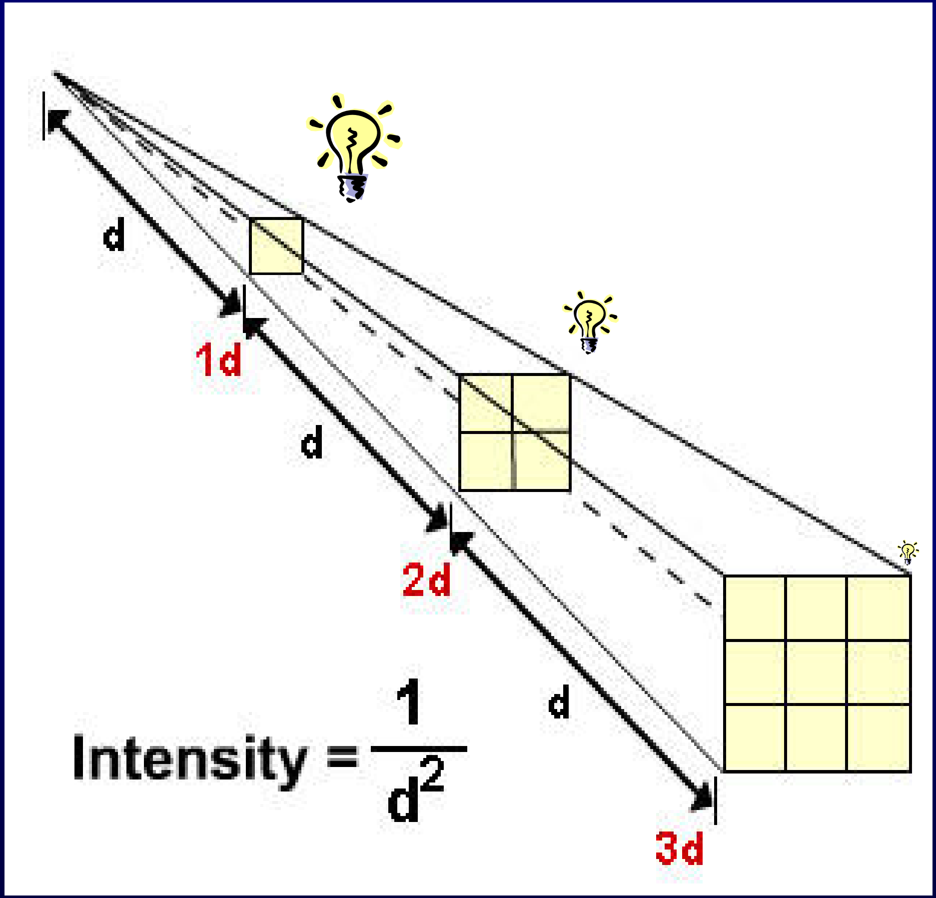
25 mrem/hr @ 6 ft

100 mrem/hr @ 3 ft

Inverse Square Law



Applies to the force of Gravity, Light, Heat, Electric Fields, Sound and Radiation.



$$\text{Intensity} = \frac{1}{d^2}$$

Intensity of a radiation field decreases as distance is increased due to geometry.

Inverse Square Law Equation

- General formula is:

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

where *I* is the Intensity (or dose rate) and *d* is the distance from the source

- Hence, $I_2 = I_1(d_1/d_2)^2$

Problem

- **The exposure rate from a 100 Ci point source of Co-60 at 2 meters is 32 R/hr.**
- **Find the exposure rate at 4 meters**

Solution

$$I_2 = I_1(d_1/d_2)^2$$

$$I_2 = 32 \text{ R/hr} \times (2/4)^2 = 8 \text{ R/hr}$$

Specific Gamma-Ray Constant

- The gamma constant, Γ, allows the calculation of exposure rate:
  - for a point source
  - of a gamma-emitting radionuclide
  - for a given activity
  - at a specified distance from the source
- Typically measured in R/hr at one meter from a 1 Ci source

Units

The units of the gamma constant are typically given as:

$$\frac{R}{hr \cdot mCi} \text{ at 1 cm} = \boxed{\frac{R \cdot cm^2}{hr \cdot mCi}}$$

or

$$\frac{R}{hr \cdot Ci} \text{ at 1 m} = \boxed{\frac{R \cdot m^2}{hr \cdot Ci}}$$

Sample Gamma Constants

$$\Gamma = \left[\frac{R \cdot m^2}{hr \cdot Ci} \right]$$

<0.1		0.1 - 0.3		0.3 - 0.5		0.5 - 1		>1	
^{109}Pd	0.003	^{99}Mo	0.18	^{63}Ni	0.31	^{59}Fe	0.64	^{60}Co	1.32
^{133}Xe	0.01	^{131}I	0.22	^{137}Cs	0.33	^{226}Ra	0.83	^{24}Na	1.84
^{125}I	0.07	^{65}Zn	0.27	^{95}Zr	0.41				
				^{54}Mn	0.47				
				^{192}Ir	0.48				

