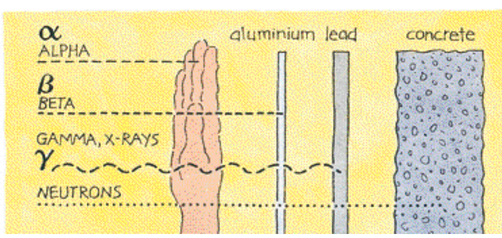
External Radiation Protection

Radiation and Shielding Material



Remember: Exposure

- The exposure rate from a point radiation source is

$$\dot{X} = \Gamma \frac{N\lambda}{r^2} = \Gamma \frac{A}{r^2}$$

- Thus, the total exposure during time t is

$$X = \Gamma \frac{A}{r^2} t$$

- Or, the equivalent gamma dose can be expressed as:

$$H(r) = \Gamma \frac{A}{r^2} t$$

External Radiation Protection

So…

$$\text{Dose} \propto \text{time}$$

$$\text{Dose} \propto \frac{1}{(\text{distance})^2}$$

- Minimise dose by
  - Minimising time
  - Maximising distance
- BUT sometimes you need to work for a period of time close to a radiation source!

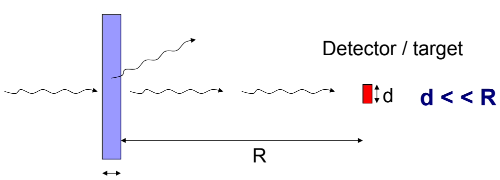
Gamma Ray Shielding

- Absorption through a thickness “x” of a shielding material is

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

- This equation is not always valid ….

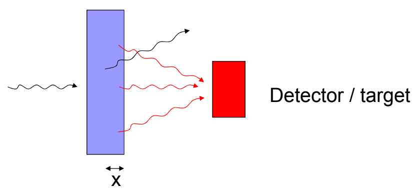
“Good” scattering geometry:



- In this scenario, sometimes called a narrow beam, only photons that transverse a thickness x of a material without interacting are detected:

$$\frac{I}{I_0} = e^{-\mu x} \qquad \mathbf{d << R}$$

Broad beam geometry or poor geometry



- In this geometry, <u>some</u> interactions actually scatter a photon toward the detector.
- So, the photons detected will be the photons that did not interact and some that did interact with the shielding material.

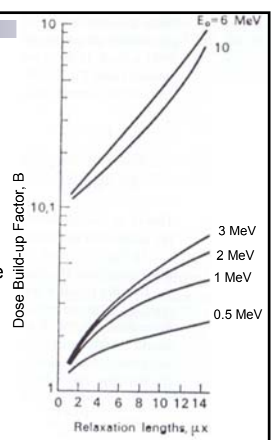
In the broad beam geometry

- The transmitted intensity of radiation through a shielding with thickness x is larger than the predicted intensity only by the exponential laws

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

- Introduce a BUILD-UP FACTOR ($B \geq 1$)!!!
- BUILD-UP FACTOR is the ratio of the intensity of the radiation, including both the primary and scattered radiation, at any point in a beam, to the intensity of the primary radiation only at that point.
- Build-up factor may apply either to radiation flux or to radiation dose.

- Since B accounts for the scattered photons into the detector by the shielding material, it will depend on:
  - Photon energy
  - Material
  - Shielding thickness and geometry
- The relaxation length, μx, is the thickness of a shielding material for which the photon intensity in a narrow beam is reduced to 1/e of its original intensity. Thus, one relaxation length is equal to 1/ μ, where μ is the mean free path.



Build up factor in lead for a plane mono-directional photon source (from Cember, pg.525)

Shielding calculations

$$I(x) = I_o \cdot B(\mu x) \cdot e^{-\mu x}$$

- Usually, we want to know what thickness (x) of a shielding material that reduces the dose to an acceptable level.

$$\boxed{I(x) < \text{limit}}$$

Given an unshielded intensity I_o

Example: What thickness of lead is required to reduce the exposure rate at 1m from a 10 Ci point source of ^{40}K to 1mR/h?

1. Calculate exposure at 1m with no Pb;
2. Calculate x needed to reduce this to 1mR/h based on $I=I_0e^{-\mu x}$;
3. Find B for this µx and re-calculate exposure based on $I=I_0Be^{-\mu x}$;

Probably not enough shielding …

4. Repeat steps 2. and 3. until finally the1 mR/h limit is reached;

1. Exposure at 1 m with no shielding

What thickness of lead is required to reduce exposure rate from 10 Ci ^{40}K to 1mR/h at 1m?

Energy of ^{40}K is E = 1.52 MeV.

