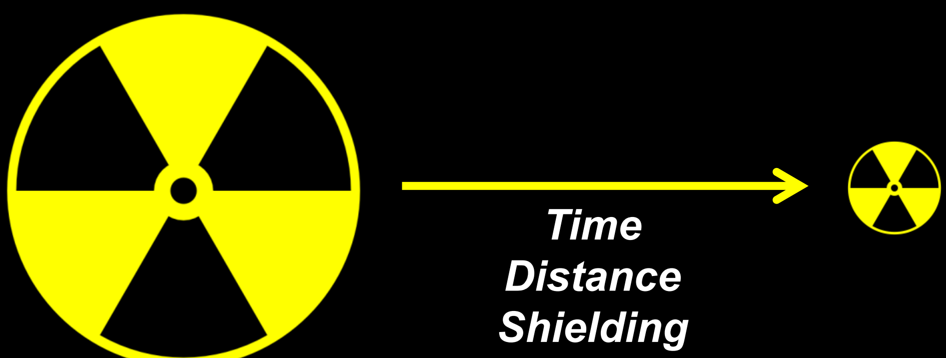
Shielding and Range

Radiation Protection



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22.S902 – DIY Geiger Counters

Prof. Michael Short

Question:

What is Vault Boy doing?

Motivation

- Understand how time and distance decrease exposure rate to radiation
- Derive rules of logarithmic attenuation
- Characterize different materials in terms of their shielding efficacy
- Design ideal, economical radiation shielding

Dose and Time

- I hope this one is self-explanatory!

Dose and Distance

- Assuming a point source of radiation:

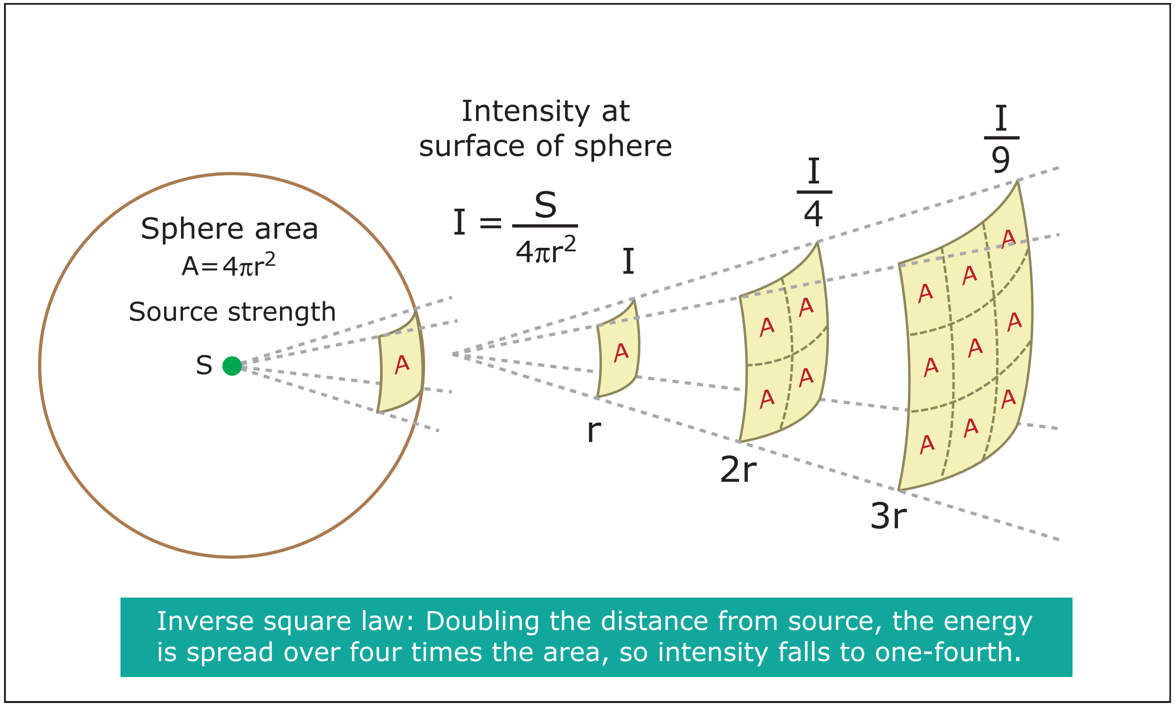

Image by MIT OpenCourseWare. After Hyperphysics.

