Nuclear Instrumentation and Measurement

Project 1

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Project Overview:

For this project, I have been tasked to find shielding required to accurately measure counts generated by a detector. In this scenario I am going to explain how I calculated the thickness of the shielding required for two materials: Aluminium (Al) and Lead (Pb). These assessments are for based on a few assumptions:

1. The radioisotope is a point source.
2. The intrinsic detection efficiency is 1.
3. The detector is fast enough such that no counts are lost due to deadtime.
4. The detector is a 3" diameter cylindrical detector that is facing the point source.
5. We will assume that we have good geometry due to a series of collimators installed in our experimental facility (ignore buildup factors).
6. The source has an activity of 1 Ci, and the rate of activity change is negligible over the course of the experiment.

Now, using these assumptions I calculated the thickness required when the detector is at distances: 10cm, 20cm, 50cm, 80cm and 100cm away.
The general overview on how I calculated the thickness was by analysing the emission intensity and photon energy with the attenuation of each material which subsequently provided the thickness. Keep in mind I would have found the exact thickness by finding the resultant intensity to be of 1e6 Counts/s. I will explain the methods and equation used below in detail and my results as a form of graphs.

Initial intensity:

In this project, one of the hardest steps I would say is calculating the initial intensity of the photon energies that were provided. This is because if the initial intensity is greater than 1e6 then you know that you need to have shielding or else it is not necessary. The equation that we predominantly use for finding the thickness is:

$$I = I_0 e^{-\mu t}$$

where:

- I = the intensity of the gammas transmitted through the absorbing material.
- I_0 = is the initial beam intensity.
- t = is the thickness of the absorbing material
- μ = is the linear attenuation coefficient which is degree to which the given absorber interacts with gammas.

Now keep in mind that that μ in this case is going to be the linear attenuation coefficient, the data that we get from NIST table 3, gives us two columns for each material for an energy spectrum. One column is mass attenuation coefficient (μ/ρ) which we want and then multiply it by the density of the material, in this case Al and Pb have 2.7g/cm^3 and 11.34 g/cm^3 respectively.

Now that we know what the equation does and how to find the linear attenuation coefficient, I exported the data from NIST and multiplied all the coefficients for all energies with each density. Then to find the initial intensity (I_0) we substitute $t = 0$ and then multiply the Emission intensity with the activity, which was given as 1 Ci. Once we do this, we can multiply that with the geometric efficiency.

$$\epsilon_{geo} = \frac{\Omega}{4\pi}$$

where ϵ_{geo} is the fraction of radiation emitted from a source that is intercepted and detected by a detector and Ω is the geometry and the equation used for that is:

$$\Omega = 2\pi(1 - \frac{d}{sqrt(d^2 + a^2)})$$

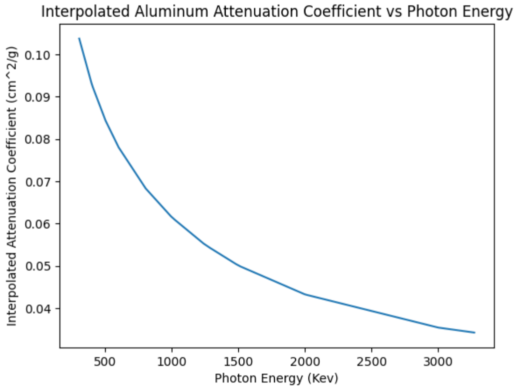
Finally, we add all the emission intensity in terms of activity and multiply that with ϵ_{geo} we get the initial intensity.

Finding thickness:

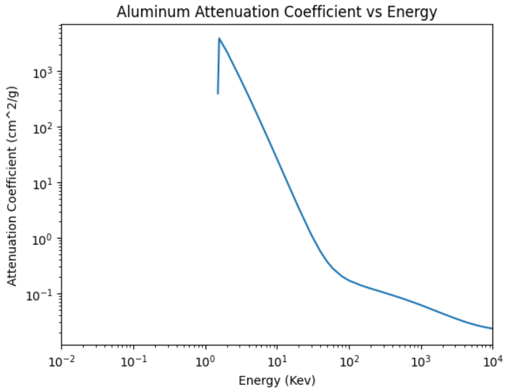
This was the second hardest part of the project in my opinion from a coding standpoint and a nuclear theory standpoint since there were different ways to calculate it, one way could be to solve the equation in terms of thickness and find the mean at the particular energies which would output the thickness at the specific distance. Another way would be to incrementally increase the thickness until the resultant intensity is less than 1e6 counts/s.

So firstly, the attenuation coefficients were not aligned with the energy levels given to us in the Photon emissions as they were in Kev vs Mev from NIST. So, we would have to linearly interpolate. To do this, I used a python module "from scipy.internpolate import interp1d". This module analysed on set of data in a data frame then compares it to another and interpolates it for you. In this case I used the data from NIST and interpolated it with the energy spectrum from Photon emission data given to us.

