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Title: Effects of Shielding on Gamma Rays

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Effects of Shielding on Gamma Rays

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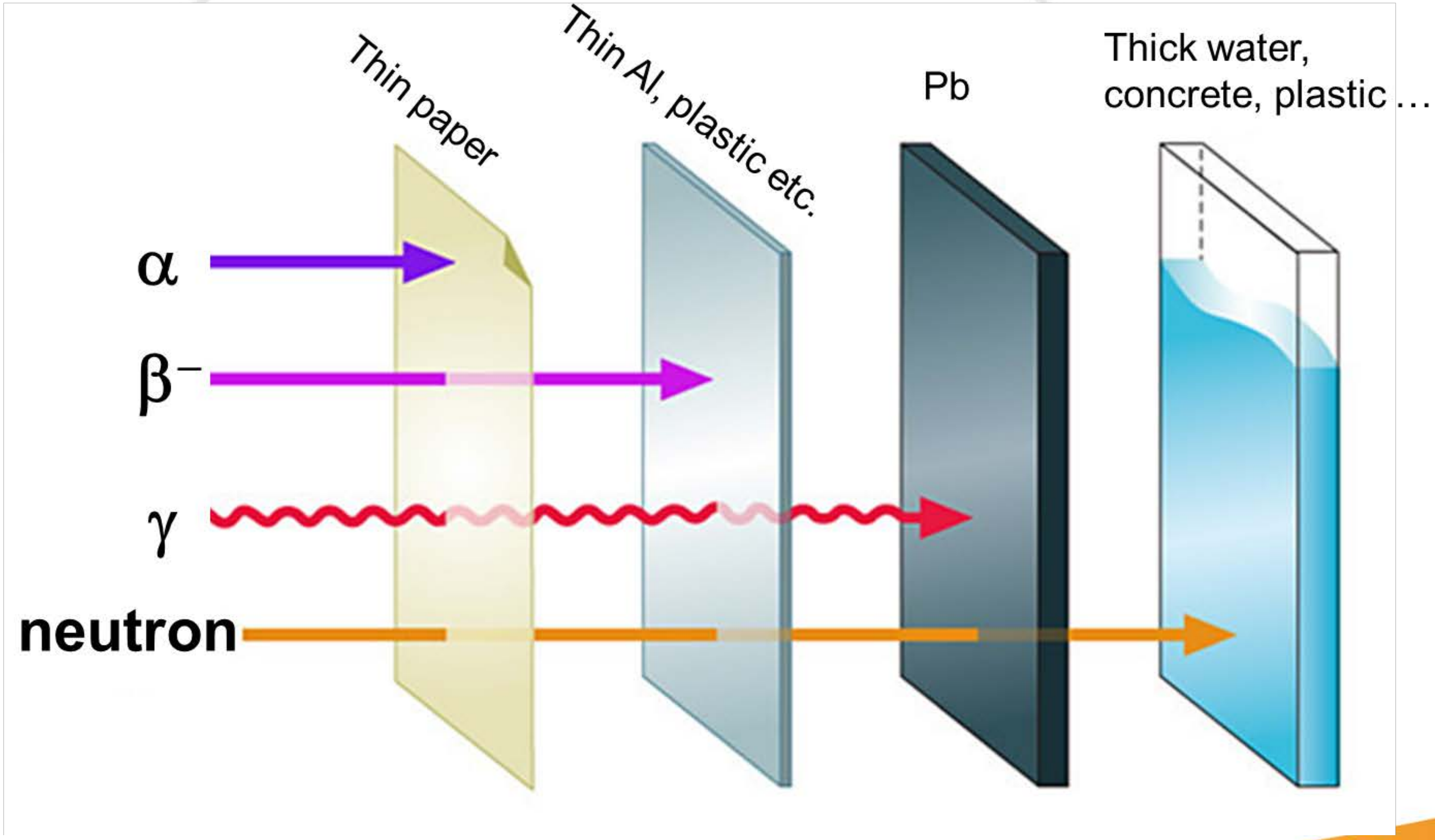
Introduction

- The interaction of gamma rays with matter results in an effect we call attenuation (i.e. 'shielding')
- Attenuation can dramatically alter the appearance of a spectrum
- Attenuating materials may actually create features in a spectrum via x-ray fluorescence

Radiation Types and Shielding

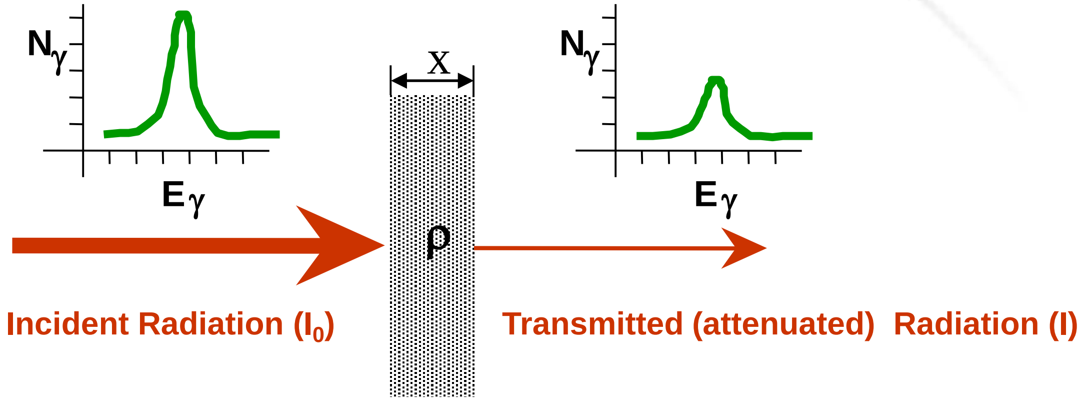
Los Alamos
NATIONAL LABORATORY
EST. 1943



Attenuation / Transmission

- $T = \exp(-\mu / \rho * \rho * x)$
- T is transmission of uncollided photons (i.e. the gamma rays still have their original full energy)
- μ / ρ is mass attenuation coefficient and varies with Z and energy
- ρ is density of shielding
- x is thickness in cm
- Applies to 'loss' of full-energy gamma-rays only

Attenuation / Transmission



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

μ = linear attenuation coefficient (cm^{-1})
x = thickness (cm)

Transmission: $$T = I/I_0 = e^{-\mu x}$$

Mass vs Linear Attenuation Coefficients

- Linear attenuation coefficients depend on density
  - Ice, water, water vapor all have different linear attenuation coefficients
  - Units are cm^{-1}
  - Some texts use μ some texts use μ_l

- Mass attenuation coefficients are independent of density

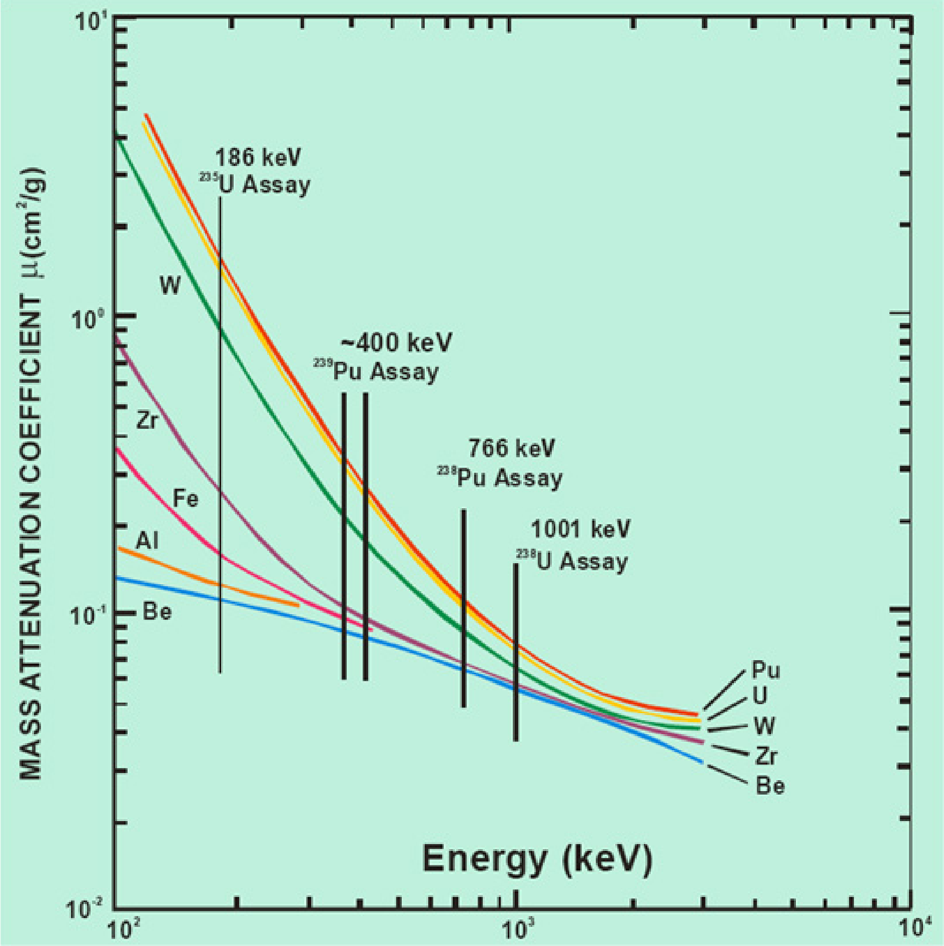
$$\mu_{mass} = \frac{\mu_{linear}}{\rho}$$

  - Ice, water, water vapor all have same linear attenuation coefficients
  - Units are cm^2/g