- The *solid angle* subtended by the object of interest determines dose rate

Dose and Distance

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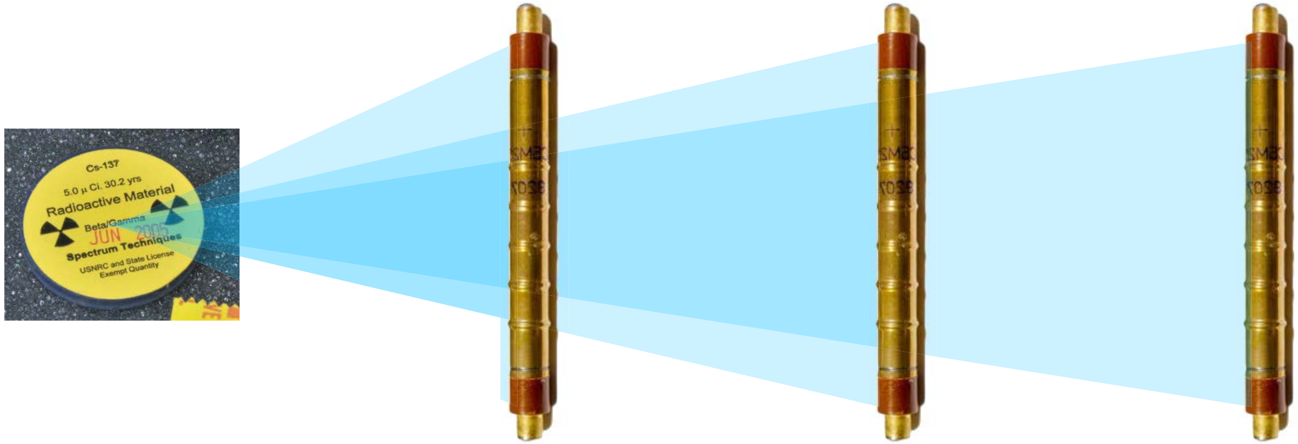


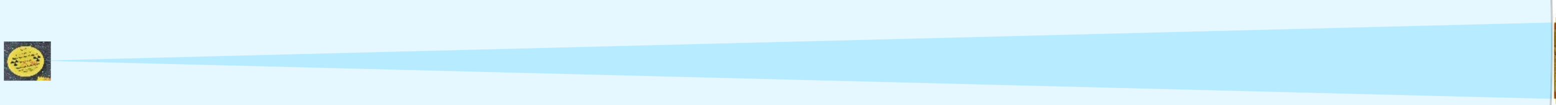
Label photo courtesy of Brook Clarke. Used with permission.
Geiger tube photo courtesy of Jeff Keyzer on Flickr.

- What is the "object of interest?"
- How do you determine if a source is a "point source?"

Dose and Distance

www.prc68.com/I/Rad_Det.shtml

- The *solid angle* subtended by the object of interest determines dose rate



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Geiger tube photo courtesy of Jeff Keyzer on Flickr.

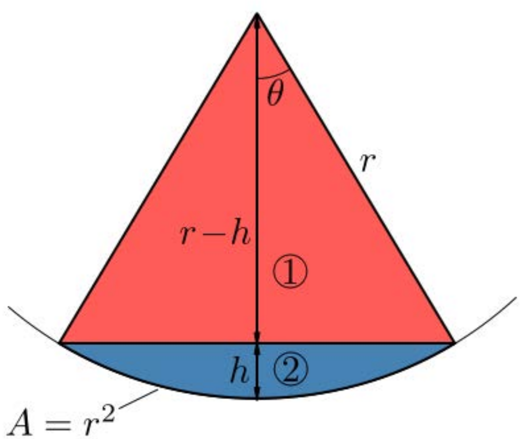
- If your object's (or your) *solid angle* (projected area) on a sphere of radius *r* is small, and the source is small in comparison, its area approximates the area projected onto the sphere

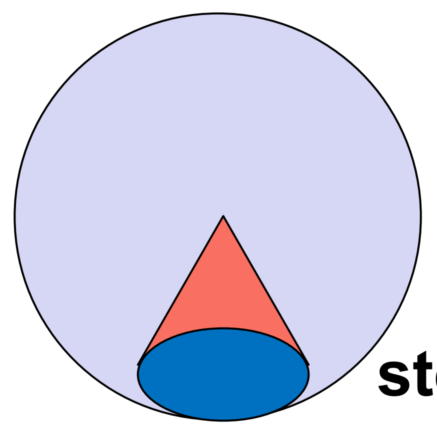
Dose and Distance

http://en.wikipedia.org/wiki/Steradian

- The *solid angle* subtended by the object of interest determines dose rate

Label photo courtesy of Brook Clarke. Used with permission.





One steradian

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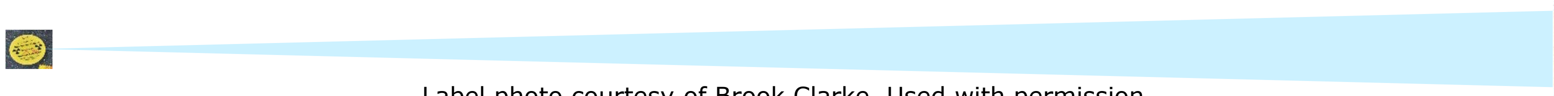
- If your object's (or your) distance from the sphere is large, and its area is small, then $r \gg h$, and you can approximate object area as sphere area