For the same activity (Ci) and the same distance (m):
Co-60 = 3 x Ir-192, 4 x Cs-137, 6 x I-131
Ir-192 = 2 x I-131
Cs-137 = 1.5 x I-131

Dose vs. Dose Rate

There are two point source equations in which the inverse square law is used:

$$D = \frac{\Gamma \, A \, t}{d^2}$$

$$D_{rate} = \frac{\Gamma \, A}{d^2}$$

Very Small Distances

Approximate gamma dose rate to the hand from a 1 Ci Sealed Source

Isotope	$\Gamma \ \frac{\text{R-cm}^2}{\text{hr-mCi}}$	Surface Dose Rate (R/min)	Dose Rate at 1 cm* (R/min)	Dose Rate at 3 cm* (R/min)
^{137}Cs	3.26	513	28	3.7
^{60}Co	13	2075	114	16
^{192}Ir	4.8	813	43	5.5
^{226}Ra	8.25	1310	72	9.7

(* depth in tissue)

(NCRP Report No. 40)

Problem

What is the exposure/dose received by an individual who spends one minute at 3 m from an unshielded 100 Ci ^{192}Ir source?

(Given Γ = 0.48 R m^2 hr^{-1} Ci^{-1})

Answer

What is the exposure/dose received by an individual who spends one minute at 3 m from an unshielded 100 Ci ^{192}Ir source?

$\Gamma = 0.48\ \mathrm{R\ m^2\ hr^{-1}\ Ci^{-1}}$
A = 100 Ci
d = 3 m
t = 1 min = 0.017 hr

$$D = \Gamma At/d^2 = (0.48\ \mathrm{R\ m^2\ hr^{-1}\ Ci^{-1}} * 100\ \mathrm{Ci} * 0.017\ \mathrm{hr})/(3\ \mathrm{m})^2$$

$$= 0.091\ \mathrm{R} = 91\ \mathrm{mR} = 91\ \mathrm{mrem}$$

Shielding Equation

$$I = I_0 e^{(-\mu x)}$$

Where:

- I_0 is the unshielded intensity (or dose rate)
- I is shielded intensity
- μ is the linear attenuation coefficient for the shielding material with units of cm^{-1}
- x is the thickness of the shielding material