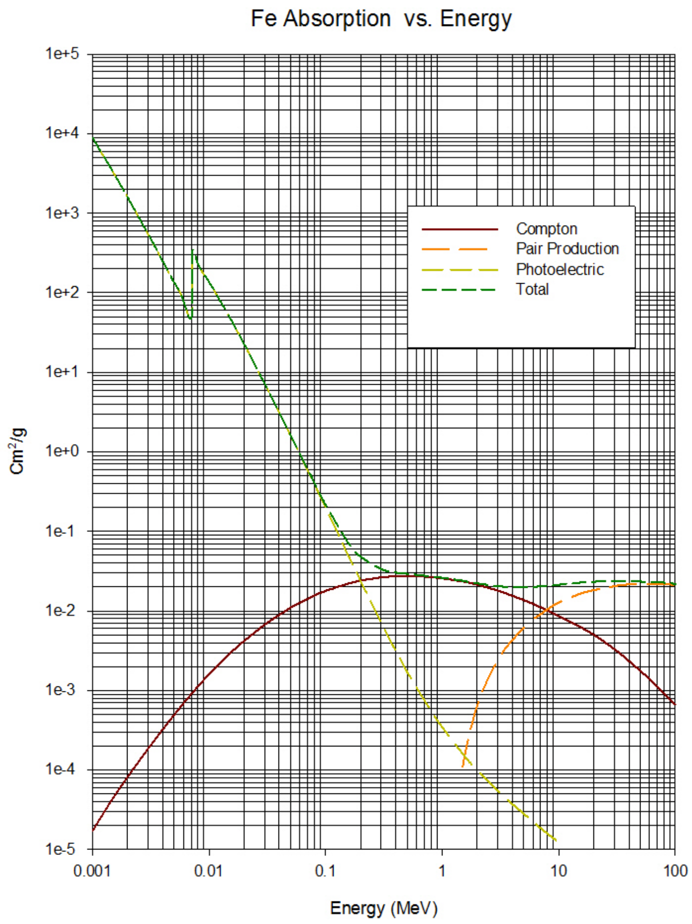
Attenuation and Atomic Number

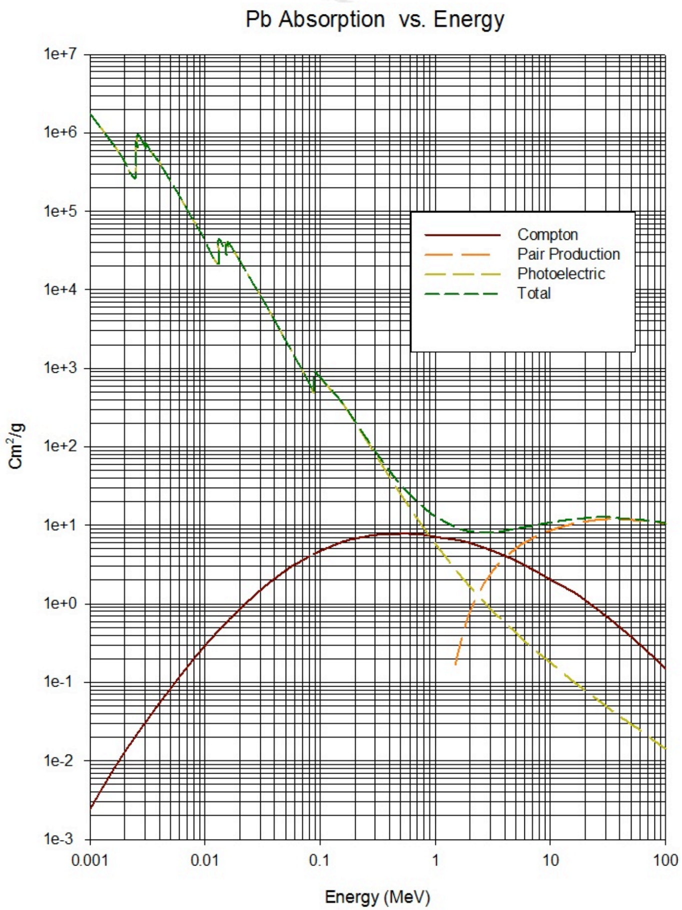
At incident photon energies below ~ 1 MeV, the Z of the shielding material matters because this is where the photoelectric effect dominates.

At around ~ 2 MeV the Compton Effect dominates and the probability for interaction becomes independent of Z.



Mass Attenuation Curve Examples

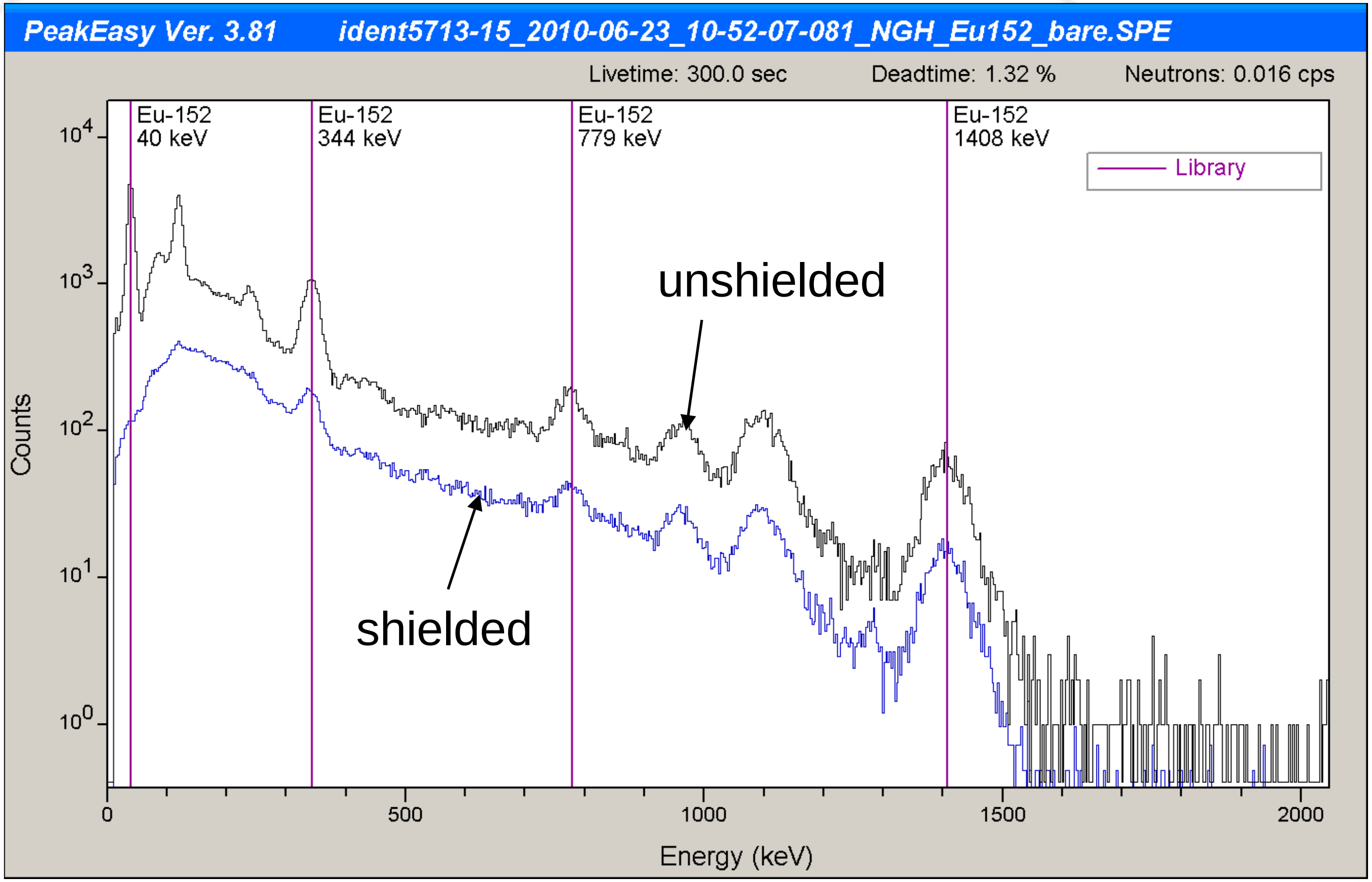




Effect of Shielding on Peaks

- Reducing peak amplitude (area)
  - Differential Attenuation:
    - low-energy peaks affected more than high-energy peaks
    - Peaks with similar energies are similarly affected
  - more pronounced with higher Z shielding materials
- Creates continuum ‘step’
  - caused by multiple and small-angle scattering
  - proportional to local peak amplitudes (areas)
- Fluorescent X-rays are sometimes visible
  - E.g. Pb x-rays are produced by Pb shielding