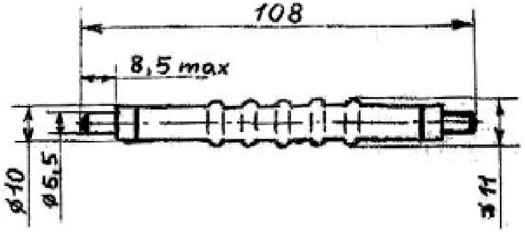
Dose and Distance Calculation



- This source has 5μCi of activity, and our SBM-20 tube is 1m away:

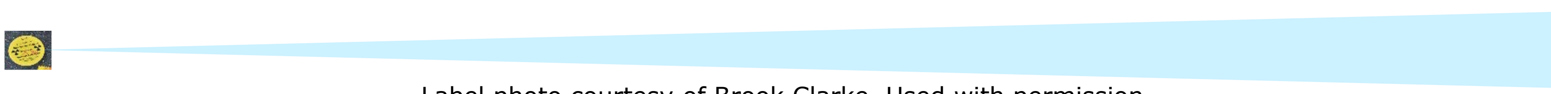
$$I = \frac{5\ \mu Ci}{4\pi\ Sr} = \left(3.7 \cdot 10^{10} \frac{Bq}{Ci}\right)\left(\frac{5 \cdot 10^{-6}\ Ci}{4\pi\ Sr}\right) = 1.47 \cdot 10^{4} \frac{\gamma - rays}{Sr - s}$$

- Ignoring shielding of air, the tube wall, etc.:



$$A \approx 0.01m \times 0.108m \approx 0.00108m^2$$

Dose and Distance Calculation



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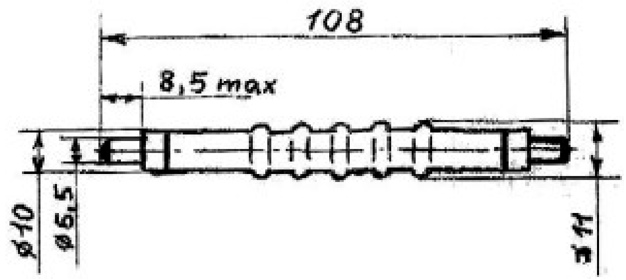

$$A \approx 0.01m \times 0.108m \approx 0.00108m^2$$

- One Steradian (Sr) on a 1m radius sphere is 1m^2:

$$\dot{\Phi} = \left(1.47 \cdot 10^4 \frac{\gamma - rays}{Sr - s}\right)\left(\frac{1\,Sr}{m^2}\right)(0.00108m^2) = 15.88\frac{\gamma - rays}{s}$$

Repeat the Question:

What is Vault Boy doing?

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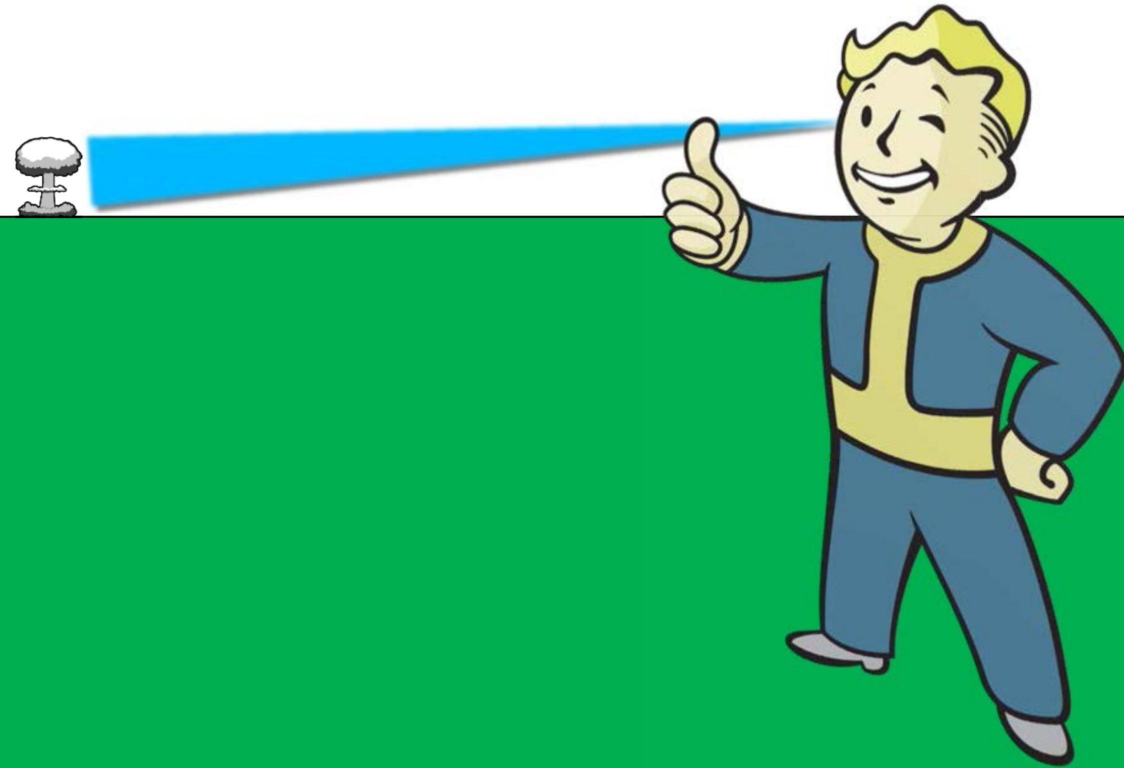


What is Vault Boy doing?

