AM36 Laboratory Report

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Abstract

The purpose of this experiment was to determine the gamma attenuation constants of tin and lead at different energies. Samples consisting of ^{60}Co,^{137}Cs, and ^{241}Am was used to produce gamma photons that would penetrate the metal plates. The intensity of radiation when several plates were between the samples and scintillator were measured and used to determine the gamma attenuation constants. The results from the ^{60}Co and ^{137}Cs proved to fit the empirical data from NuDat very well. However due to certain errors described in Section 4, there was a significant deviation from what was interpolated for ^{241}Am.

1 Introduction

In 1896, when conducting an experiment with fluorescent minerals, Henri Becquerel discovered what we now know today as radioactive decay. Uranium salts were emitting radiation similar to X-rays that the famous Wilhelm Röntgen had recently discovered, however they were able to do this in complete isolation. This was confounding back then due to the fact that these salts were producing energy without the help of an external source.[1] This led to a frenzy of new research regarding this exotic phenomenon, among them was none other than Ernest Rutherford. Rutherford conducted several experiments with different radioactive materials and classified the rays emitted during decay into three main groups according to the intensity of the penetration; α, β, and γ rays. He did this by measuring the intensity as a function of depth of the rays when passing through certain materials, in his case it was aluminium foil. It was then found out that what was once considered witchcraft was actually part of nature, the ability to transmute an atom into another was caused by the spontaneous decays of elements due to moving to a lower energy state.

After several decades, much progress was made. However most notably in this experiment, physicists such as Einstein and Arthur Compton made revolutionary discoveries regarding the physics of particles. Einstein with his Nobel prize-winning achievement, the photoelectric effect; revealing how elements have characteristic ionizing wavelengths. The photoelectric effect is observed when light with a specific frequency shone onto a material emits electrons. The kinetic energy of each electron is given by

$$K = hf - \phi.$$

Where h is Planck's constant, f the frequency of light, and ϕ the threshold energy to ionize the material. The emitted electron, with a distinct energy, will then travel in the same direction as the photon to preserve momentum. This is a key property that is used in many light-detecting instruments, specifically the *photomultiplier tube* (PMT).

Almost two decades later in 1923, Compton discovered Compton scattering; the phenomenon in which the particle nature of light is observed. In Compton scattering, light that interacts with an atom is *scattered* and its wavelength effectively reduced, in order to preserve energy; the change of wavelength is given by

$$\lambda' - \lambda = k(1 - \cos(\theta)).$$

Where λ, λ' is the wavelength before respective after interaction, k an appropriate constant, and θ the angle between the old and new path of the photon. Scintillators make use of both of these effects to detect different kinds of radiation, in the case of high-energy photons Compton scattering dominates.[2] Although Compton scattering does occur in the experiment, the dominating effect is photoabsorption.

In this experiment a scintillator and PMT is used to determine the *gamma absorption coefficient* (μ) for tin and lead at different energies of γ-rays. The methods used are similar to that of Rutherford and are discussed further in

section 2. According to theory, the intensity of the photons decay exponentially as it penetrates the material, this can be written as:

$$I(x) = I_0 e^{-\mu x} \tag{1}$$

Where I is the intensity as a function of the penetration depth, and I_0 a constant prescribed with the intensity without penetration.[3]

For this experiment, we wish to determine the value of the variable μ. Thus, the formula used for most of our calculations is:

$$\mu = -\frac{ln(\frac{I(d)}{I_0})}{d} = \frac{ln(\frac{I_0}{I(d)})}{d}$$

2 Methods

2.1 Experiment setup

For the experiment, we were provided with 3 radiation sources (Cobalt, Caesium and Americium) and two different radiation detectors. The first detector had a thick scintillator, with a large crystal which would emit photons into the PMT. The second detector also had a PMT, but the scintillator was very thin in comparison.