0.75” Fe Shielding Eu-152



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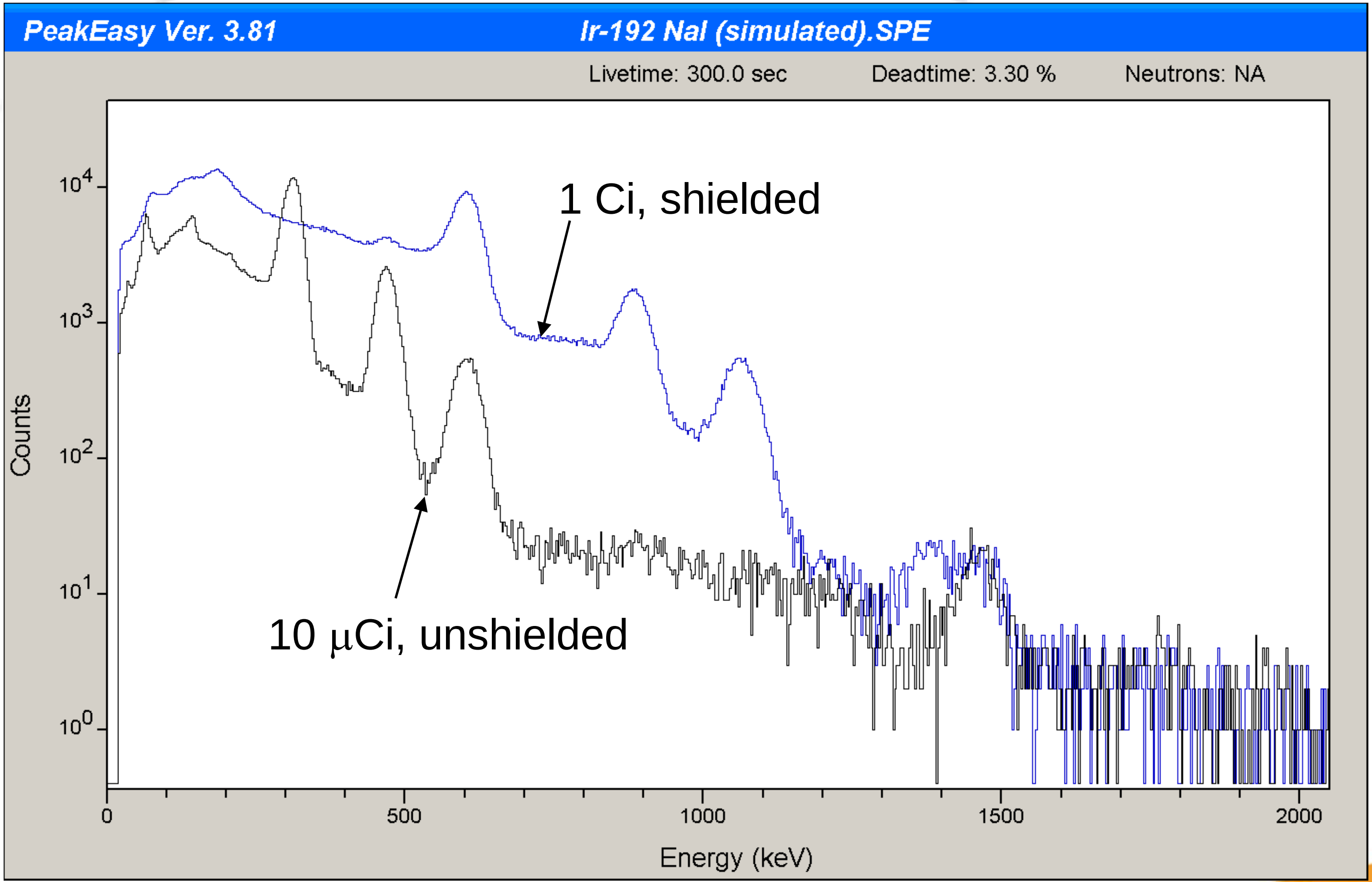
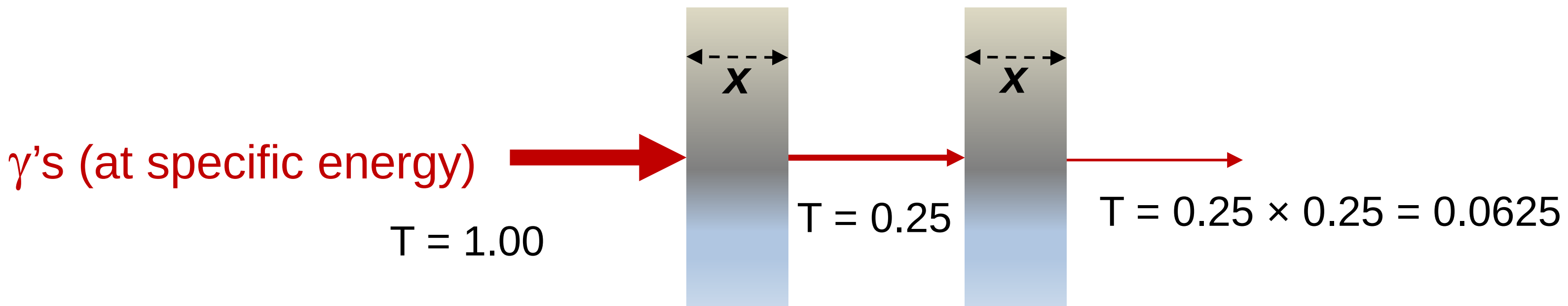
6.5 cm Pb Shielding Ir-192

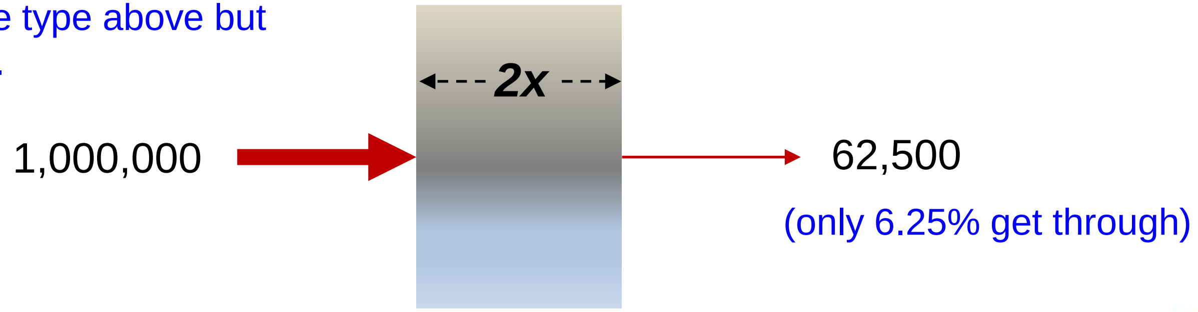


Transmission is Multiplicative

Shielding of the same type and thickness , ***x***

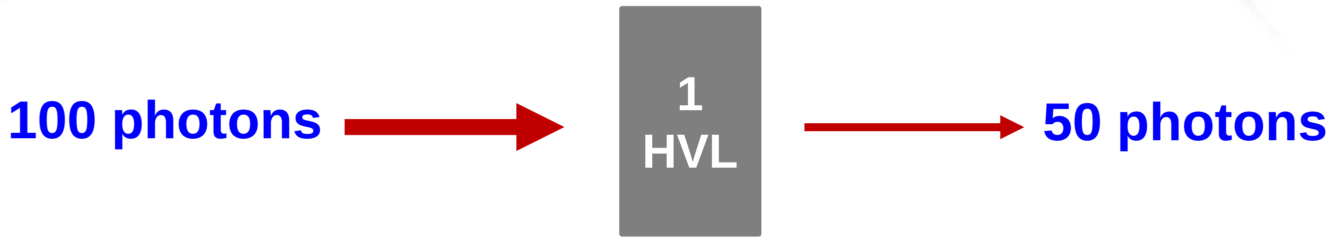


Let's say 1,000,000 gammas at same energy as above are incident upon an attenuator of the same type above but of <u>twice</u> the thickness.



Half-Value Layers

A half-value layer (HVL) is the amount of material required to reduce the radiation intensity at a specific energy by ½.



Energy [keV]	H_2O [cm]	Fe [cm]	Pb [cm]	U [cm]
60	3.4	0.070	0.012	0.005
186	5.0	0.6	0.05	0.025
414	6.6	1.0	0.3	0.14
1001	9.8	1.5	0.9	0.5
2614	16.2	2.3	1.4	0.8

Infinite Thickness

What if we use 10 half-value layers?

Transmission, T, through
one HVL is 1/2

$$T^{10} = \left(\frac{1}{2}\right)^{10} \cong \frac{1}{1000}$$

Only one photon out of a thousand gets through 10 HVLs.
For all practical purposes, we can consider these photons COMPLETELY SHIELDED.

How much shielding to kill 186 keV?

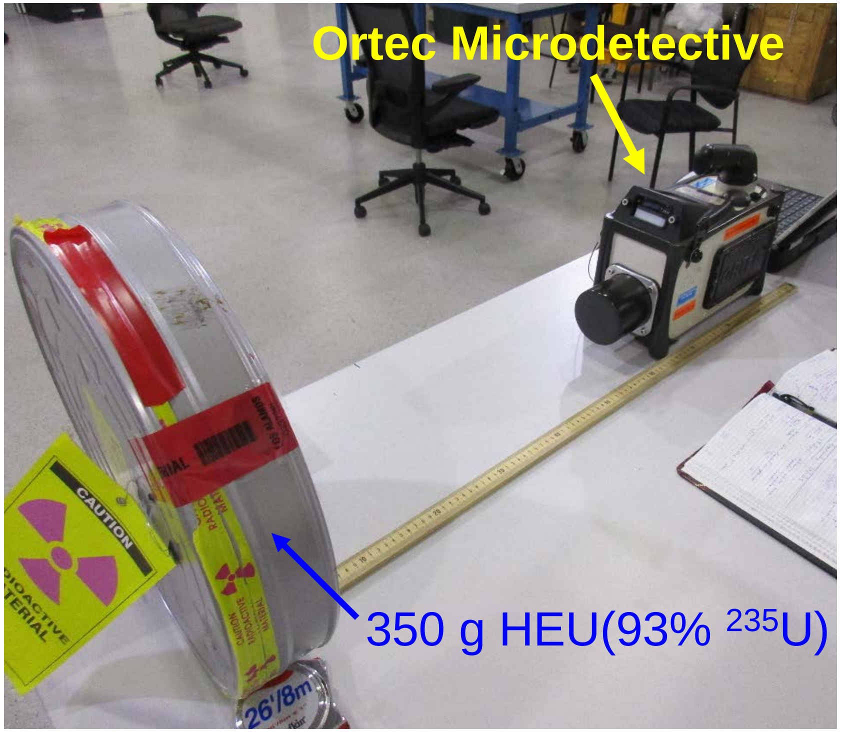
As an example let's look at what it takes to totally shield the main, direct gamma-ray signature of ^{235}U, that is the peak at 186 keV.

