Radioactivity: Random Decay Processes and Shielding Application

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Background

The purpose of this lab was to study the processes of the decay of radioactive materials. Two radioactive materials (Cobalt-60 and Strontium-90) are placed inside a Geiger-Müller tube that measures the emissions from the radioactive materials. Understanding these principles when designing spacecraft and its instrumentation are crucial as radiation from the sun can be harmful to the occupants and can interfere with the spacecraft's instruments and sensors.

Theory

Radioactive decay occurs because of an imbalance in the repulsion of protons and the nuclear force holding the nucleus together. This results in the emission of alpha, beta or gamma particles. An alpha particle consists of two protons and two neutrons. Alpha particles are highly ionizing but are ineffective at penetrating materials. Beta particles consist of one electron. They are ionizing and can penetrate materials more effectively than alpha particles. Gamma rays are photons of high energy light that can penetrate through most materials. The penetration of ionizing ration can be modeled assuming that the number of absorbed particles is negatively proportional to the thickness of the material and the number of original emission, thus:

$$dN = -\mu N\, dx$$

Integration yields:

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

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

This leads to a linear relationship so the value for μ can be easily found.

The average value for the instantaneous rate of decay can be modeled as:

$$R_{ave} = \frac{\ln(2)}{T_{1/2}} N_0 e^{-t\ln 2/T_{1/2}}$$

However, radioactive decay is a random process that is not affected by any outside states. Thus a gaussian distribution can be used to model the range of values. The standard deviation is then:

$$\sigma_R = \sqrt{R_{ave}}$$

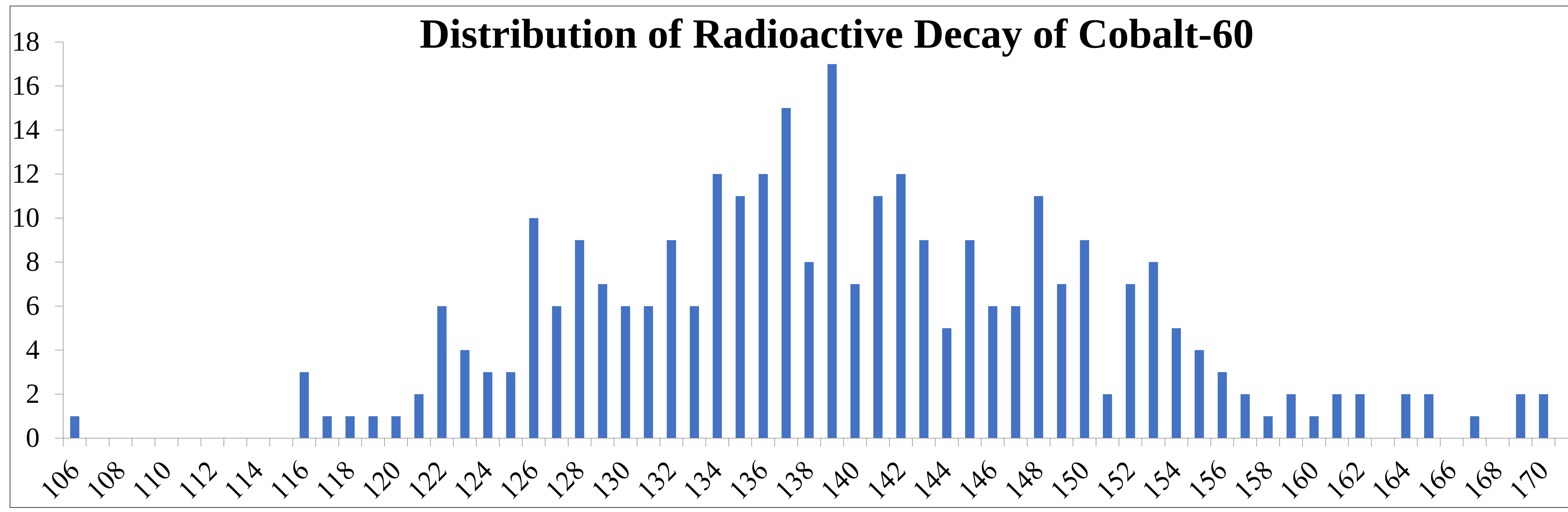

Figure 1: Decay rate of cobalt-60 displays a gaussian curve

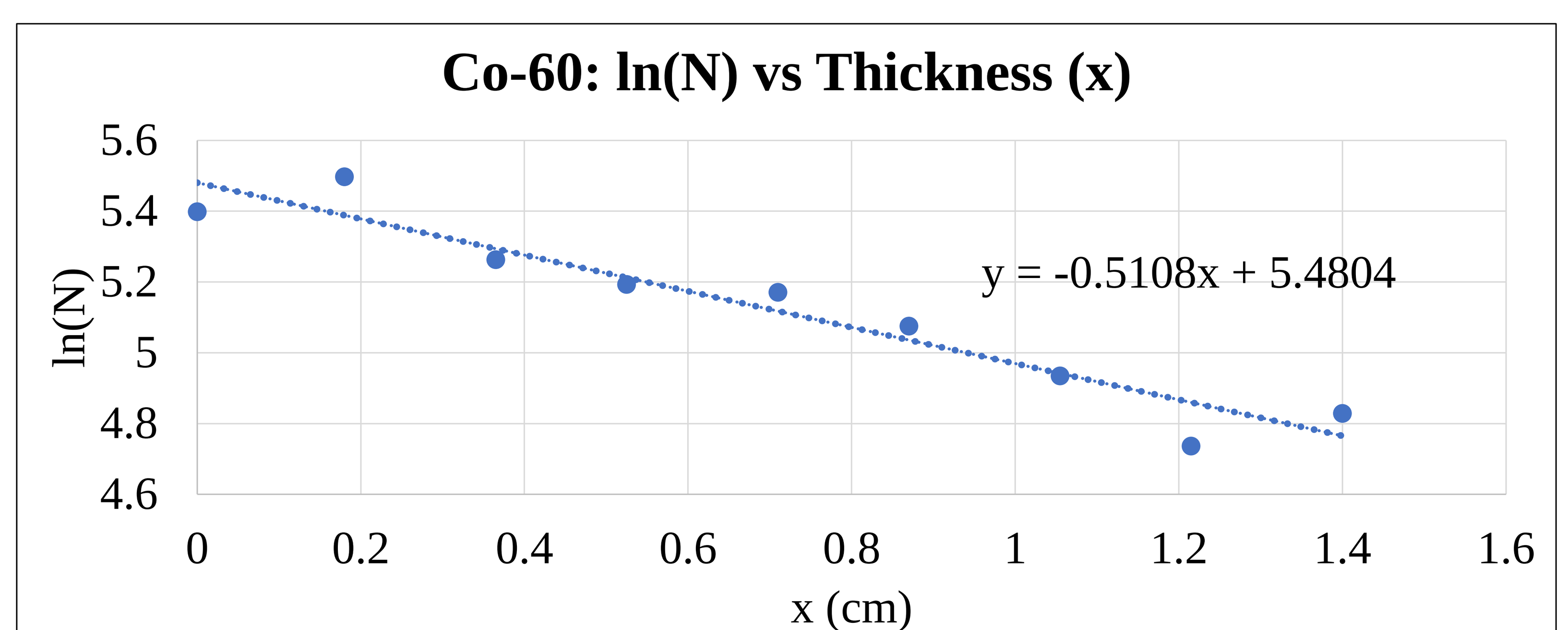

Figure 2: Relationship between the thickness of the lead sheets and Co-60 particles that were not blocked