Photon emission probability, f = 0.18

The mass attenuation coefficient of lead is 2.52 x 10^{-3} m^2/kg

The linear mass attenuation of lead is 0.581 cm^{-2} at 1.52 MeV

Remember we know how to calculate the exposure rate in air at a distance r from an unshielded gamma radiation source using:

$$\dot{X} = \frac{e}{4\pi r^2 \omega_{air}} E \cdot f \cdot \left(\frac{\mu_{en}}{\rho}\right)_{air} \cdot N\lambda$$

Thus,…

$$\dot{X} = \frac{e}{4\pi r^2 \omega_{air}} E \cdot f \cdot \left(\frac{\mu_{en}}{\rho}\right)_{air} \cdot N\lambda$$

$$\dot{X} = \frac{1.6\cdot10^{-19}C}{4\pi(1m)^2\cdot(34eV\cdot\frac{1.6\cdot10^{-19}J}{1eV})} 1.52MeV\cdot(1.6\cdot10^{-13}J/MeV)\cdot(0.18)\cdot$$

$$(2.52\cdot10^{-3})m^2/kg\cdot(10Ci\cdot\frac{3.7\cdot10^{10}Bq}{1Ci}) =$$

$$\dot{X} = 95.532\,\text{C/kg/s}$$

$$\boxed{\dot{X} = 1.333\ \text{R/h}}$$

2. Shielding calculation (without build up)

- I_0=1.333 R/h
- I(limit) = 10^{-3} R/h

$$\frac{I}{I_0} = e^{-\mu x} = \frac{10^{-3}R}{1.333R}$$

$$\mu x = 7.2$$

$$x = \frac{7.2}{0.581\,cm^{-1}} = 12.4cm$$

This lead thickness is an underestimation since it does not account for the build-up!

3. Shielding calculation (with build up)

E (MeV) / µx	7	10
1	3.02	3.74
1.52	3.39	4.37
2	3.68	4.84

B(µx=7.2)= 3.45

B= 3.45 for µx=7.2 and 1.52 MeV photons

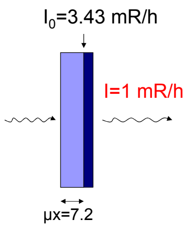
$$I = I_0 B\cdot e^{-\mu x} = 1.333\,\text{R/h}\cdot(3.45)\cdot e^{-7.2}$$

$$= 3.43\cdot10^{-3}\,\text{R/h}$$

It is too BIG!! We want I ≤ 1mR/h

We have to add some extra shielding (more than the µx of 7.2)!

How much more is needed?



2. Shielding calculation
(<u>without</u> build up)

$$e^{-\mu x} = \frac{10^{-3}}{3.43 \cdot 10^{-3}}$$

$$\mu x = 1.234 \; or \; x = 2.1 cm$$

$$\Rightarrow \mu x_{total} = 7.2 + 1.23 = 8.43$$

Alternatively you can add a HVL of lead
for 1.52 MeV! See example 10.4.

3. Shielding calculation (<u>with</u> build up)

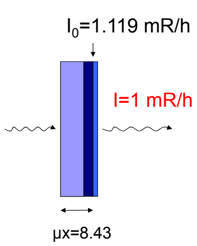
Again interpolating B(8.43) =3.87
(Pb, 1.5 MeV)

$$I = I_0 B \cdot e^{-\mu x} = 1.333\,\mathrm{R/h} \cdot (3.87) \cdot e^{-8.43}$$

$$= 1.119 \cdot 10^{-3}\,\mathrm{R/h}$$

It is still a bit too BIG!! We want I ≤ 1mR/h!

Going through the same loop again …. Getting tired?



2. Shielding calculation
(<u>without</u> build up)

$$e^{-\mu x} = \frac{10^{-3}}{1.119 \cdot 10^{-3}}$$

$$\Rightarrow \mu x = 0.115$$

$$\Rightarrow \mu x_{total} = 8.43 + 0.115 = 8.54$$

To be on a safe side and over estimate the
thickness of shield, we can round up to **8.6**.

3. Shielding calculation (with build up)

From the interpolation of B(8.6)=3.93

$$I = I_0 B \cdot e^{-\mu x} = 1.333\ \text{R/h} \cdot (3.93) \cdot e^{-8.6}$$
$$= 0.964 \cdot 10^{-3}\ \text{R/h}$$

Finally!!! This is less than 1mR/h!

So **µx = 8.6** is sufficient, now let's find the thickness of the Pb shield:

$$x = \frac{8.6}{\mu} = \frac{8.6}{58.1 m^{-1}} = 0.15 m$$

15 cm of Pb is needed for the shielding!

More complicate example …

See textbook, pg. 527, example 10.5.

What to do if a point source emits more than one photon energy per disintegration?