2.2 Calibration

Due to the nature of the experiment, measuring the penetration depths of γ-rays and determining μ, the larger scintillator was chosen; i.e. scintillator 1. Choosing scintillator 2 would not have given measurable results since the rays would not interact and easily penetrate. The scintillator was then connected to a PMT, this was done because the scintillator emits photons while the PMT amplifies and translates the signal into a potential that can be qualitatively described.

Calibration was required because of changes in the environment that affect the sensitivity of the equipment, i.e. humidity, temperature, etc will affect the voltage over the detector. This was done by referencing the decay scheme for the elements ^{60}Co, ^{137}Cs, and ^{241}Am from NuDat.[4][5][6] Since these elements produce γ-rays, the spectrum observed will consist of discrete peaks, with characteristic energy levels attributed to the element. This is due to the fact that the atom decays to a lower energy state and in the process emits a γ photon; it is known that the photons come in quantized packets with distinct energies for each atom.

The observed characteristic peaks with corresponding channels were then matched to the energy from decays with similar probabilities; see Table 1. A total of *eight*

reference energies were used. It is further assumed that the data from the PMT is processed in the form of a linear function, $y(x) = kx + m$. This relationship was then determined through a least-square regression.

2.3 Measurements

Before taking the measurements of the intensity for each radioactive sample as a function of distance, several plates had to be measured. Two plates were chosen and each plate was measured once on every side. This was done with plates made of tin and lead. Once all the measurements were taken, the mean was produced and used for interpolation in the results.

After the plates were measured and guaranteed to be of similar length, no significant deviation from the mean, measurements for the intensity could finally take place. The first measurement taken was a control for the background radiation. Then the decay count when no plates were present between the samples and the scintillator. This was done to find the initial intensity. The decays were tallied over a live time of 90 seconds.

The live time is generally shorter than the real time, because the equipment needs a short period of time to register a gamma photon. During this time it can't detect another one, and must shut down all measurements. Thus, these shorts periods of inactivity are dead time, and not relevant to our measurements.

Because of the discrete nature of the gamma radiation spectrum, the intensity was measured by taking the integral over an interval including the characteristic peaks; the end points were chosen such that the derivative was small so as to not take in unwanted peaks. This was repeated with the addition of one to five plates between the samples and the scintillator.

3 Results

3.1 Calibration

The relationship for $keV/channels$ was approximated with a least-square regression and found out to be $\{k = 0.310keV/chn, m = -1.926keV\}$.

Element	Channel	Energy (keV)	Probability (%)
^{60}Co	4281	1332.49	99.98
^{60}Co	3789	1173.23	99.85
^{137}Cs	2168	661.66	85.10
^{137}Cs	100	32.06	3.64
^{241}Am	201	59.54	35.9
^{241}Am	43	13.9	37.0

Table 1: Observed channels with corresponding peaks.

The thickness used was $d_{tin} = 1.93 \pm 0.04mm$ and $d_{lead} = 2.00 \pm 0.01mm$.

Plates	1	2
Side 1	2.02	2.02
Side 2	2.00	2.02
Side 3	2.00	2.00
side 4	2.00	2.01

(a) Thickness of tin plates (mm)

Plates	1	2
Side 1	1.90	1.94
Side 2	1.90	1.93
Side 3	1.90	1.93
Side 4	1.93	2.02

(b) Thickness of lead plates (mm)

Table 2: Measured thickness for two plates made of two different materials.

3.2 Radiation measurements

Element/# of plates	1	2	3	4	5
^{60}Co	14647	12828	12338	11389	10602
^{137}Cs	120756	107215	97737	85730	76351
^{241}Am	6218	5663	4245	3616	3361

Table 3: Observed intensity of the decays through several layers of tin plates.

Element/# of plates	1	2	3	4	5
^{60}Co	13506	12149	11340	10275	8400
^{137}Cs	107863	85592	68895	54721	44657
^{241}Am	5636	5106	4537	3930	3567

Table 4: Observed intensity of the decays through several layers of lead plates.