He is estimating a solid angle!

What About Shielding?

Turner, p. 188 (2007)

Say *N* gamma rays reach a distance *x* without interaction. Define a constant of proportionality relating the number that interact in a distance *dx*:

$$dN = -\mu N dx$$

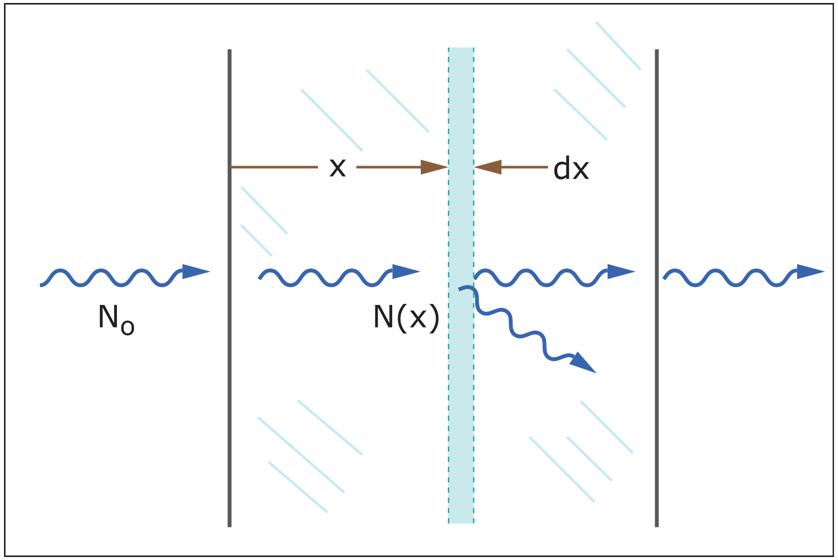


Image by MIT OpenCourseWare. After Turner (2007).

This constant (μ) is the *linear attenuation coefficient*. Solve the differential equation to get:

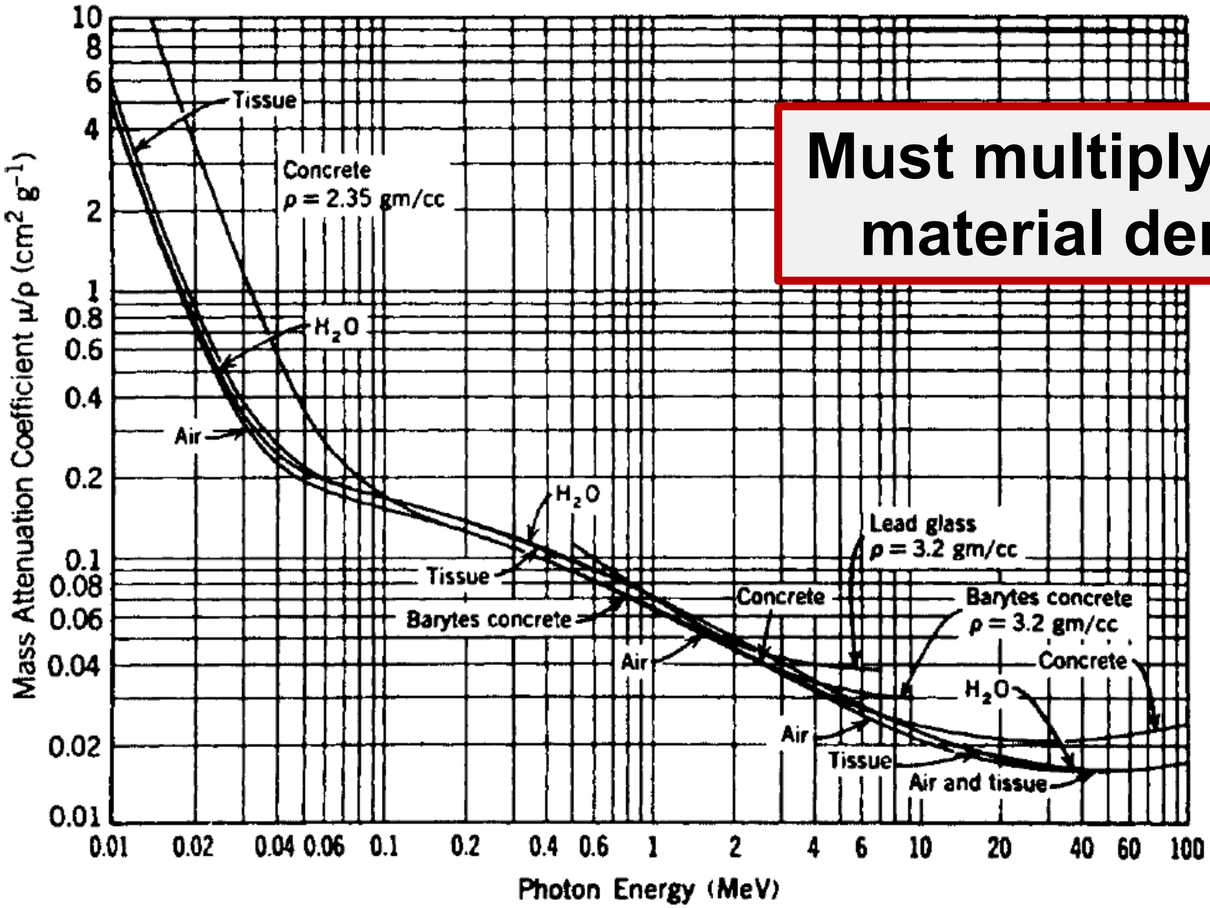
$$N = N_0 \ @ \ x = 0 \Rightarrow c = \ln N_0$$