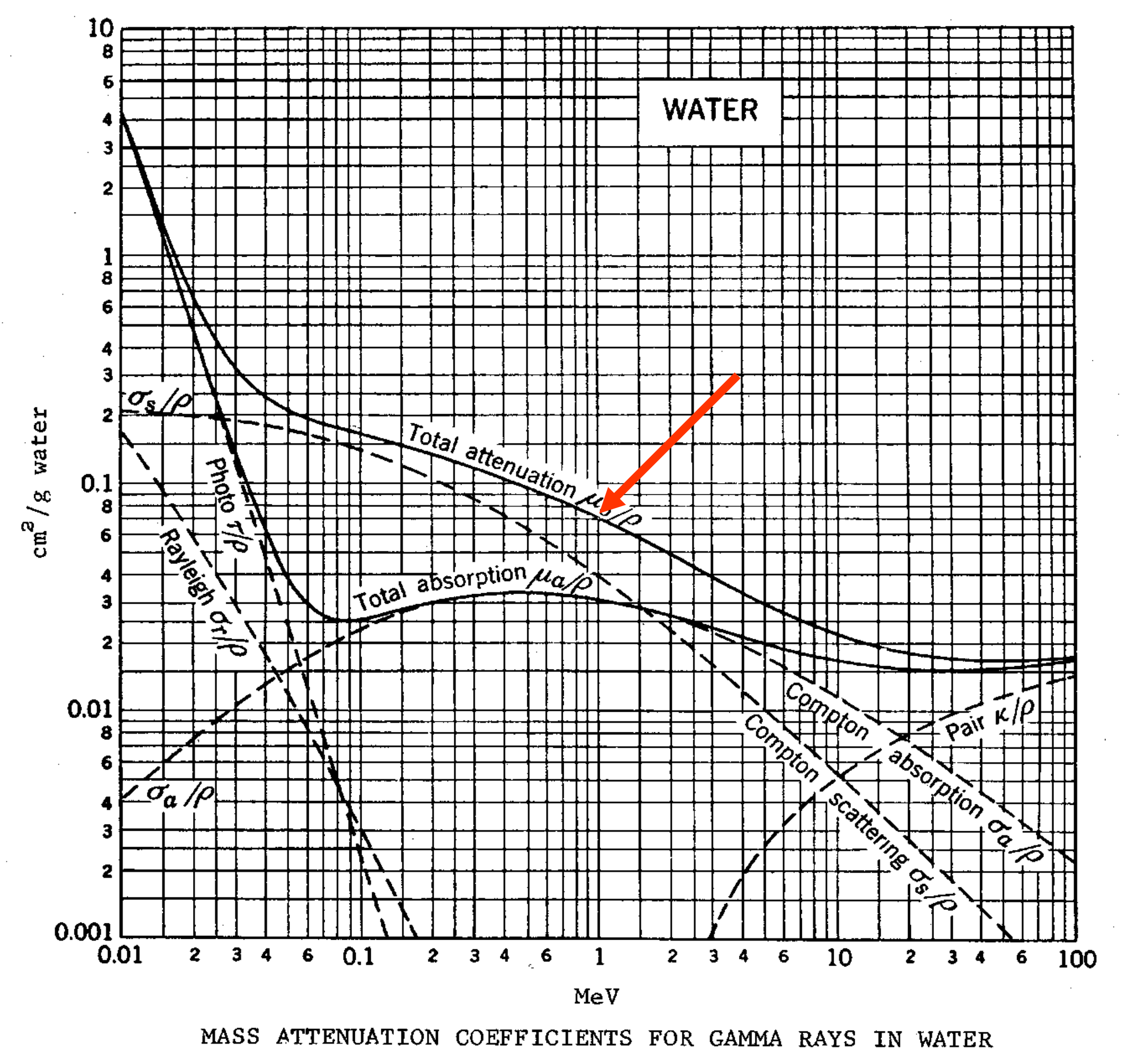
Shielding Calculations

- To perform shielding calculations, the linear attenuation coefficient, μ, for the shielding material must be determined
- In most tables you will find the mass attenuation coefficient which is μ/ρ and has dimensions of cm^2/g
- To go from cm^2/g to cm^{-1}

$$(\mu/\rho)(\rho) = \mu$$

- Example: What is the linear attenuation coefficient for 1 MeV photons in water?

Attenuation Coefficients vs. Energy



MASS ATTENUATION COEFFICIENTS FOR GAMMA RAYS IN WATER

(0.0708 cm²/g)

Calculating μ

- The mass attenuation coefficient, μ/ρ, for 1 MeV photons for water is 0.07 cm^2/g

- To get the linear attenuation coefficient, we multiply by the density of the absorber material

- The density of water is 1 g/cm^3

- $(\mu/\rho)(\rho) = (0.07\ cm^2/g)(1\ g/cm^3) = 0.07\ cm^{-1}$

Shielding Problem

What is the dose rate after shielding a source that emits only 1 MeV photons if the unshielded dose rate is 100 mSv/h and the source is shielded by 1 cm of lead?

Shielding Problem

First, you need the linear attenuation coefficient, μ

- The mass attenuation coefficient for 1 MeV photons in lead is 0.07 cm^2/g,
- The density of lead is 11.35 g/cm^3
- $\mu = (\mu/\rho)(\rho) = (0.07\ cm^2/g)(11.35\ g/cm^3) = 0.78\ cm^{-1}$

