Measuring the Effects of Materials on Limiting Radioactive Decay

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Abstract

The goal of this experiment was to analyze the radioactive decay of the Cobalt-60 (Co-60) and Strontium-90 (Sr-90) radioactive materials. To do this, we placed a sample of one of the materials inside of Geiger-Müller (GM) Tube that creates an electrical signal every time a gamma ray passes through the tube. We can count these signals to determine a rough estimate for the rate of decay of Cobalt and Strontium. Our experiment was considered to be a success if 68% of the trials are within ±1σ of the mean decay rate, where σ is the standard deviation (or uncertainty) of any given trial. We also expected to have 95% of our trails lie within ±2σ of the mean decay rate. For our trials, the standard deviation (σ) was 10.69, 69.67% of our samples were within one σ and 94.67% of our samples were within two σ so we considered this experiment to be a success.

Background

All unstable atomic nuclei have radioactive emissions. This is caused by the radioactive decay of the materials, where neutrons and protons do not effectively balance the repulsion between the positively charged protons with the attraction of the nuclear force felt by neutrons and protons causing radioactive rays to be emitted [2]. There are multiple classes of radioactive emissions, but the three most common and easiest emissions to capture are alpha (α), beta (β), and gamma (γ) [2].

	Sr-90		Co-60	
	β_1^-	546.0 keV	β_1^-	317.1 keV
			γ_1	1173.23 keV
			γ_2	1332.49 keV
Half-life $T_{1/2}$	28.79 years		5.2747 years	
Decay Constant λ	$7.6344 \cdot 10^{-10}$ s^{-1}		$4.1669 \cdot 10^{-9}$ s^{-1}	

*Figure 1: Radioactive decay properties** of Strontium-90 and Cobalt-60. The decay constant $\lambda = \frac{\ln 2}{T_{\frac{1}{2}}}$ represents a probability of decay for any atom at any instant in time within the given time frame [2].*

We can use a Geiger-Müller (GM) Tube to measure this radioactive decay. The number of emissions detected in a given second can change wildly, but over time these measurements begin to follow a Normal (Gaussian) Curve, with the majority of the recordings falling within an expected range of value. This experiment uses a high amount of data in order to restrict the effects of random intrinsic effects, allowing for a more ideal and accurate set of data. The second half of this experiment was closely related to issues seen on spacecraft and astronauts. Gamma (γ) rays are similar to x-rays, though they have higher energy. This makes them just as, or more, dangerous after being exposed to them over a long period of time. Experiments like this one help determine the best materials and their respective amounts for protecting astronauts and space systems. Normally, the Earth's magnetic field protects the surface from the majority of these harmful particles and rays.

Theory & Methods

This experiment was composed of two parts: measure the number of emissions from a sample of

Co-60; and measure the effectiveness of lead and aluminum in stopping emissions from Cobalt and Strontium, respectfully.

The first trial was just measuring the radioactive emissions from a sample of Cobalt-60. We placed the sample at the bottom of the GM tube (depicted below) and calibrated its height to make sure we were able to record at least 100 counts/sample.

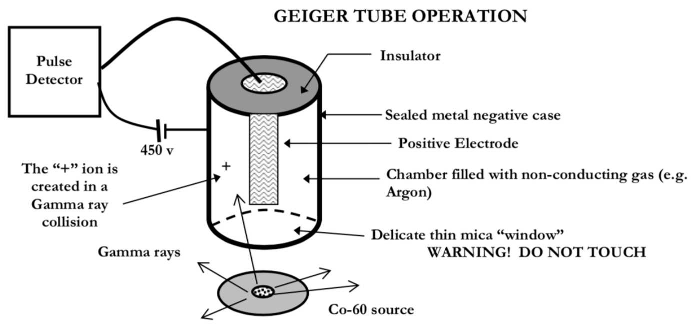


Figure 1: Representation of a Geiger-Müller (GM) tube used over the course of this experiment [2].

Once the GM tube was calibrated, we gathered and recorded 300 samples over a period of twenty-five minutes. The sample was not touched during this time, nor was there any material between the sample and the GM tube except air.

The second part of the experiment involved using either lead (Pb) or aluminum (Al) to shield the GM tube and absorb the gamma (γ) and beta (β) emissions from the Co-60 and Sr-90 samples. These "absorbers" were placed between the sample and the opening of the GM tube. We started with the Co-60 source and one Pb sheet with a thickness of 0.175cm. We gathered three samples over a 180 second period. After recording the results, we added another Pb plate and repeated the trial. In total, we did this with 1, 2, 3, 4, 6, and 8 plates for a total of 7 trials and 21 samples [2]. The thickness of each of these lead (Pb) plates can be found in the Raw Data appendix. Finally, we repeated the trial but used one 10-layer Al foil slide.