$$\frac{dN}{N} = -\mu dx \Rightarrow \ln N = -\mu x + c \qquad N(x) = N_0 e^{-\mu x}$$

Attenuation Coefficients

Turner, p. 190 (2007)

Note μ has units of cm^{-1}, yet tables give values in units of $\frac{cm^2}{g}$



Must multiply by the material density!

Source: Morgan, K. Z., and J. E. Turner, eds. *Principles of Radiation Protection*. Wiley, 1967.

Additive Attenuation Coefficients

How do you deal with multicomponent materials?

Composites, alloys, foams, concrete…

$$N(x) = N_0 e^{-\left(\frac{\mu}{\rho}\right)\rho x} \quad \Rightarrow \quad N(x) = N_0 e^{-\sum_{i=1}^{n}\left[\left(\frac{\mu}{\rho}\right)_i \rho_i\right]x}$$

Each component *i* combines additively in the exponential

Now, where to find values of $\left(\frac{\mu}{\rho}\right)$?

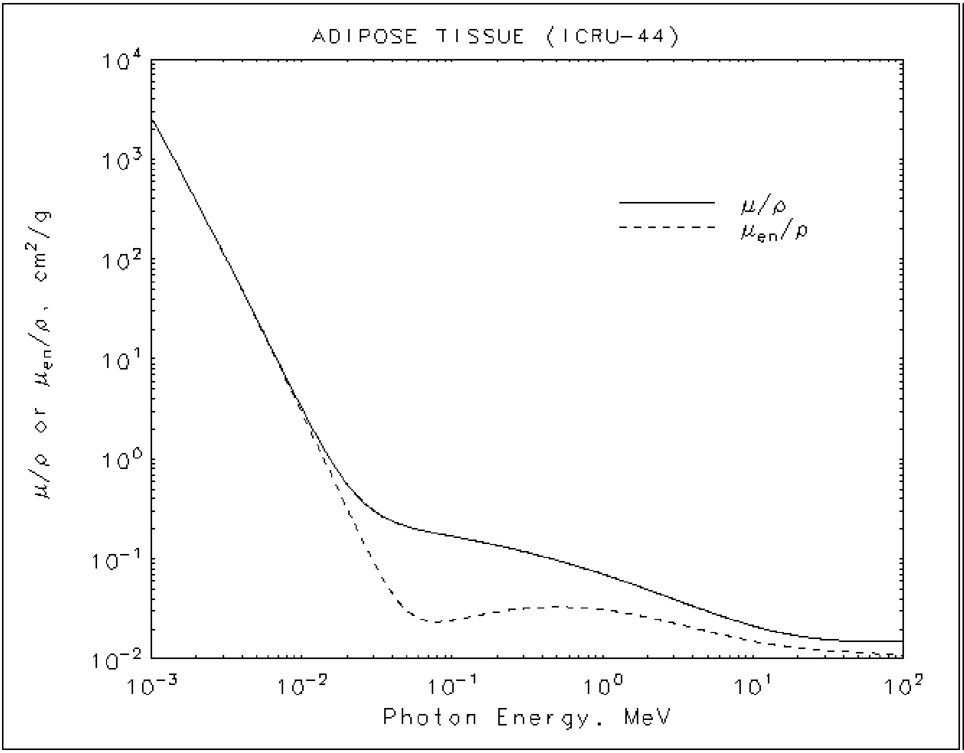
http://www.nist.gov/pml/data/xraycoef/index.cfm

