Effect of Lead Thickness on Radiation Detection

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Abstract

In our investigation, we examined how varying thicknesses of lead influence the detection of radiation emitted by Cobalt-60, a widely utilized radioactive isotope. Utilizing a scintillator, we quantified the radiation intensity across different lead shields. Our observations revealed a predictable decline in radiation intensity with increased lead thickness, aligning with theoretical expectations. Notably, this attenuation follows an exponential trend, underscoring the complex dynamics of radiation shielding. These insights contribute valuable knowledge towards optimizing radiation protection materials, emphasizing the exponential nature of radiation attenuation through lead. This understanding is crucial for designing more effective shielding strategies in both medical and industrial applications, enhancing safety protocols against radioactive exposure.

1 Introduction

The study of radioactive decay remains a cornerstone in understanding nuclear processes, with Cobalt-60 frequently serving as a pivotal subject due to its prevalent use in both medical and industrial applications. This isotope's emission characteristics offer a valuable window into the dynamics of gamma radiation, a form of energy crucial in a variety of fields. The attenuation of this radiation by shielding materials, particularly lead, is of paramount importance for ensuring safety and efficacy in these applications. Lead is traditionally favored for its high density and atomic number, which contribute to its effectiveness in absorbing gamma radiation. However, the relationship between lead thickness and radiation attenuation is not merely a matter of linear correlation but involves more complex interactions that significantly influence shielding design. This experiment aims to elucidate these interactions by systematically varying the thickness of lead shielding to observe its impact on radiation detection from Cobalt-60, thereby providing insights that could refine our approach to radiation protection.

2 Experimental Setup and Procedure

2.1 Materials and Equipment

The primary materials and equipment used in this experiment include:

- Cobalt-60 radioactive source
- Lead sheets of varying thicknesses in mm (1.530, 3.060, 5.860, 8.670, 14.500, 20.300, 29.000)
- Scintillator
- Multi-channel analyzer (MCA) and single-channel analyzer (SCA)
- Data acquisition Software (Maestro)
- Python programming environment (miniconda with Python notebooks)

2.2 Apparatus

The experimental setup consists of a Cobalt-60 source, a Radiation Detection Module, and lead sheets of varying thicknesses. The Cobalt-60 source emits gamma radiation, which is detected by the scintillator. The lead sheets are placed between the source and the scintillator to measure the attenuation of the radiation. The Radiation Detection Module is connected to a data acquisition system(Maestro), which records the intensity of the radiation over time in a histogram plot. The data is then passed to a Python program, which allows us to measure the radiation intensity at different lead thicknesses with our plot analysis.

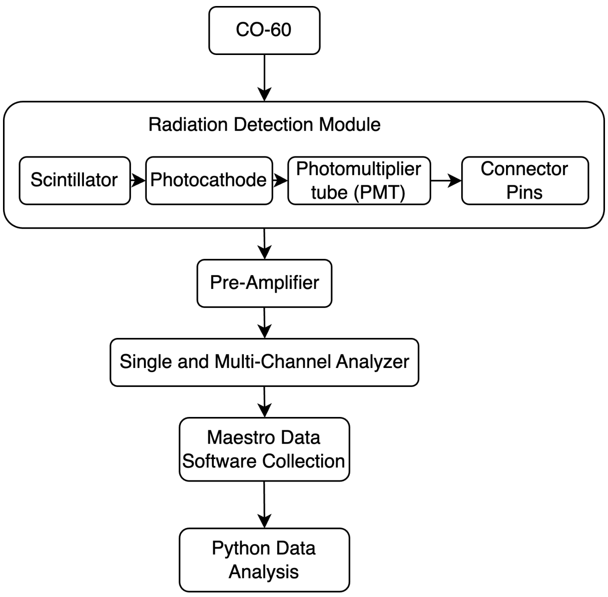

Figure 1: Apparatus Flow Chart

2.3 Scintillator

The scintillator is a device that detects radiation by converting the energy of incoming photons into visible light. This light is then detected by a photomultiplier tube, which amplifies the signal and converts it into an electrical pulse. The scintillator used in this experiment is a sodium iodide (NaI) crystal, which is commonly used for detecting gamma radiation. The crystal is coupled to a photomultiplier tube, which amplifies the light signal and converts it into an electrical pulse.

2.4 Photomultiplier to Electronic Multiplier

The photomultiplier tube is a device that converts the light signal from the scintillator into an electrical pulse. It consists of a series of dynodes, which are metal electrodes that are held at successively higher voltages. When a photon strikes the first dynode, it releases an electron, which is then accelerated towards the next dynode. This process is repeated at each dynode, resulting in a cascade of electrons that is amplified at each stage. The final output is a large number of electrons, which is then converted into an electrical pulse. This pulse is then passed to a electronic preamplifier to be then processed by the data acquisition system, which records the number of pulses over a given time interval. This allows us to measure the intensity of the radiation emitted by the Cobalt-60 source.