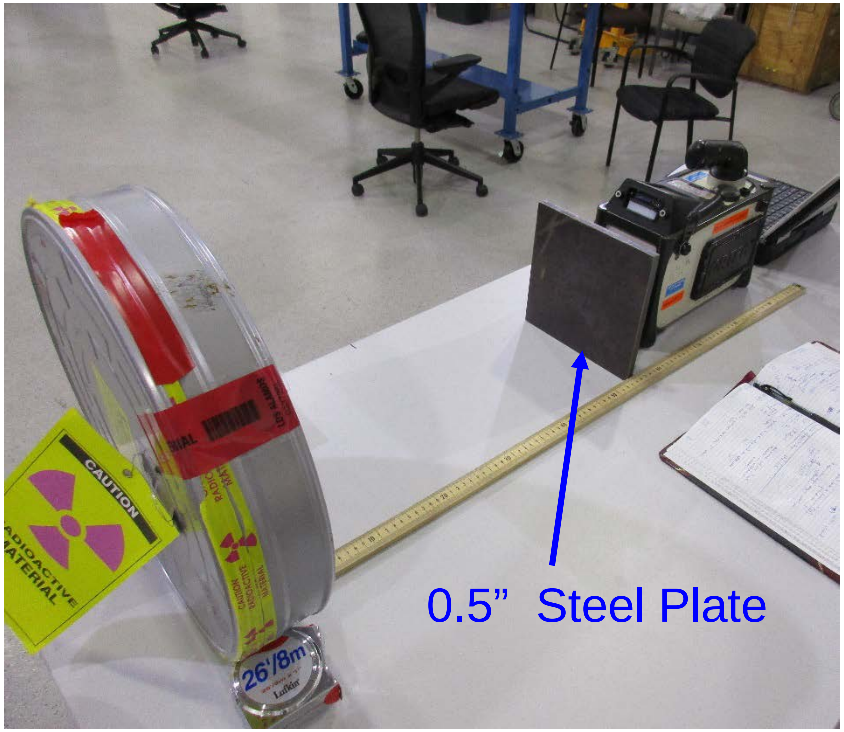
- To kill the main ^{235}U signal you need:
  - Water: ~ 50 cm
  - Fe: ~ 6 cm
  - Pb: ~ 0.5 cm
  - U: ~ 0.25 cm

If you surround HEU with more than 2.5 mm of DU, the only direct ^{235}U gamma rays that you will see will come from the DU itself.

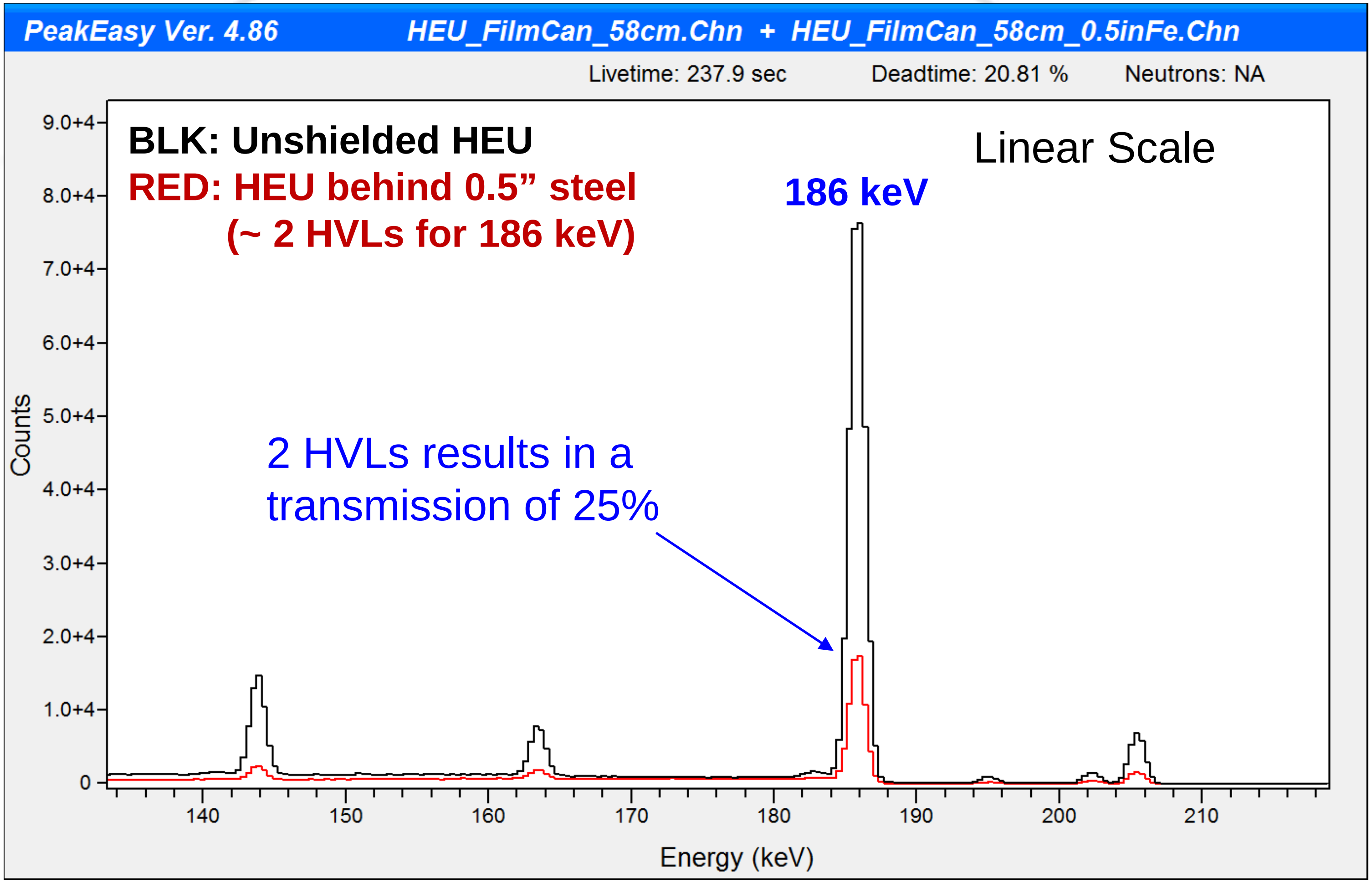
Bare vs. Shielded HEU

Measurements of 9x9" HEU (93% ^{235}U) foils (~350 g total) in a film can were conducted in both bare and shielded configurations.





HEU Shielded by 0.5" of Steel



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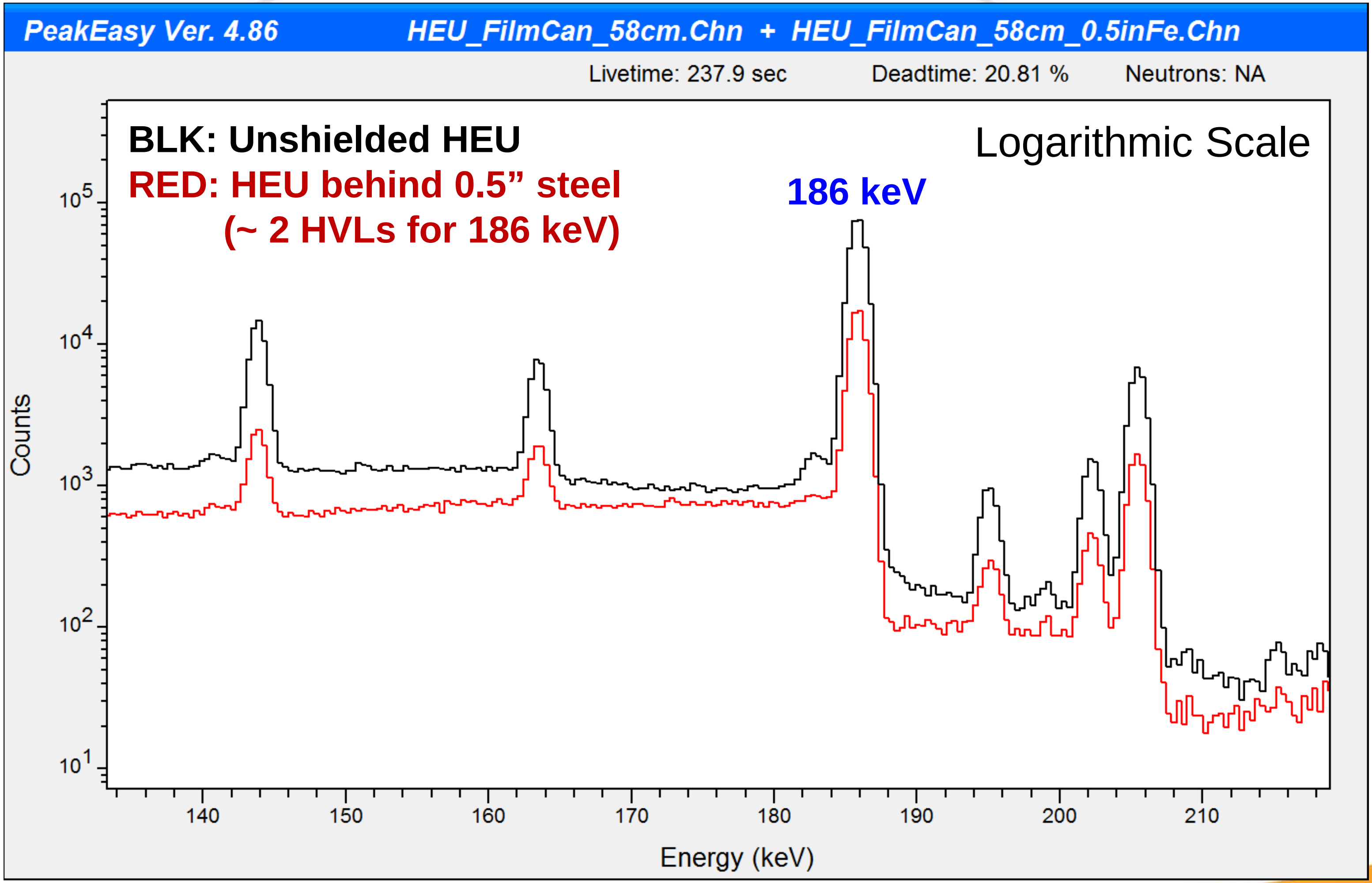