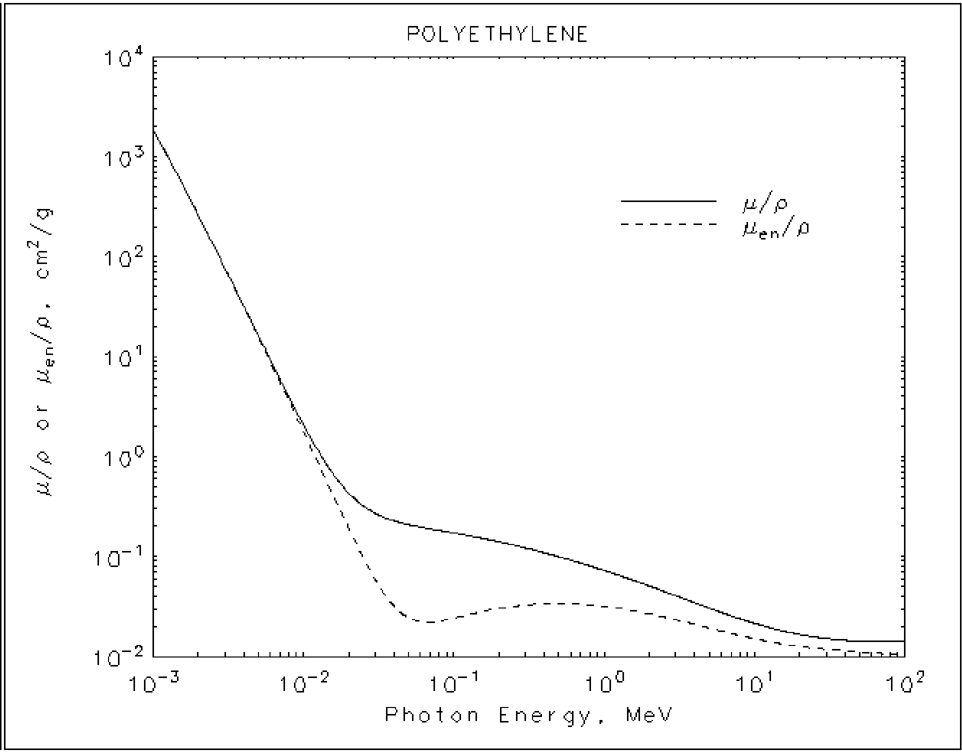
NIST (National Institute of Standards and Technology) maintains an active database!

Example: Cheap Shielding

What makes better shielding, plastic or bacon grease?

http://www.nist.gov/pml/data/xraycoef/index.cfm





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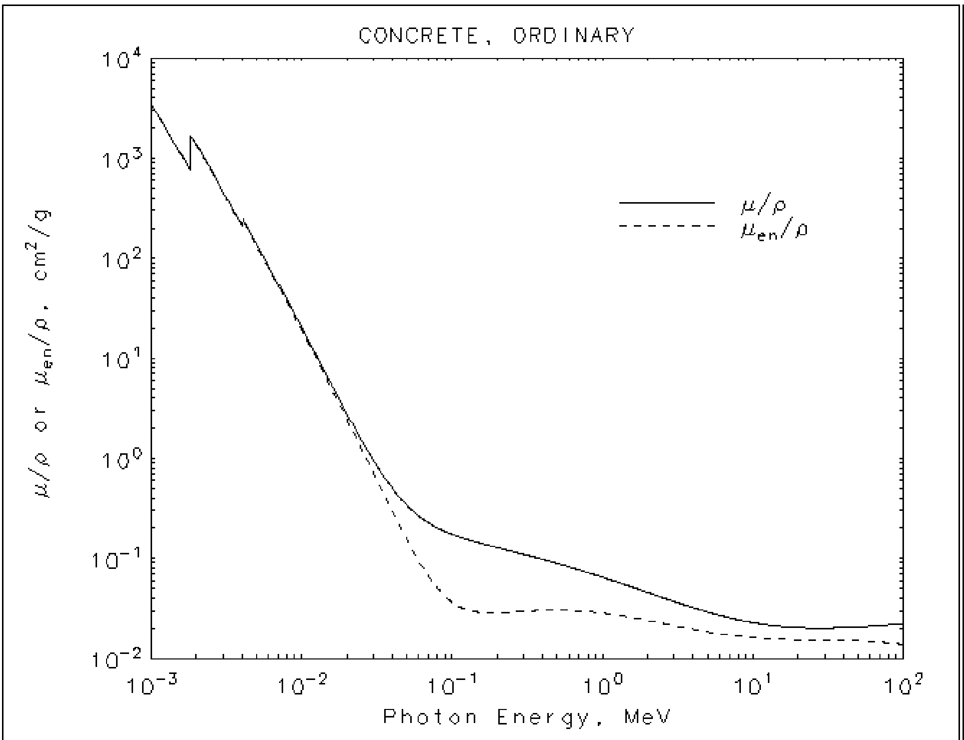
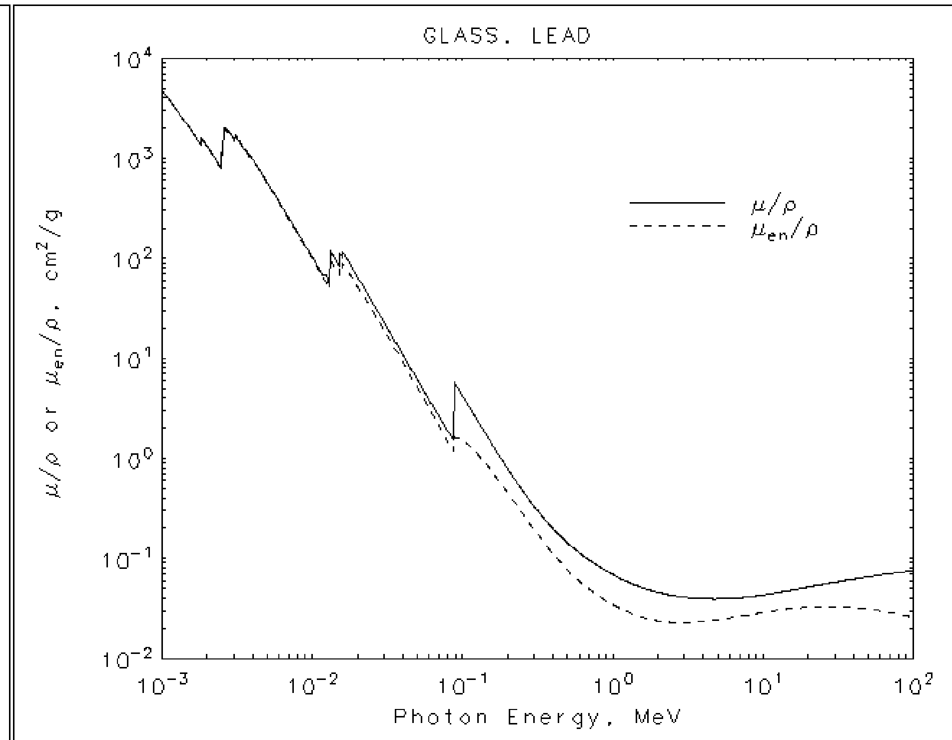
About the same! Why???