We used a similar process on the Sr-90 sample. Each trial involved taking three samples over a 180 second time period. We did one trial with a single Pb sheet, and then trials with Al foil slides containing 1, 5, 10, 20, 25, and 30 layers. Each of these layers had a thickness of 1.3 microns.

Results

The first part of the experiment was a success. We successfully recorded the samples of unblocked Cobalt-60 using the Gieger-Müller (GM) tube and a histogram of the results can be approximated to a Gaussian Bell Curve, as shown in Figure 2.

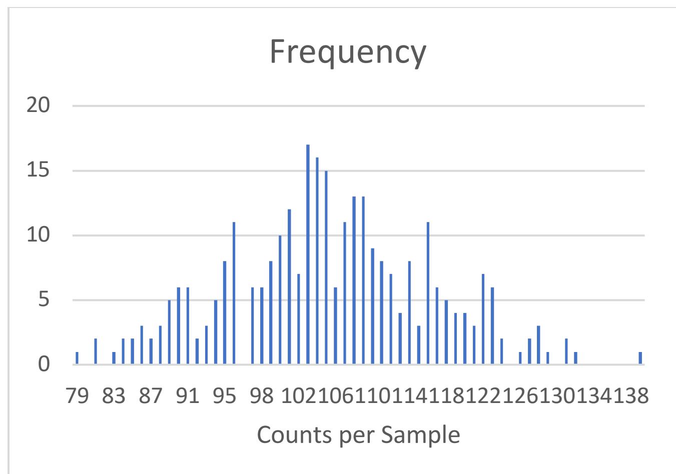


Figure 2: Measured frequency of the Geiger Counts per second from a radioactive Cobalt-60 source. The x-axis represents the number of Geiger Counts in a given 1-second-sample, the y-axis represents the frequency of the specific Geiger Count value [4].

The mean of this data was 105.58 counts/sample, with a standard deviation (σ) of 10.699 [1]. We expected about 68% of the data to lie within $\pm 1\sigma$ (94.88 → 116.28) [2]. 209 of the 300 total samples, or 69.67%, were within this range meaning this portion of the experiment was a success. We also expected about 95% of the data to lie within $\pm 2\sigma$ (84.18 → 126.98) [2]. 284 of the 300 total samples, or 94.67%, were within this range meaning this portion of the experiment was also a success, though it was slightly under the mark given in the lab instructions.

The second part of the experiment involved using lead (Pb) and aluminum (Al) sheets to absorb some of the radiation from the Cobalt-60 and Strontium-90 sources. Figure 3 is the ln(N) vs. X graph for the Co-60 gamma ray shielding tests through lead.

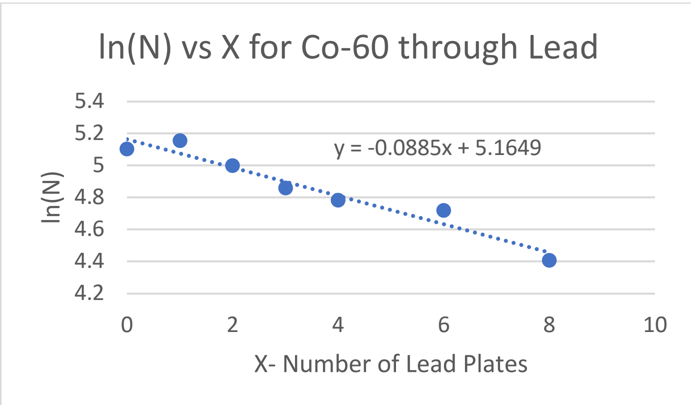


Figure 3: Graph of the natural log of the Geiger Counts versus the number of lead plates present between the Cobalt-60 source and the GM tube [4].

As expected, this graph resembles a straight line with a negative slope. The equation on the graph ($y = -0.0885x + 5.1649$) matches up directly to Equation 1.

$$\ln N' = -\mu x + \ln N_0 \qquad (1)$$

Based on Equation 1, μ is equal to about 0.0885±0.0098 and representative of the absorption coefficient for Pb of Co-60 gamma rays.