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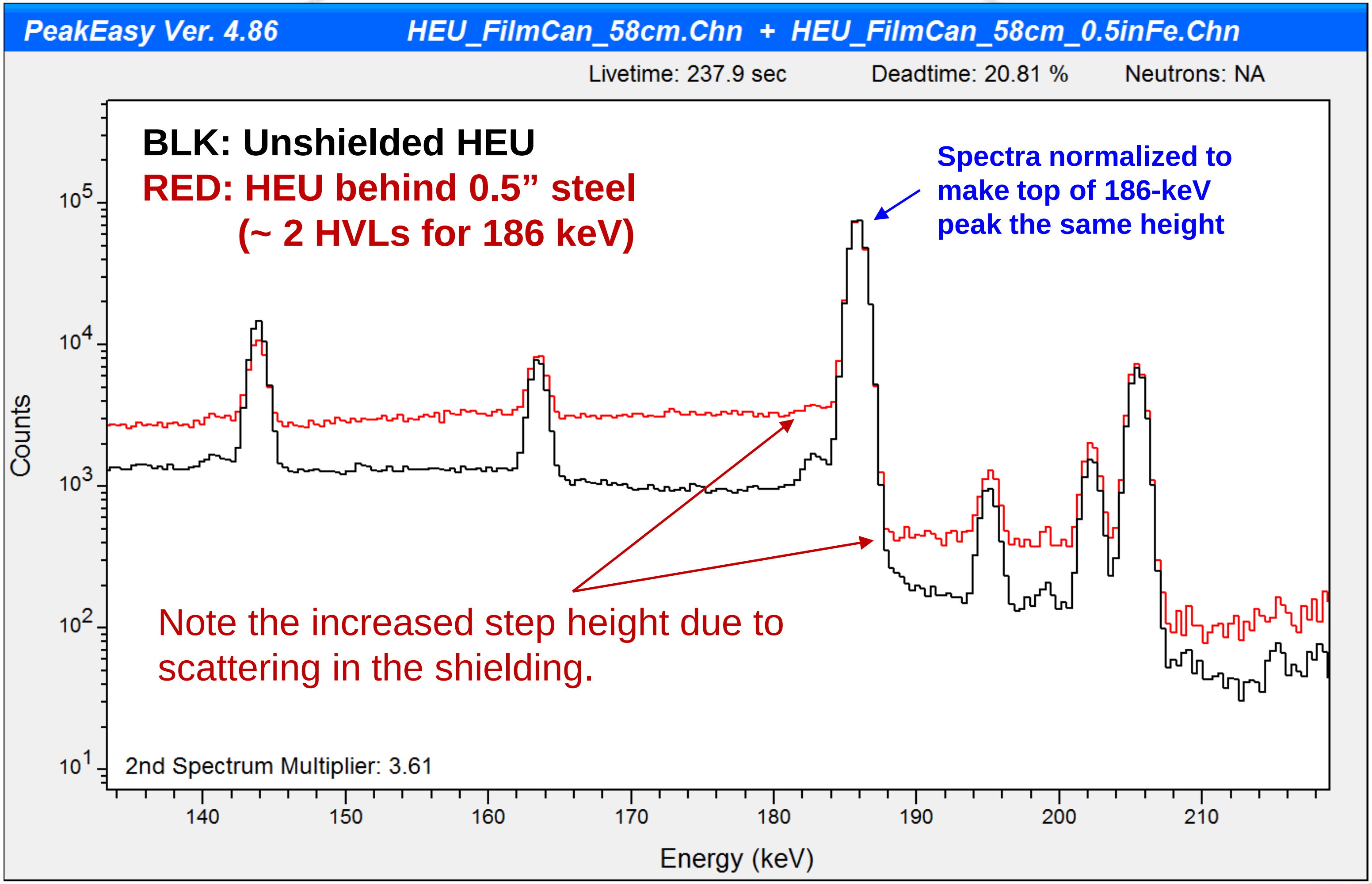
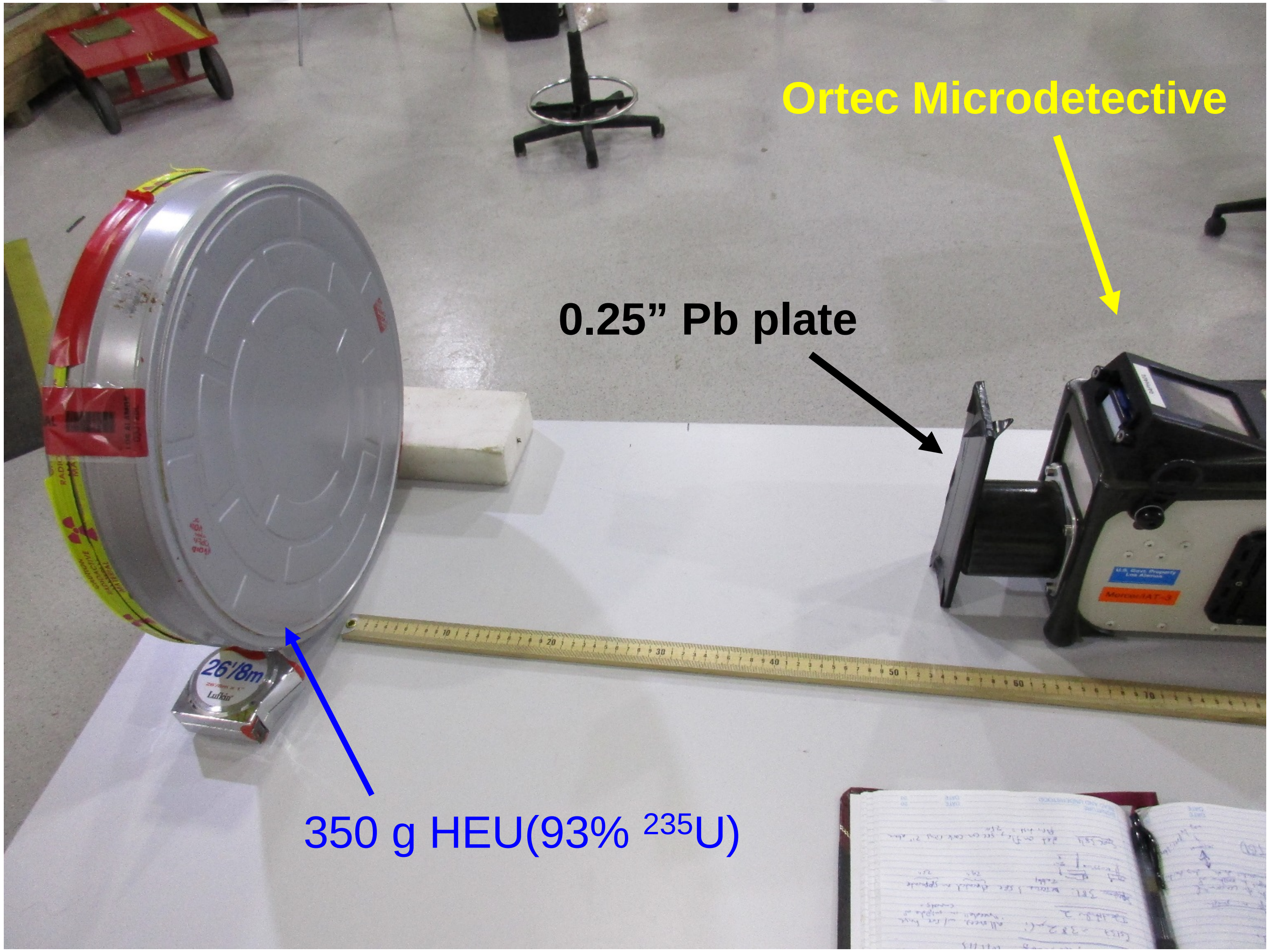