Plate	Energy (keV)	μ (cm^{-1})
Sn	1332.5	0.3378 ± 0.0393
Sn	661.7	0.5556 ± 0.0147
Sn	59.5	0.8358 ± 0.3150
Pb	1332.5	0.5414 ± 0.0625
Pb	661.7	1.151 ± 0.012
Pb	59.5	0.6093 ± 0.0711

Table 5: Interpolated gamma attenuations with a 95% confidence interval.

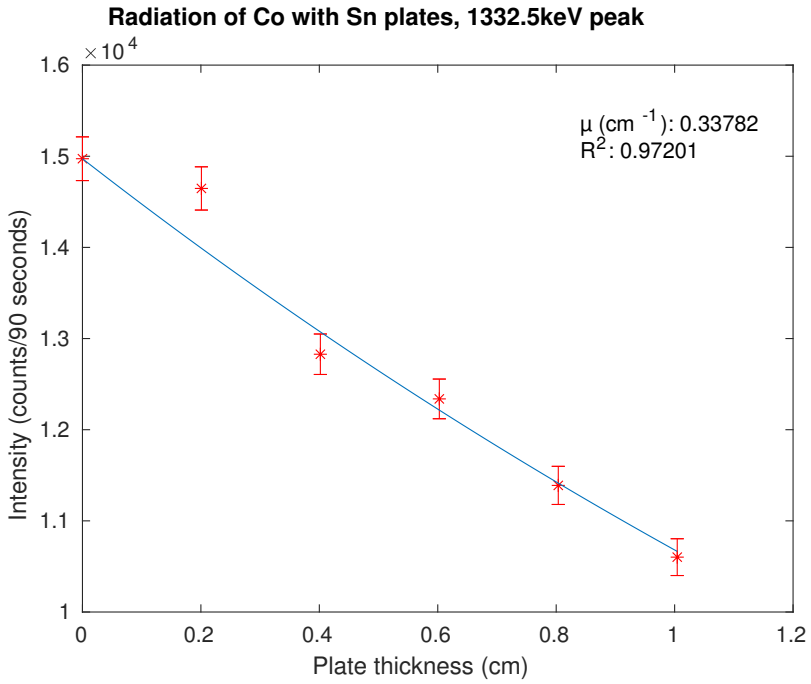

Figure 1: Radiation counts for a cobalt radiation source through tin plates.

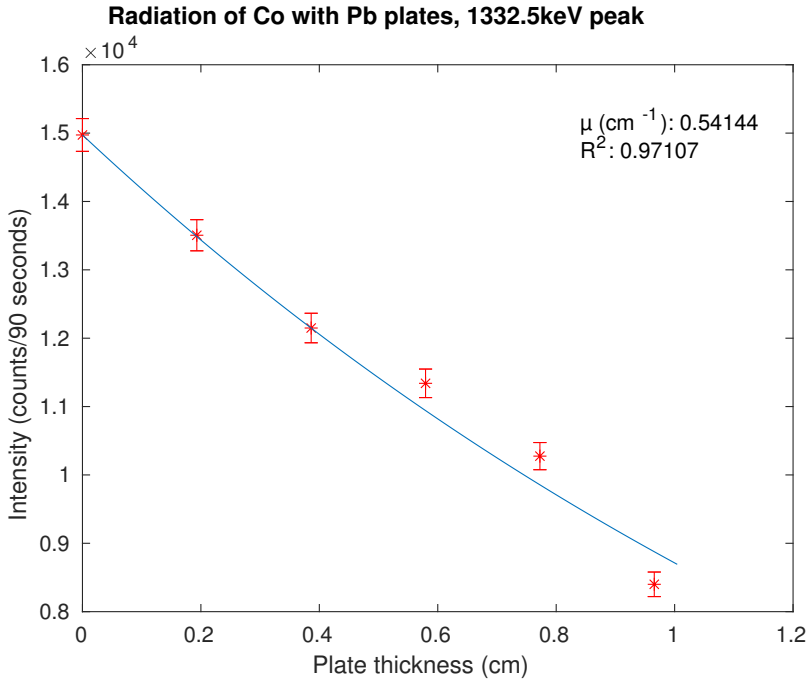

Figure 2: Radiation counts for a cobalt radiation source through lead plates.