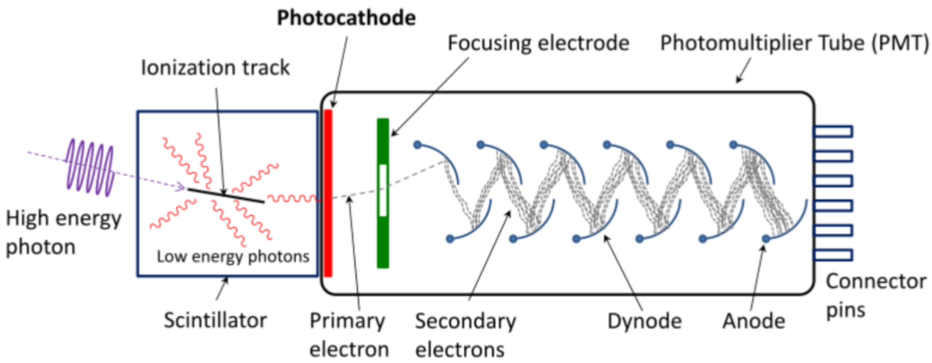

Figure 2: Radiation Detection Module [1]

2.5 Single and Multi-Channel Analyzer (Cobalt-60 Gamma Ray Spectrum)

The single-channel analyzer (SCA) is a device that allows us to select a specific range of energy from the photomultiplier tube. This is useful for filtering out background radiation and other unwanted signals. The multi-channel analyzer (MCA) is a device that allows us to record the number of pulses at each energy bin. This allows us to measure the intensity of the radiation emitted by the Cobalt-60 source as a histogram where number of occurrences for a specific energy bin is measure as a count. The MCA and the SCA is connected to a computer, which allows us to record and visualize the data. The MCA creates a spectrum of the detected events The data is then processed using a Python program, which allows us to compare the radiation intensity at different lead thicknesses.

2.6 Data Collection

The data acquisition system record the intensity of the radiation emitted by the Cobalt-60 source at different lead thicknesses. The data is then processed using a Python program, where the the data first was exported from the data acquisition system. Initially, the data was exported as a .lvm file from the data acquisition system and then converted to a .csv file. Subsequently, it was read into a Python program using the Pandas library. From data, graphs are generate to show the radiation intensity at different lead thicknesses.

These graphs are then analyzed to determine the relationship between lead thickness and radiation attenuation using Possion distribution fit on the histograms of the data.

Listing 1: Code Snippet - LVM to CSV Conversion

```python
def lvm_to_csv(lvm_filename, csv_filename):
# Remove the head data from the LVM file first
# Open the LVM file for reading
with open(lvm_filename, 'r') as lvm_file:
    # Read the entire file into memory
    lines = lvm_file.readlines()

data_lines = lines

# Open the CSV file for writing
with open(csv_filename, 'w', newline='') as csv_file:
    writer = csv.writer(csv_file)

    colums = "Time      Col1    Col2    Scale"
    writer.writerow( colums.strip().split() )


    # Write data to CSV file
    for line in data_lines:
        # Split the line into values based on whitespace
        values = line.strip().split()
        writer.writerow(values)
```

3 Results

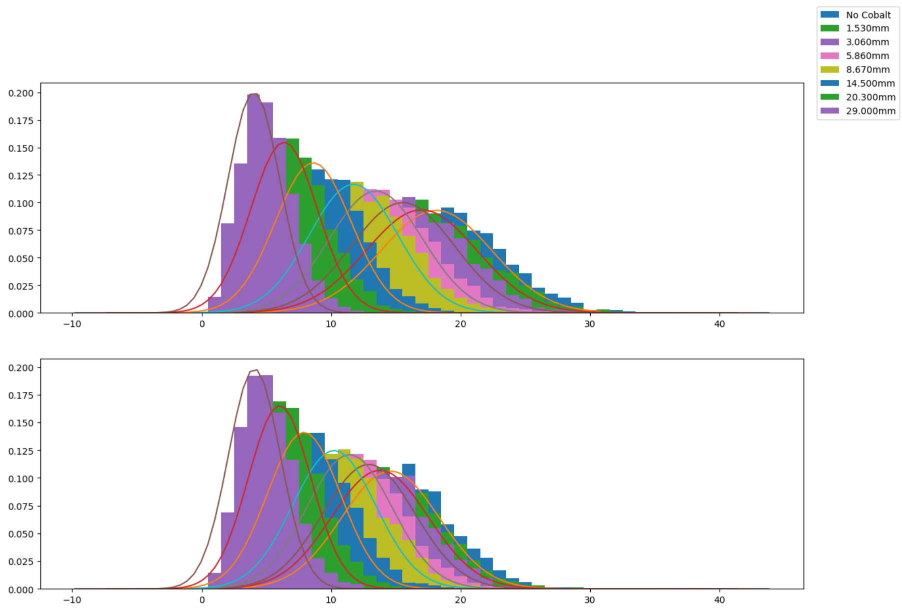

Figure 3: Radiation Detection Histogram

The experimental data collected from the Cobalt-60 source, under varying thicknesses of lead shielding, was analyzed to understand the effect of lead on radiation attenuation.