HEU Shielded by 0.25” of Pb



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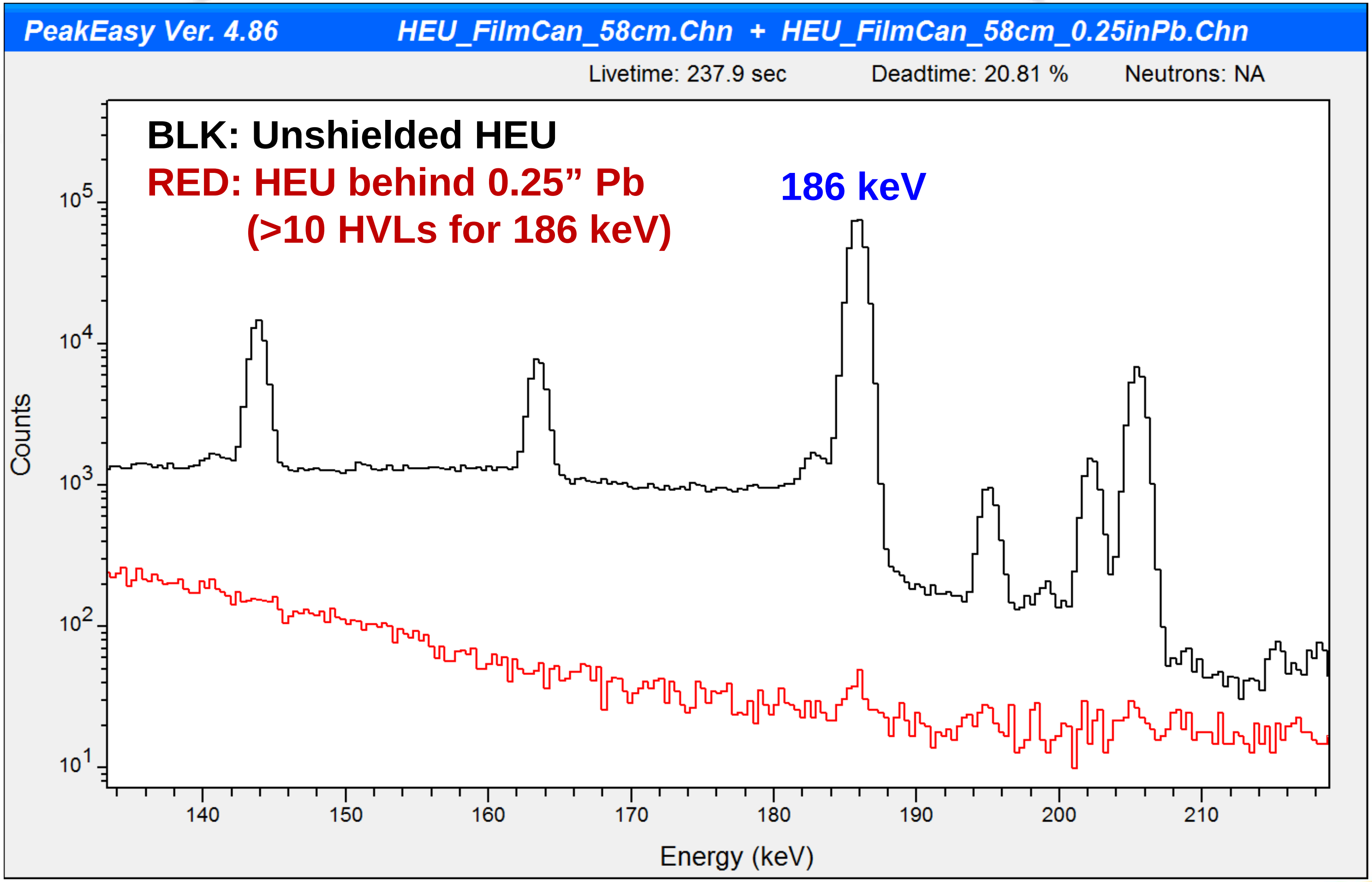

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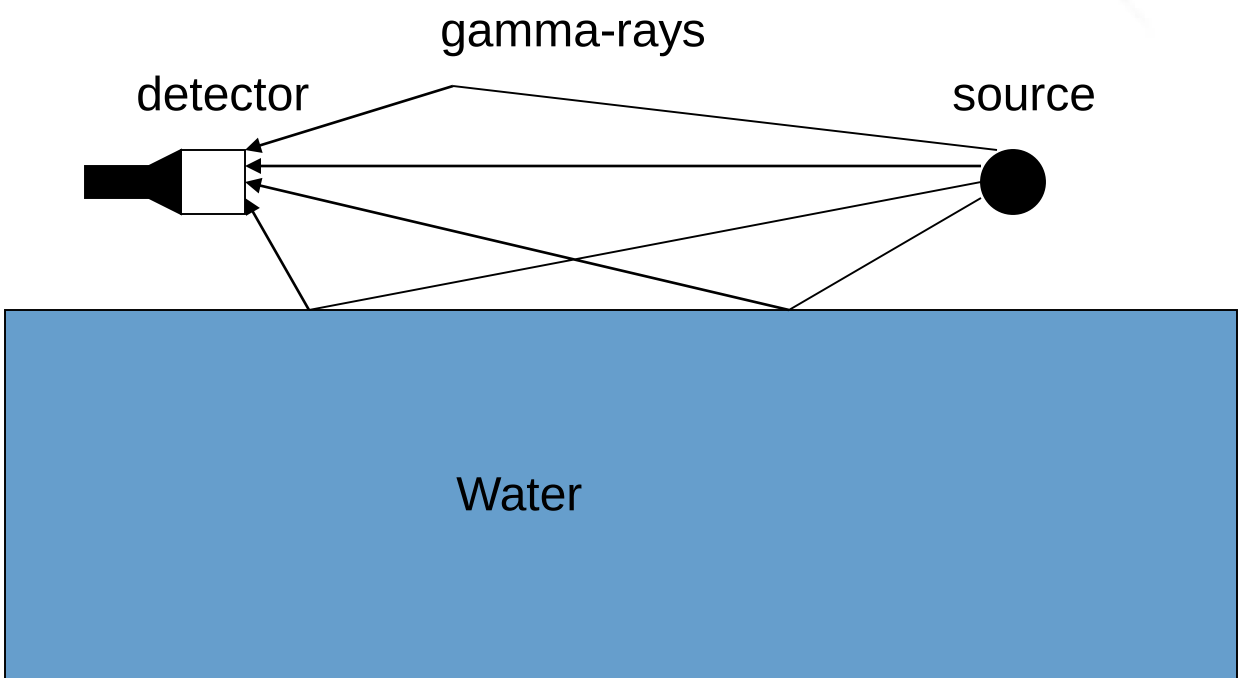
Shielding Effects on Continuum

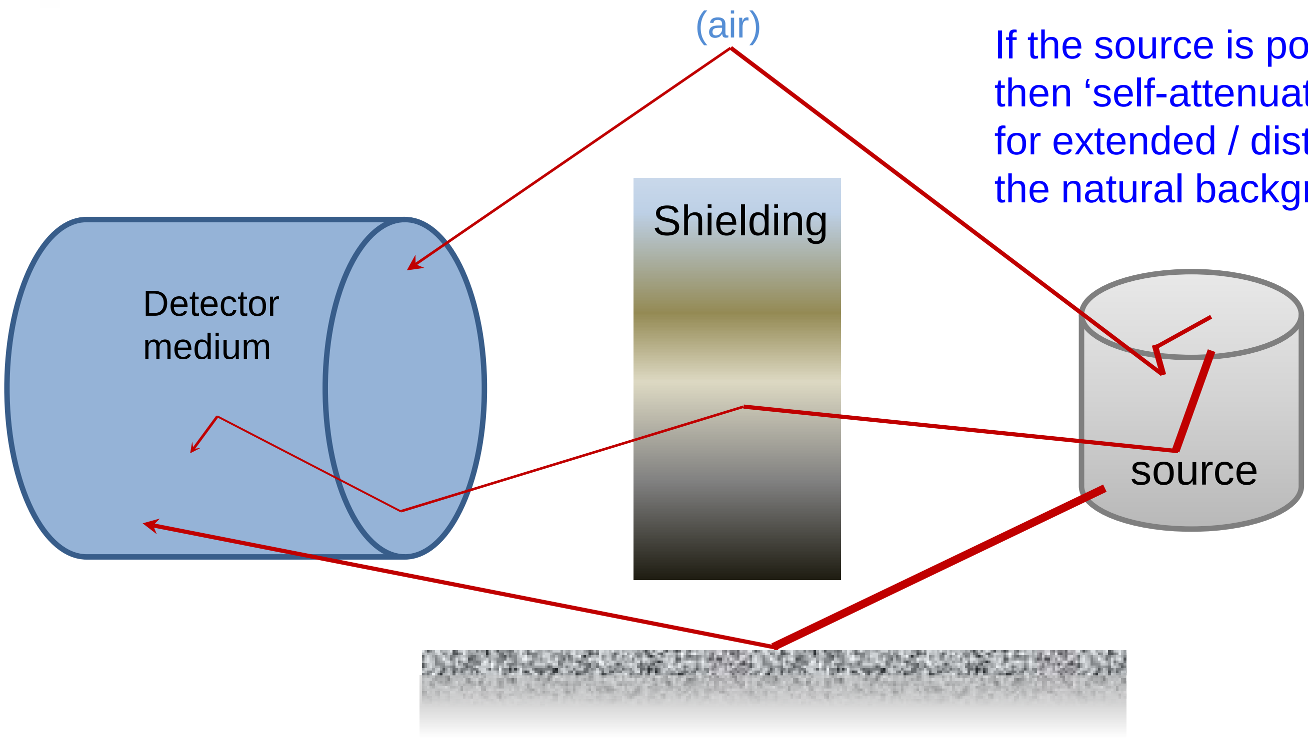
- What produces counts in the continuum?
  - Compton scattering in the detector medium
  - Compton scattering in the source itself
  - Compton scattering in the rest of the environment
    - I.e. ground, air, walls, detector electronics, people, and **shielding**, etc.
- How to get zero continuum?
  - Infinite detector medium + point source in a vacuum
- Scattering produces continuum counts to the low-energy side of the full-energy peaks

Scattering without Shielding



Where does Scattering Occur?