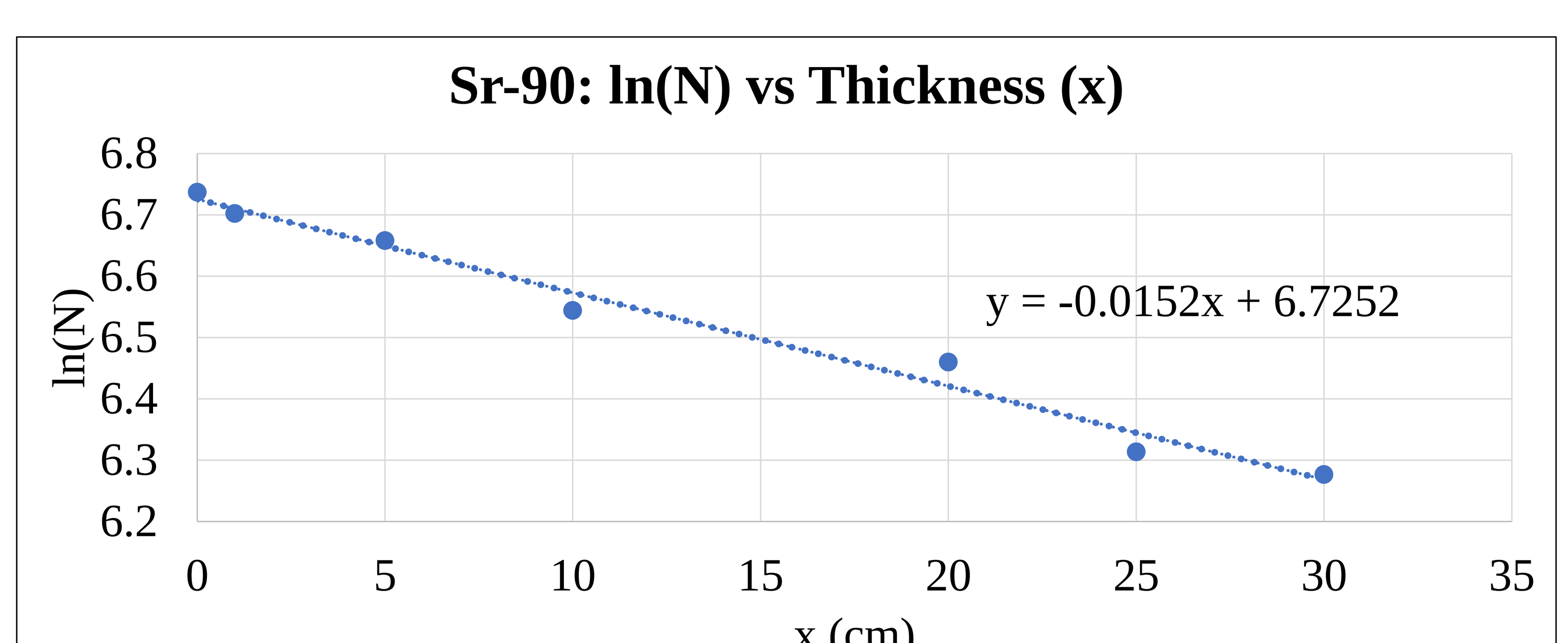

Figure 3: Relationship between the thickness of the aluminum sheets and Sr-90 particles that were not bocked

Table 1: Co-60 lead sheets

Thickness (x)	Mean Count N	σ	Ln(N)
1.4	125	7	4.828314
1.215	114	9	4.736198
1.055	139	17	4.934474
0.87	160	7	5.075174
0.71	176	4	5.170484
0.525	180	4	5.192957
0.365	193	5	5.26269
0.18	244	27	5.497168

Table 2: Sr-90 Aluminum sheets

Thickness (x)	Mean Count N	σ	Ln(N)
1	814	31	6.70196
5	779	38	6.658011
10	695	38	6.543912
20	639	27	6.459904
25	552	15	6.313548
30	532	12	6.276643
0	843	22	6.736967

Method

In the first part of the experiment a sample of Cobalt-60 was placed under a Geiger–Müller tube. The Pasco interface was set to record the number of samples over a 5 second interval. The location of the sample was adjusted so that around 100 mean counts were obtained per sample. Then the experiment was run for 25 minutes to obtain 300 samples. In the second part of the experiment the effectiveness of aluminum and lead at blocking the gamma rays emitted from Cobalt-60 and beta particles of Strontium-90 was tested. One of the samples was placed below the Geiger–Müller tube then sheets of lead or aluminum were added between the tube and sample to block some of the particles emitted.

Results

During the first phase of the experiment, the random nature of radioactive decay of cobalt-60 is observed. After analyzing the data, using figure 1, the average decay rate value is 140 decays per second with uncertainty of ± 11 decays per second (±σ). It is expected that 68% of the data should fall within (±1σ) and 95% of the data within (±2σ), which was found experimentally to be correct as 68% of the data was within (±1σ) and 95% of the data was within (±2σ). This result concludes that due to the random nature of radioactive decay, it is expected that out of 100 decay readings 32 of them will be outside the uncertainty range of the average decay rate value.

Using the data from table 1 and 2, lead was able to block Sr-90 far more than Co-60 because only 3.44% of Sr-90 radiation made it through the lead sheet compared to the 110.4% of the Co-60. Aluminum blocked the radiation of Sr-90 more than Co-60 by 18.7%. It let 101.4% of Co-60 through compared to only 84.4% of Sr-90. Meaning lead is a better material to block Sr-90. This supports the value for the absorption coefficient given by the slope of the ln(N) vs thickness graphs shown in figure 2 and 3. Figure 2 shows that the absorption coefficient of Co-60 is 0.5108±0.058567. The value for Sr-60 is 0.0152± 0.000922 displayed in figure 3. This proves that Sr-60 can be absorbed better.

More than 100% of the radiation of Co-60 passed through the materials which is not possible. This is due to random intrinsic uncertainty because the decay was changing randomly. During this experiment, there was also random measurement when measuring the thicknesses of the plates due to the variability.

References

[1]Detecting Radiation. (n.d.). Retrieved from https://www.imagesco.com/articles/geiger/build_your_own_geiger_counter_-gm_tube.html

[2] *Radioactivity* [PDF]. (2016, September 25). Daytona Beach: ERAU.