Example: Cheap Shielding

What makes better shielding, concrete or leaded glass?

http://www.nist.gov/pml/data/xraycoef/index.cfm





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It depends on the energy!

What About Energy Degradation?

Turner, p. 188 (2007)

You can ignore this for "good geometries" and gammas

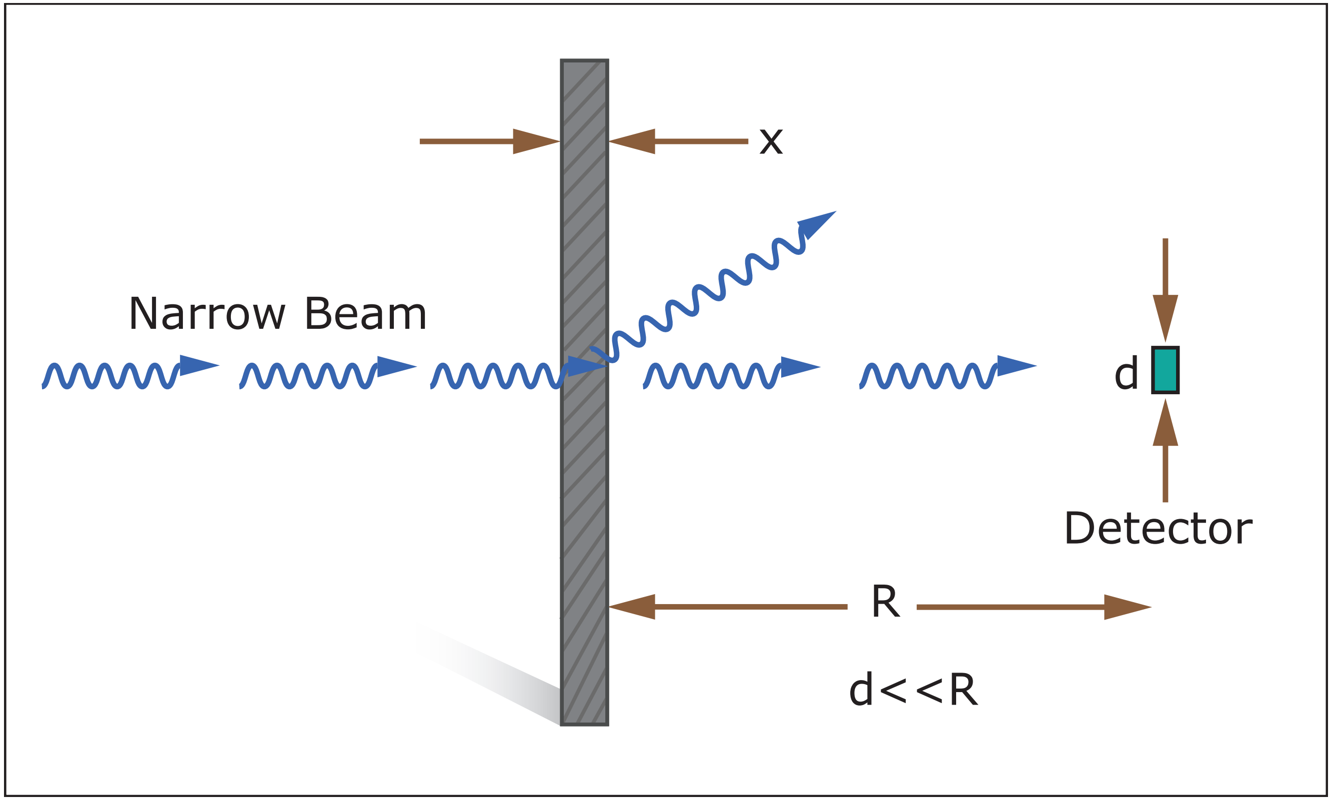