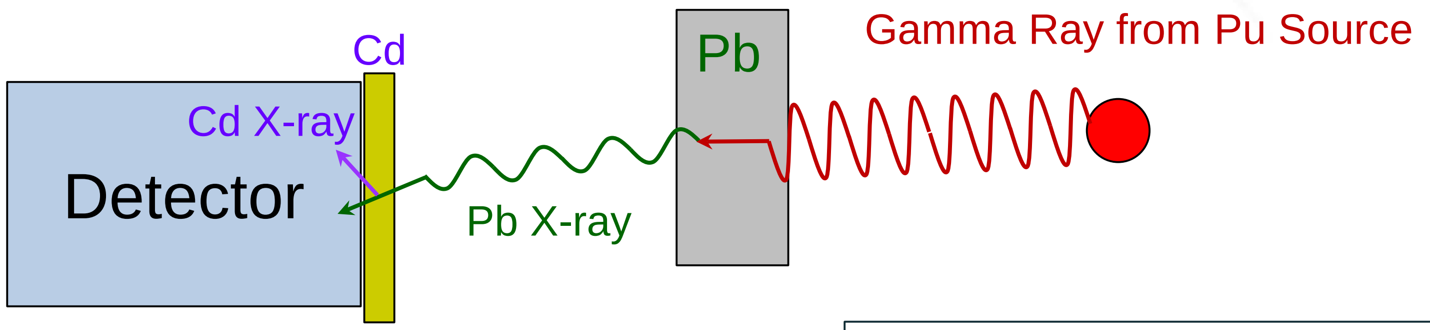
Scattering can occur in the detector medium, in the air, in the source itself, in shielding, etc.



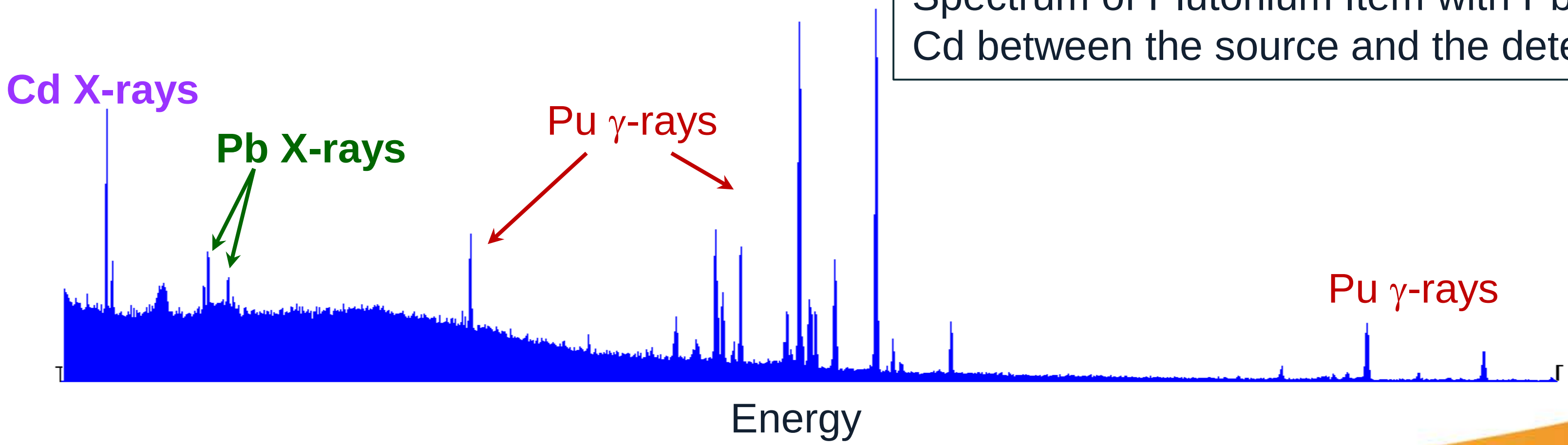
If the source is point-like (e.g. 10 uCi of ^{137}Cs) then 'self-attenuation' is minimal. But not so for extended / distributed sources like SNM or the natural background

X-Ray Fluorescence (XRF)

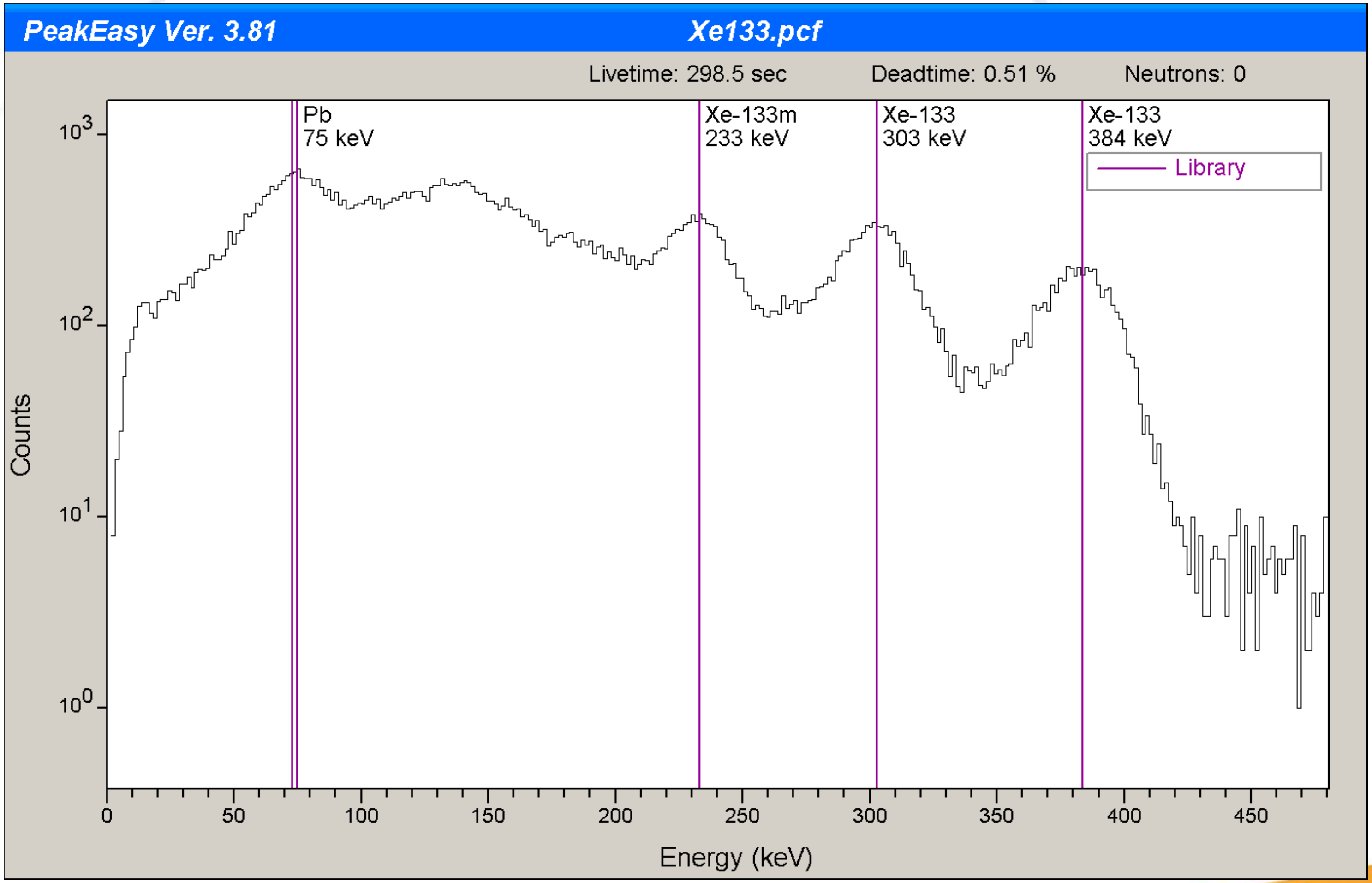
Gamma rays from the source ionize the attenuating material via the photoelectric effect (shown) or the Compton effect, resulting in the emission of characteristic x rays.