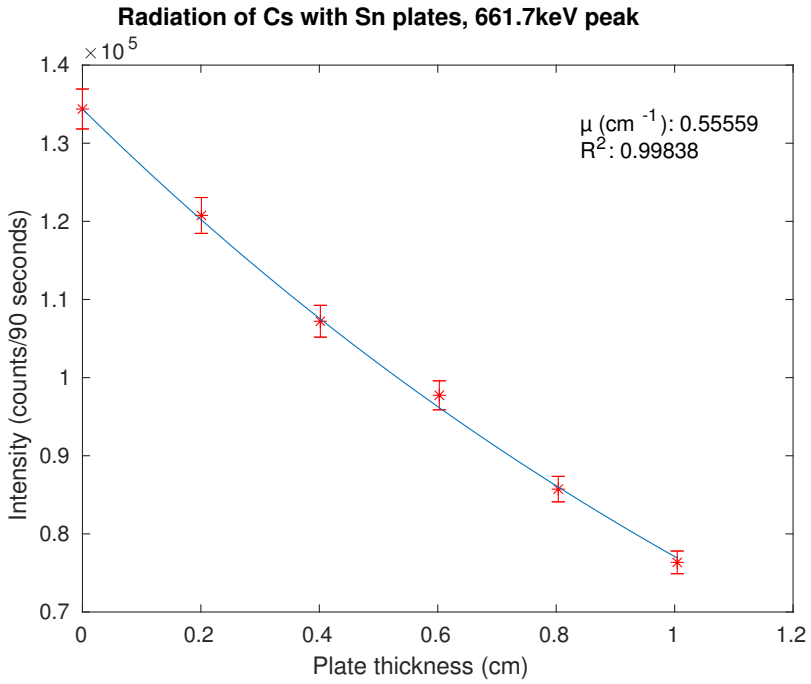

Figure 3: Radiation counts for a caesium radiation source through tin plates.

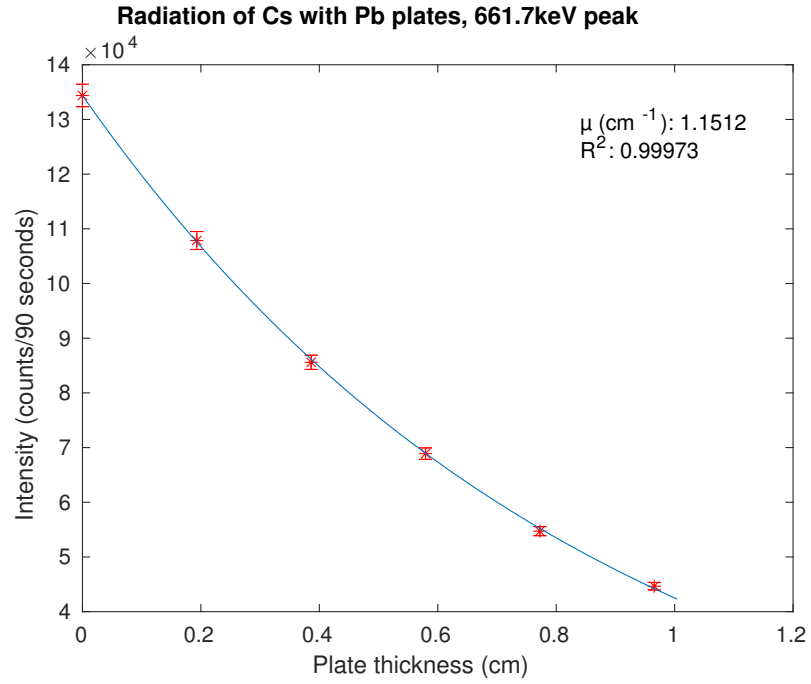

Figure 4: Radiation counts for a caesium radiation source through lead plates.