Image by MIT OpenCourseWare.

Assume that all gammas which interact leave the beam

Thinking About the Lab

How will you determine how many gammas interact with your Geiger counter?

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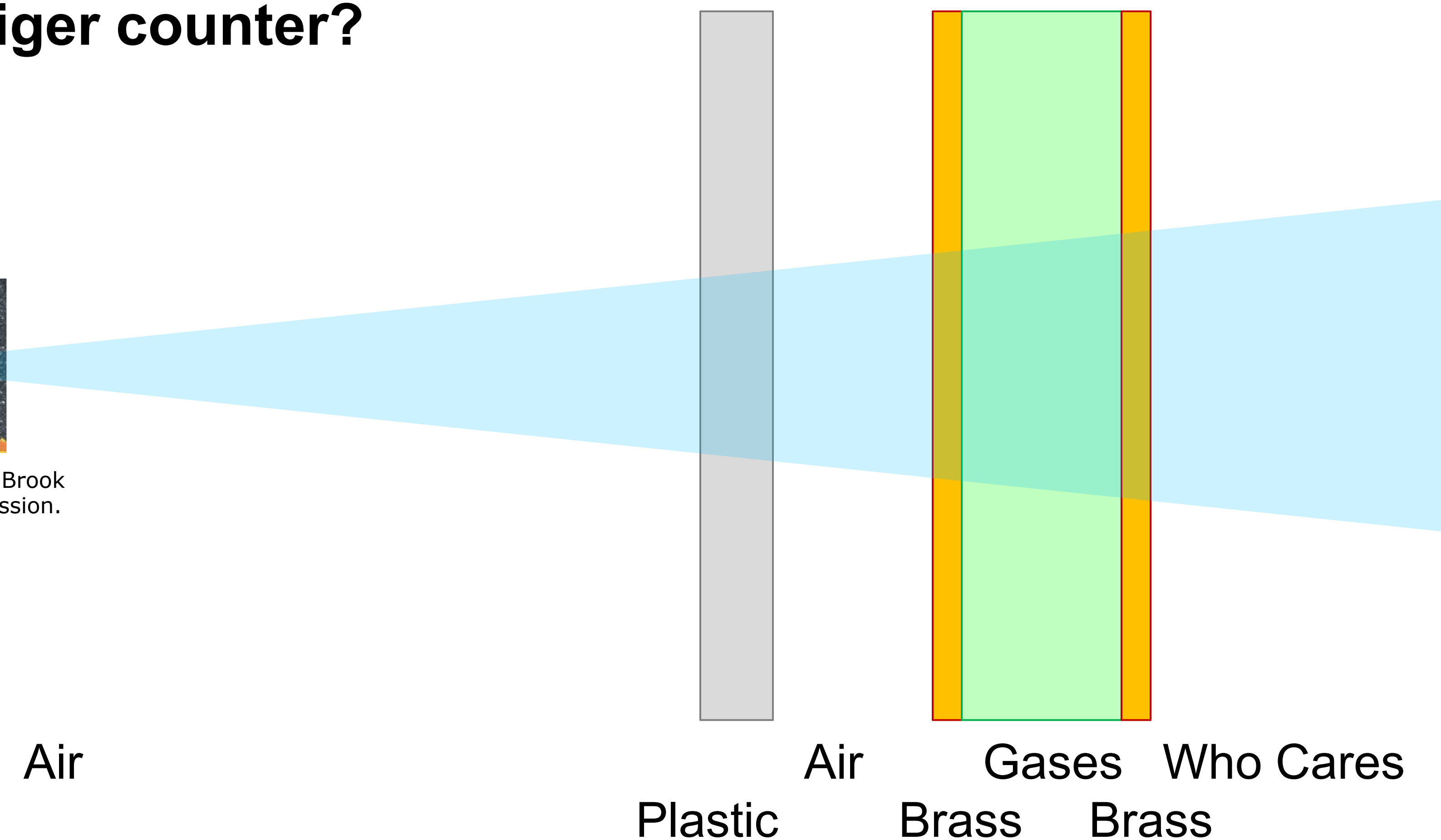

Questions?

22.S902 Do-It-Yourself (DIY) Geiger Counters
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