Spectrum of Plutonium Item with Pb and Cd between the source and the detector



0.5 cm of Pb producing X-Rays with Xe-133



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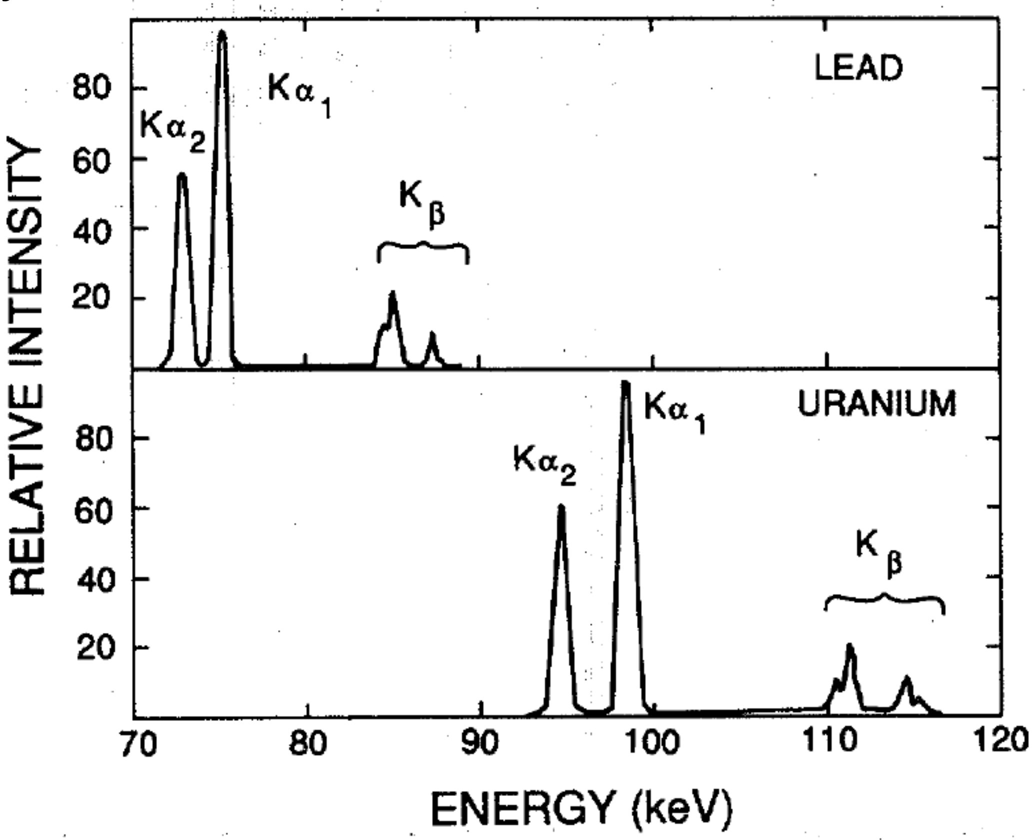
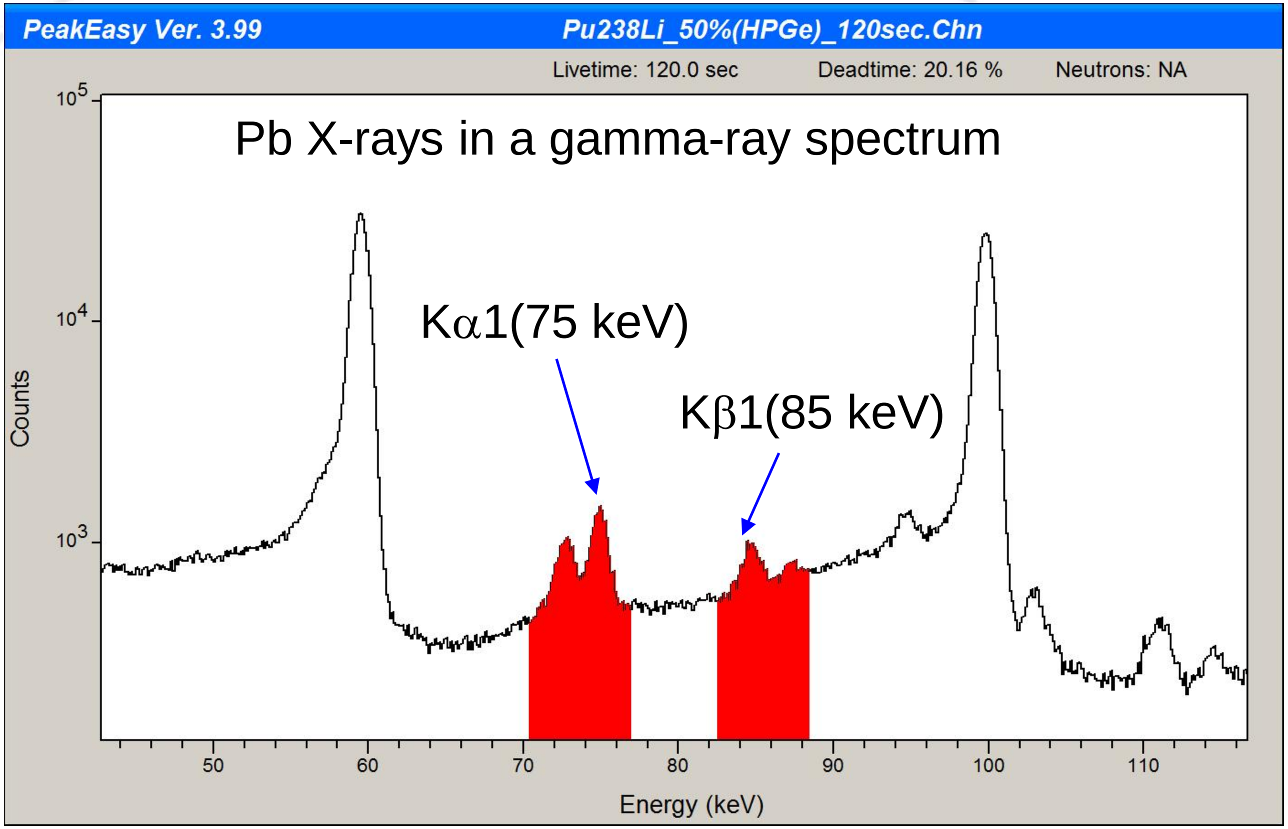
X ray Peak Patterns

Since all elements build on the same inner-shell electron structure, peaks from characteristic x rays exhibit the same pattern, only shifted by energy, within the limits of detector resolution.



Pb XRF in a HPGe Spectrum

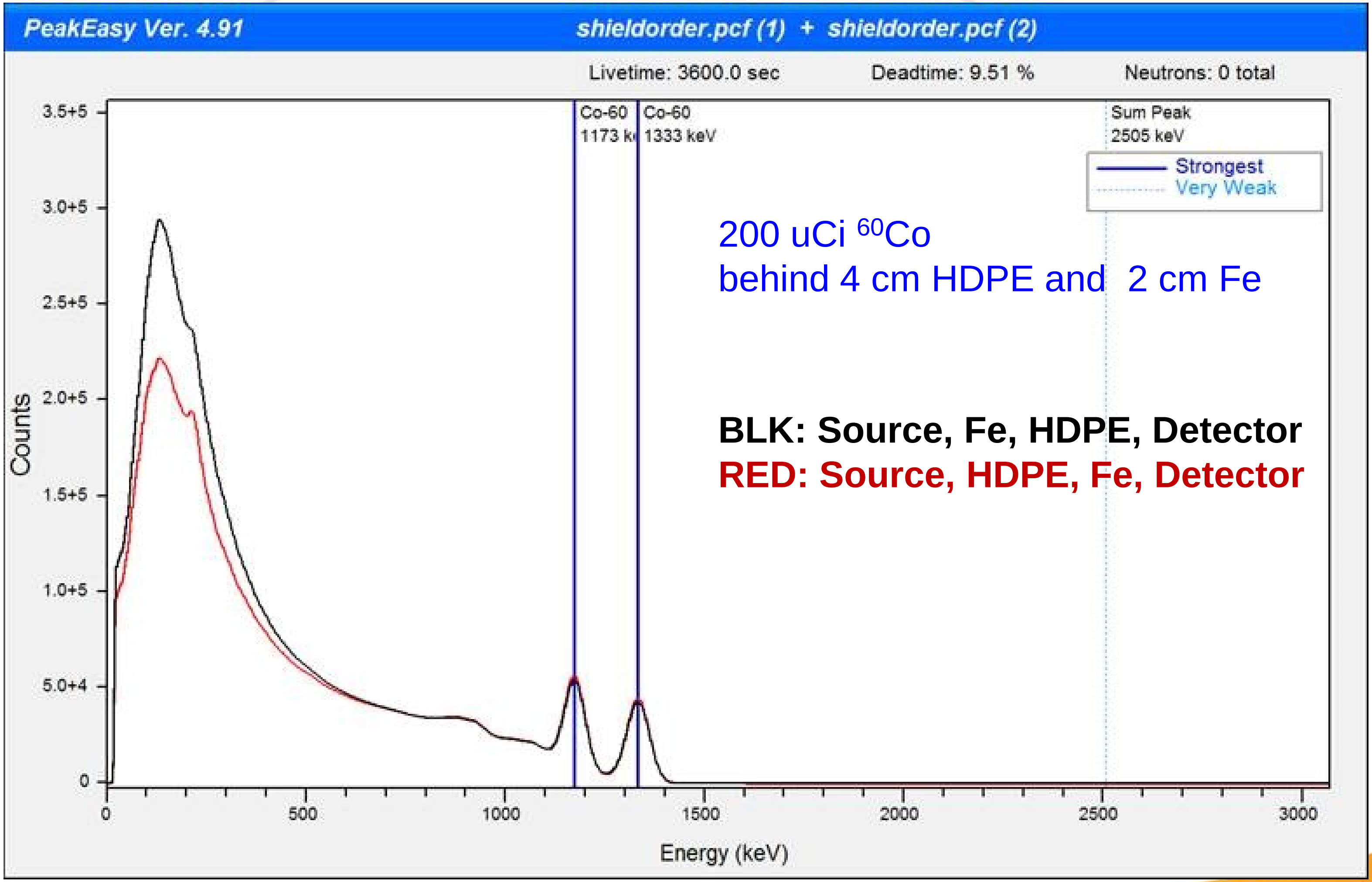


What indicates that these x rays might be from a Pb collimator and not Pb shielding the source?

Making Predictions

- Low-Z shield
  - peak attenuation less dependent on energy
    - less of a difference between how much low- and high-energy peaks are attenuated
  - low-energy photons will more likely undergo Compton scattering raising the low-energy continuum
- High-Z shield
  - peak attenuation more dependent on energy
  - low-energy photons will more likely undergo photoelectric absorption and not contribute to the continuum
  - for high-activity sources, strong, low-energy peaks can be completely masked, leaving only weaker, high-energy peaks, Example: Ir-192

Shielding Order Effects



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Rules of Thumb

- For a given source, all energies are attenuated, but low-energy photons will be attenuated more than high-energy
- Higher Z shielding increases attenuation of lower-energy gamma-rays relative to higher-energy gamma-rays
- Shielding and scatter cause ‘steps’ under peaks and add counts to the Compton continuum to the left of the peaks
- For most shielding materials, one can predict attenuation for gamma-rays above 400 keV based only on the effective shielding density and thickness.