The histograms in Figure 3 illustrate the distribution of detected radiation events for different lead thicknesses, alongside a control setup with no lead shielding.

Each histogram was normalized to reflect the probability density, enabling a direct comparison between runs with different total counts. The histograms show a clear exponential decrease in event frequency with increasing lead thickness, supporting the hypothesis that lead effectively attenuates gamma radiation. A Gaussian fit was applied to each dataset to quantify the central tendency (mean) and dispersion (standard deviation) of the events. The parameters of the fits indicate a shift in the mean towards lower values and an increase in the standard deviation with increasing lead thickness, suggesting a decrease in the intensity and a broadening of the distribution of detected events, respectively. This behavior is consistent with an exponential attenuation model, where the penetration of gamma rays through lead decreases exponentially with increased path length. The fitting procedure, implemented in Python, utilized the norm.fit method from the scipy.stats library to estimate the parameters of a normal distribution that best describe the data. The resulting fits are shown as smooth curves overlayed on the histograms in Figure 3. The code snippet used for generating the histograms and fitting the data is as follows:

Listing 2: Python Code Snippet - Histograms

```
    def histrograms():
        """
            Shows lead data
        """
        datas = [
            pd.read_csv("./data_csv/No Cobalt.csv"),
            pd.read_csv("./data_csv/1.530mm.csv"),
            pd.read_csv("./data_csv/3.060mm.csv"),
            pd.read_csv("./data_csv/5.860mm.csv"),
            pd.read_csv("./data_csv/8.670mm.csv"),
            pd.read_csv("./data_csv/14.500mm.csv"),
            pd.read_csv("./data_csv/20.300mm.csv"),
            pd.read_csv("./data_csv/29.000mm.csv")
        ]

        legend_Label = [
            "No Cobalt",
            "1.530mm",
            "3.060mm",
            "5.860mm",
            "8.670mm",
            "14.500mm",
            "20.300mm",
            "29.000mm"
        ]

        # Set the figure size larger with the 'figsize' argument
        # This sets the figure size to 15x10 inches
        fig, axs = plt.subplots(2, figsize=(15, 10))
        for i in range(len(datas)):
            # Histogram
            axs[0].hist(
                datas[i]['Col1'],
                bins=np.arange(
                    min(datas[i]['Col1']),
                    max(datas[i]['Col1']) + 1,
```

```
                1
            ),
            align='right',density=True,
            label=legend_Label[i])

        axs[1].hist(
            datas[i]['Col2'],
            bins=np.arange(
                min(datas[i]['Col2']),
                max(datas[i]['Col2']) + 1,
                1
            ),
            align='right',density=True)

        # Fit
        mu1, sigma1 = norm.fit(datas[i]['Col1'])
        mu2, sigma2 = norm.fit(datas[i]['Col2'])

        xmin, xmax = plt.xlim()
        x = np.linspace(xmin,xmax,100)

        p1 = norm.pdf(x,mu1,sigma1)
        p2 = norm.pdf(x,mu2,sigma2)

        axs[0].plot(x,p1)
        axs[1].plot(x,p2)
        # axs[0].errorbar(x,p1,yerr=0.01,xerr=0.1)

    fig.legend()
    plt.show()
```

4 Conclusion

This experiment has provided quantifiable insights into the exponential nature of gamma radiation attenuation by lead. Our findings have confirmed that the intensity of radiation detected decreases as the thickness of lead shielding increases. This attenuation was characterized by a notable exponential trend rather than a linear one, indicating the complex interaction between gamma radiation and the lead barrier. The practical applications of these results are far-reaching, especially in enhancing safety protocols where radiation exposure is a concern. In medical imaging and radiotherapy, where precise dosage and protection are critical, to nuclear power generation and radioactive waste management, the insights from this study could inform better shielding designs, minimizing health risks while maximizing the efficacy of radiation use. Future research could explore a wider range of materials with different atomic numbers and densities to compare their shielding effectiveness. Additionally, investigating the secondary effects, such as the production of bremsstrahlung radiation when gamma rays interact with high-Z materials, could further refine our understanding of radiation protection. Finally, studying the impacts of different geometric configurations of the shielding could lead to the development of more effective and efficient protective structures.

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5 References

1. Greg O. Sitz. "PHY353L Spring 2024 Lecture 2" Lecture, Physics 353L, University of Texas, Austin, TX, January 29, 2024.

2. Radiation Detection Module. (n.d.). Retrieved September 14, 2021, from https://www.amptek.co
detection-module/