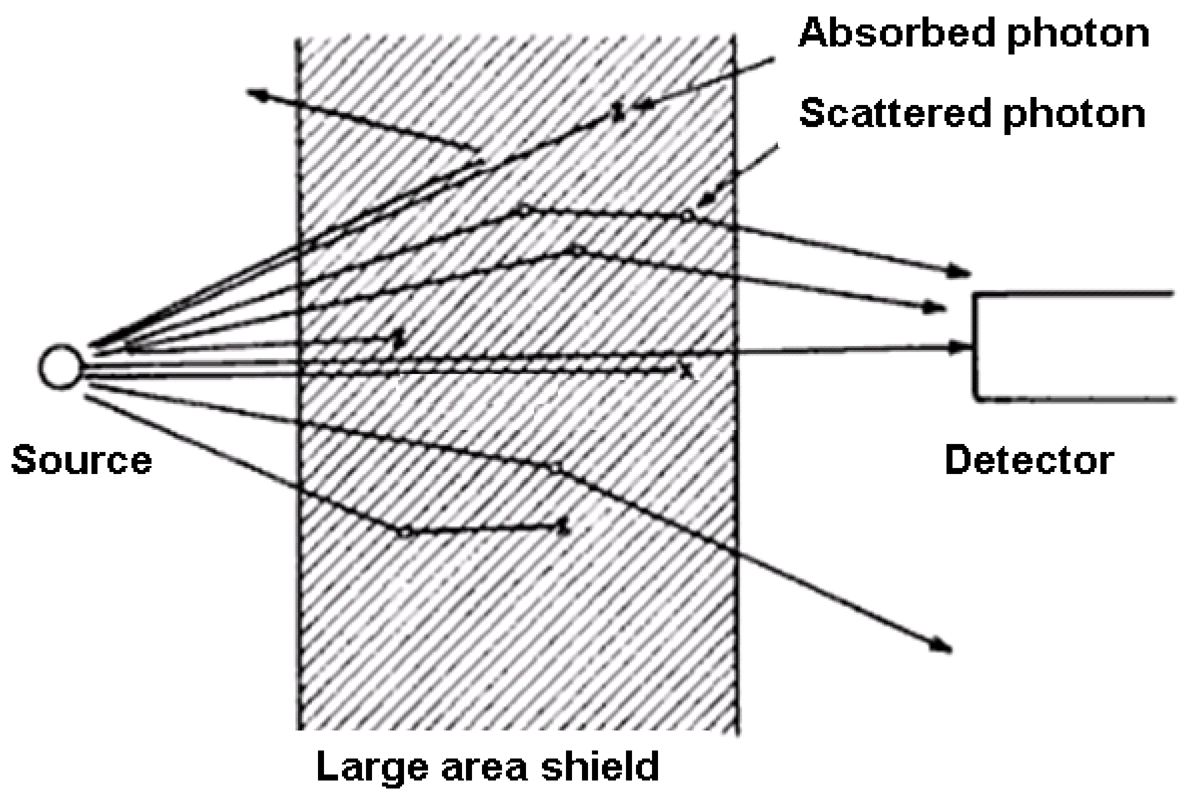
Shielding Problem (cont)

Now use the shielding equation to determine the shielded dose rate:

- $I = I_0 e^{(-\mu x)}$
- $I = (100\ \text{mSv/h})\ \exp[-(0.78\ \text{cm}^{-1})(1\ \text{cm})]$
- $I = (100\ \text{mSv/h})(0.46)$
- $I = 46\ \text{mSv/h}$

Attenuation & Buildup

The shielding equation does not fully account for photon interactions within shielding material when you have broad beams or very thick shields. To account for scattered photons and other secondary radiations, we use the buildup factor, B.



Buildup Factor

$$I = I_0 \, B \, e^{(-\mu x)}$$

- $B = [1° + 2° / 1°] \geq 1$

1° = unattenuated radiation
2° = scattered radiation

- The buildup factor is dependent on the type and amount of shielding material and the energy of the photon.
- Buildup factors have been calculated for many different types of shielding materials, and can be found in tables.

QUESTIONS?

END OF EXTERNAL DOSE CALCULATIONS

Review

- List the three methods of reducing your exposure/dose:
- Intensity decreases ___________ with the square of the distance

  from the source due only to the change in ___________.
- Using the inverse square law, calculate the dose rate at 4 feet away from a point source if the dose rate is originally 1000 R/hr at 2 feet.
- The specific gamma ray constant, Γ, provides the dose rate,

  typically in units of ______, for a given activity of a _______ source

  at a specified __________.

Review

- Given $\Gamma = 1.32$ R-m^2/hr-Ci, calculate the dose resulting from standing 10 meters away from a 10 Ci Co-60 point source for 2 hours.

Review

- Given an initial dose rate of 10 R/hr from a source of 10 MeV photons, calculate the shielded dose rate after applying a 3 meter shield of water. (Ignore buildup; μ/ρ = 0.02 cm^2/g, and ρ = 1 g/cm^3 for water)

Review

- The shielding equation does not account for _________. To adjust for this, we use the __________ factor, B, in the equation.

Review

- List the three methods of reducing your exposure/dose:
- Intensity decreases ___________ with the square of the distance

  from the source due only to the change in ___________.
- Using the inverse square law, calculate the dose rate at 4 feet away from a point source if the dose rate is originally 1000 R/hr at 2 feet.
- The specific gamma ray constant, Γ, provides the dose rate,

  typically in units of ______, for a given activity of a _______ source

  at a specified __________.

Review

- **Given Γ = 1.32 R-m^2/hr-Ci, calculate the dose resulting from standing 10 meters away from a 10 Ci Co-60 point source for 2 hours.**

Review

- Given an initial dose rate of 10 R/hr from a source of 10 MeV photons, calculate the shielded dose rate after applying a 3 meter shield of water. (Ignore buildup; μ/ρ = 0.02 cm^2/g, and ρ = 1 g/cm^3 for water)

Review

- The shielding equation does not account for ______________. To adjust for this, we use the __________ factor, B, in the equation.