To give an idea of the interpolated data vs non interpolated data:



vs



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Now that we have the interpolated data what I did was write a for loop within the distances from the detector and then calculate the thickness by implementing the formula $I = I_0 e^{-\mu t}$ in terms of thickness and then run the initial intensities calculated before with accounted geometric efficiency. Then we run each interpolated attenuation coefficient through the formula and a test thickness. The for loop ends once a condition reaches and that is when the detected count rate is less than or equal to 1e6 Counts/s. To do this you would sum the detected intensities at the particular attenuation coefficient and the desired thickness and then multiply it with the geometric efficiency.

So the final output would be the thickness of a particular material (Al and Pb) at a particular distance from the detector (10cm, 20cm, 50cm, 80cm and 100cm) and a particular thickness of the shielding. Here are the results:

Aluminium:

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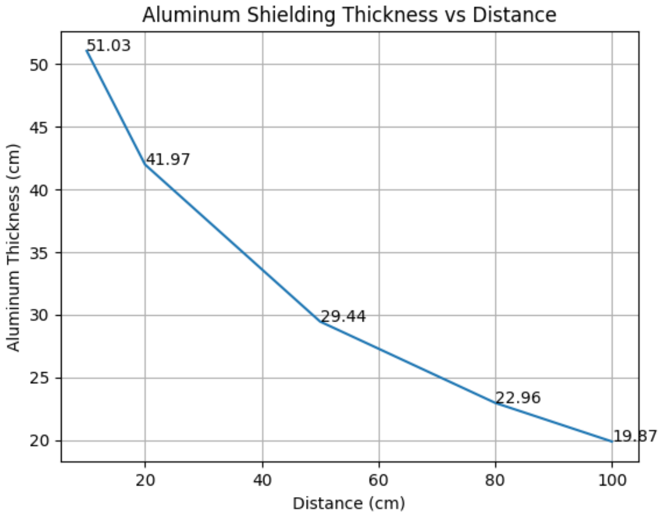
Distance: 10 cm, Detected Intensity: 1.60e+09 Counts/s, Required Aluminum Thickness: 5.10e+01 cm
Distance: 20 cm, Detected Intensity: 4.31e+08 Counts/s, Required Aluminum Thickness: 4.20e+01 cm
Distance: 50 cm, Detected Intensity: 7.05e+07 Counts/s, Required Aluminum Thickness: 2.94e+01 cm
Distance: 80 cm, Detected Intensity: 2.76e+07 Counts/s, Required Aluminum Thickness: 2.30e+01 cm
Distance: 100 cm, Detected Intensity: 1.77e+07 Counts/s, Required Aluminum Thickness: 1.99e+01 cm
```

When plotted:



Lead:

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Distance: 10 cm, Detected Intensity: 1.60e+09 Counts/s, Required Lead Thickness: 1.01e+01 cm
Distance: 20 cm, Detected Intensity: 4.31e+08 Counts/s, Required Lead Thickness: 8.33e+00 cm
Distance: 50 cm, Detected Intensity: 7.05e+07 Counts/s, Required Lead Thickness: 5.85e+00 cm
Distance: 80 cm, Detected Intensity: 2.76e+07 Counts/s, Required Lead Thickness: 4.56e+00 cm
Distance: 100 cm, Detected Intensity: 1.77e+07 Counts/s, Required Lead Thickness: 3.95e+00 cm
```
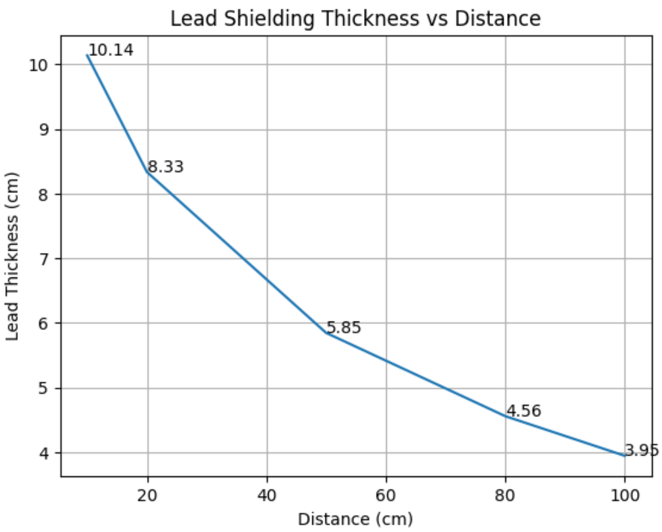

When plotted:



Now to explain both data, the “Detected Intensity” is the initial intensities that are above $1e6\frac{counts}{s}$ as you can see from uploaded data. From both data sets you can see that the detected intensities are the same that is because that is the intensity from the sources without shielding from either material, so they have to be the same.

Regarding the graph, we see that there is a similar trend for both, where there is a logarithmic decreased in the thickness required as the distance of the point source increases from the detector. This makes perfect sense to logic as the further you go away the detection decreases as the geometric efficiency reduces as well. The reason why Al requires more thickness as seen in the graphs for each distance is because Al is a much lower Z value compared to Pb which is 13 and 82 respectively. So, the higher Z the more shielding you give at the same level of thickness as a lower Z material. Therefore, Al needs more thickness than Lead.