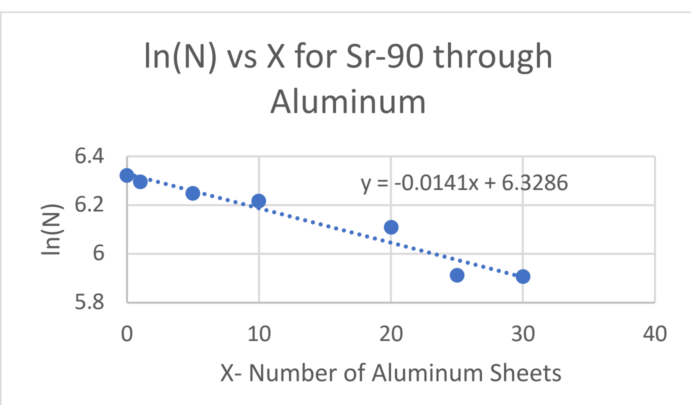


Figure 4: Graph of the natural log of the Geiger Counts versus the number of aluminum sheets present between the Strontium-90 source and the GM tube [4].

As expected, this graph resembles a straight line with a negative slope. The equation on the graph ($y = -0.0141x + 6.3286$) matches up directly to Equation 1.

Based on Equation 1, μ in this case is equal to about 0.0141±0.0015 and representative of the absorption coefficient for Al of Sr-90 gamma rays.

$$\left(\frac{N_{1\,Material}}{N_{no\ shielding}}\right)_{Radiation} \times 100\% \quad vs \quad \left(\frac{N_{1\,Material}}{N_{no\ shielding}}\right)_{Radiation_2} \times 100\%$$

Equation 2 [2]

Equation 2 is the general formula for comparing the effectiveness of materials in shielding different types of radiation. For the singular lead plate trials, the end result from Equation 2 was 105.68% : 4.37%. We believe this is an error, since our average Geiger Count from the Cobalt-60 test with 1 Sheet was larger than the Geiger Count of the same radiation with 0 lead sheets, which does not fit with the expected parameters of the experiment. The lead plate should have shielded the GM Tube from some of the radiation, not amplified it. The is most likely due to Random Measurement Uncertainties in the measurements received from the GM Tube. The Strontium-90 tests were not run with more than 1 lead plate, so it is impossible at this point to try and use a different value for $N_{1\,Material}$ in Equation 2.

The aluminum portion of the experiment was met with equal failure. Using the trials with 10 aluminum sheets, Equation 2 produced 101.42% : 90.01%. The lead plates are not expected to allow more radiation through as compared to 0 plates. No part of Equation 2 should return a result of greater than 100%, since the value is the percent of radiation that is able to pass through N_1 number of plates/sheets. We considered this experiment to be a failure due to the Random Measurement Uncertainties in the Cobalt-60 trials. An additional source of error in the measurements over the course of all the trials is Random Intrinsic Uncertainty from the randomness of radiation emitted by any given source. This source of uncertainty is why the histogram of the frequency of radiation samples received by the GM Tube follows a Gaussian Bell Curve.

References

[1] Jefts, David. "Raw Data." ERAU, Daytona Beach, FL, 24 Oct. 2018

[2] Schumacher, Donald. "Radioactivity: Random Decay Processes and Shielding Application" ERAU, Daytona Beach, FL, 6 Nov. 2017. Reading.

[3] Tipler, Paul Allen, and Gene Mosca. Physics for Scientists and Engineers. 6th ed., Macmillan, 2007.

[4] Jefts, David. "Plot Data." ERAU, Daytona Beach, FL, 29 Oct. 2018

Calculations

Penetration of ionizing radiation through a material

$$dN = -\mu N dx$$

Rearrange and then integrate…

$$\frac{1}{N} dN = -\mu dx$$

$$\int_{N_0}^{N'} \frac{1}{N} dN = -\mu \int_0^x dx$$

$$\ln N' - \ln N_0 = -\mu x$$

Natural log linear equation modelling radiation penetration through a material.

μ is the proportionality constant called the absorption coefficient

$$\ln N' = -\mu x + \ln N_0 \quad \rightarrow \quad \text{Equation 1}$$

Formula to compare the effectiveness of lead sheets in blocking radiation

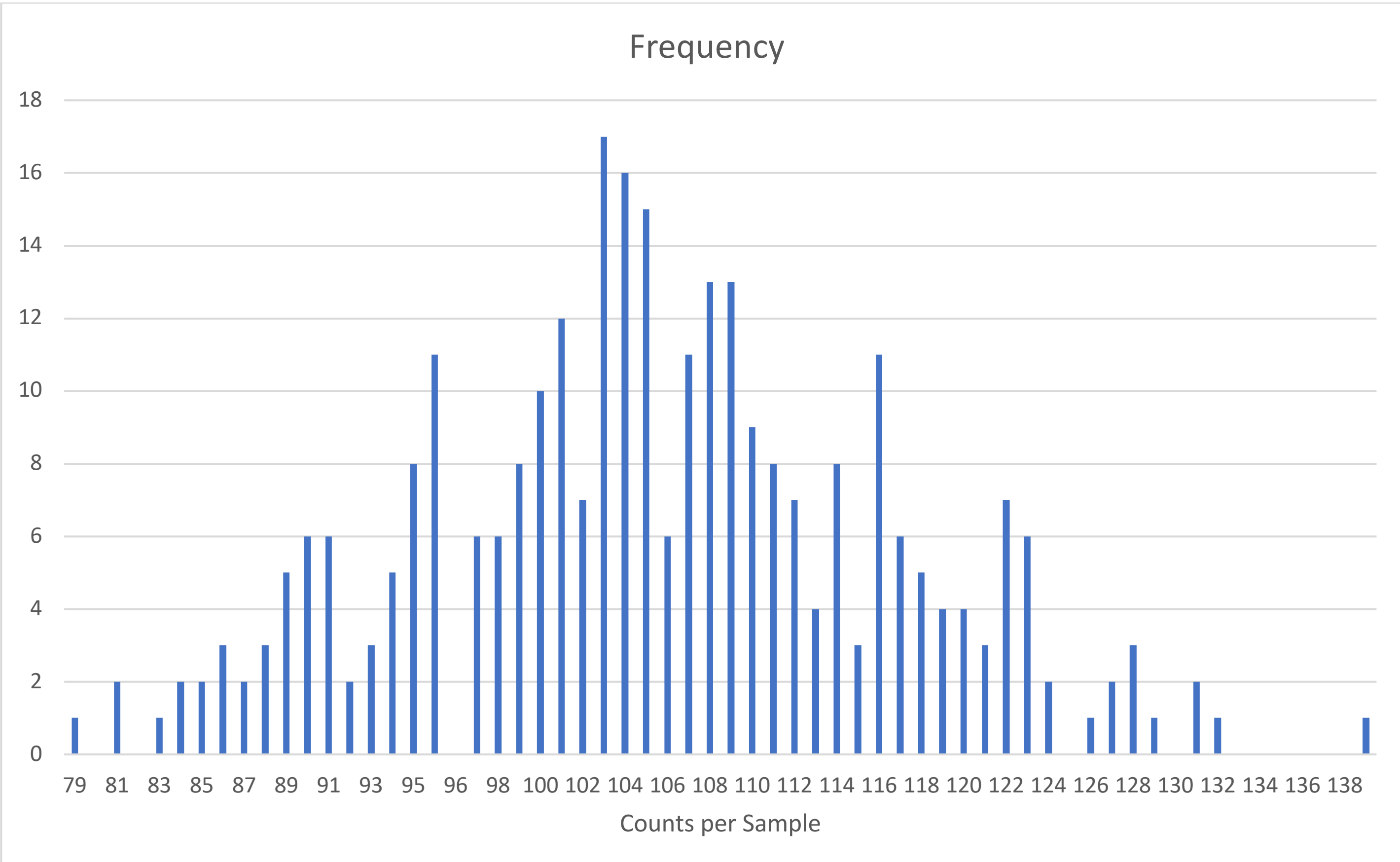
$$\left(\frac{N_{1\ Pb-sheet}}{N_{no\ shielding}}\right)_{Co-60} \times 100\% \quad vs \quad \left(\frac{N_{1\ Pb-sheet}}{N_{no\ shielding}}\right)_{Sr-90} \times 100\%$$

Formula to compare the effectiveness of aluminum sheets in blocking radiation

$$\left(\frac{N_{1\ Al-sheet}}{N_{no\ shielding}}\right)_{Co-60} \times 100\% \quad vs \quad \left(\frac{N_{1\ Al-sheet}}{N_{no\ shielding}}\right)_{Sr-90} \times 100\%$$

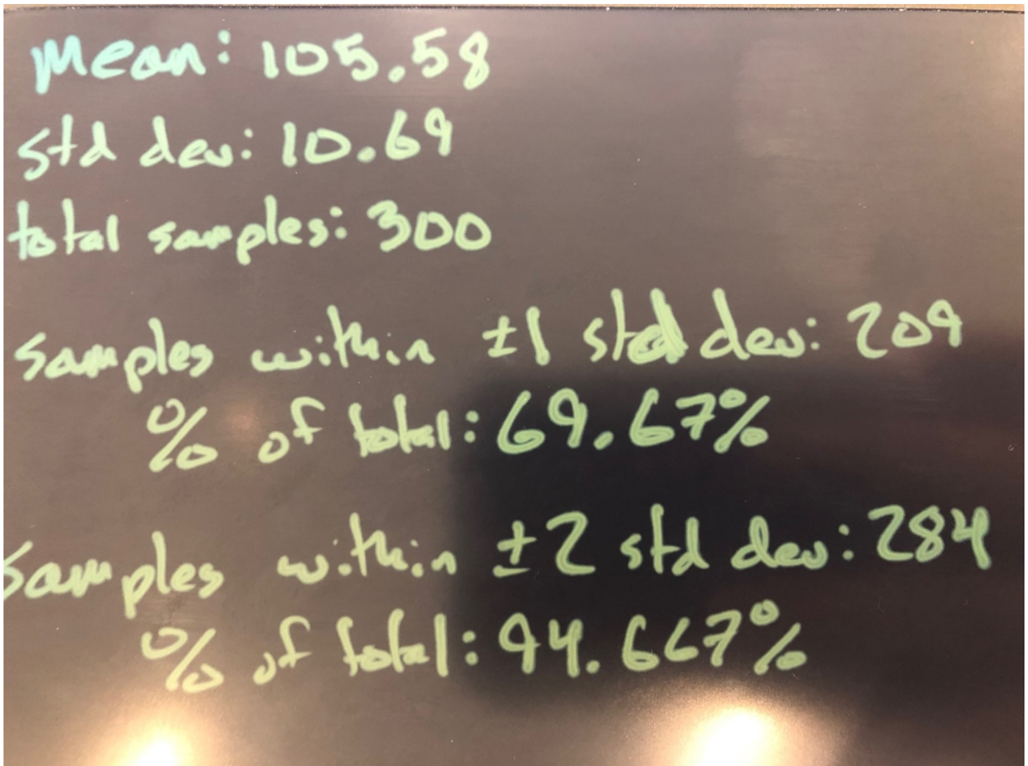
$$\left(\frac{N_{1\ Material}}{N_{no\ shielding}}\right)_{Radiation} \times 100\% \quad vs \quad \left(\frac{N_{1\ Material}}{N_{no\ shielding}}\right)_{Radiation_2} \times 100\%$$

Plot Data

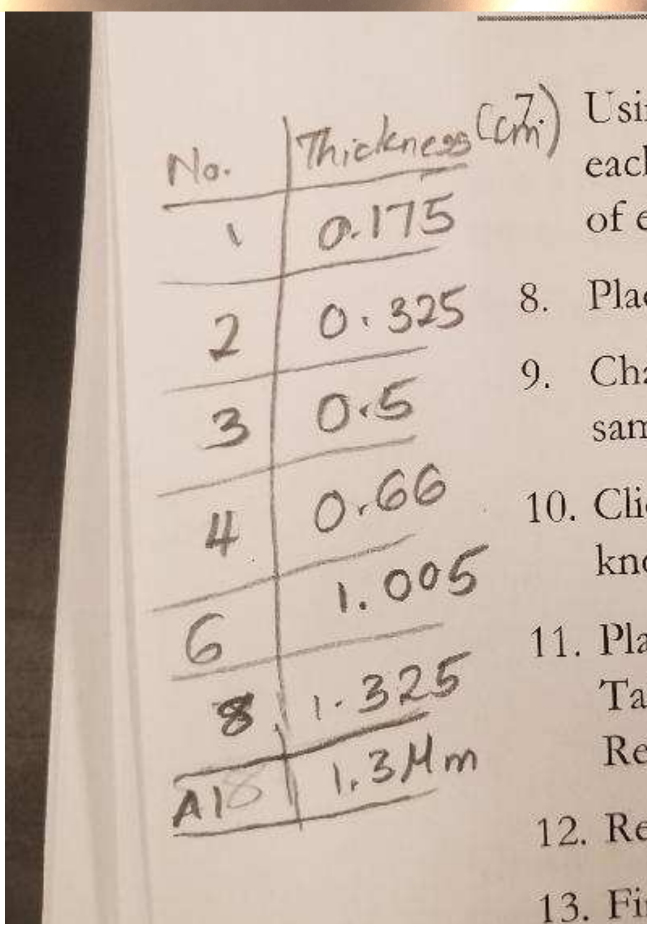


Frequency
18
16
14
12
10
8
6
4
2
0
79 81 83 85 87 89 91 93 95 96 98 100 102 104 106 108 110 112 114 116 118 120 122 124 126 128 130 132 134 136 138
Counts per Sample

Raw Data



mean: 105.58
std dev: 10.69
total samples: 300
samples within ±1 std dev: 209
% of total: 69.67%
samples within ±2 std dev: 284
% of total: 94.667%



No.	Thickness (cm)
1	0.175
2	0.325
3	0.5
4	0.66
6	1.005
8	1.325
Al	1.3μm