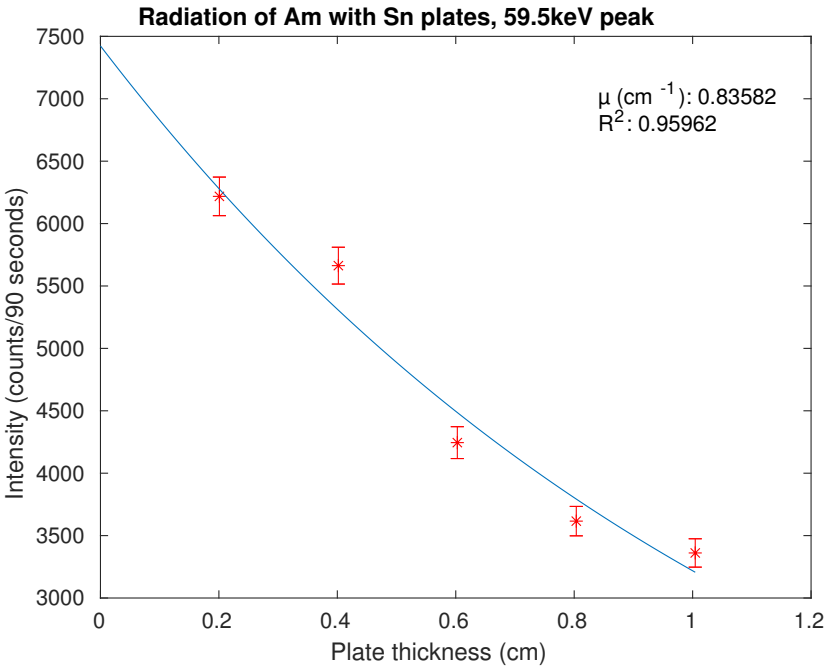

Figure 5: Radiation counts for an americum radiation source through tin plates.

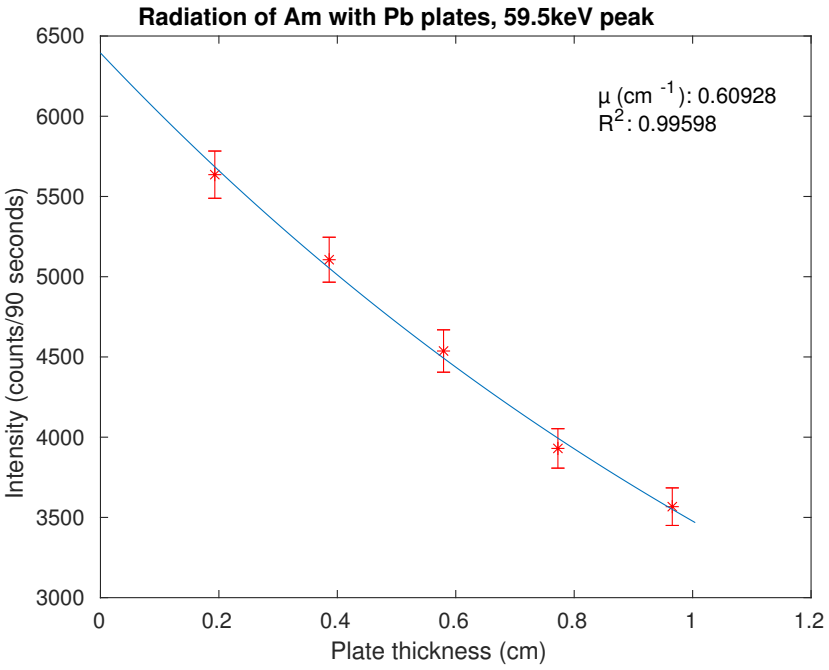

Figure 6: Radiation counts for a americum radiation source through lead plates.

3.3 Comparison to NuDat

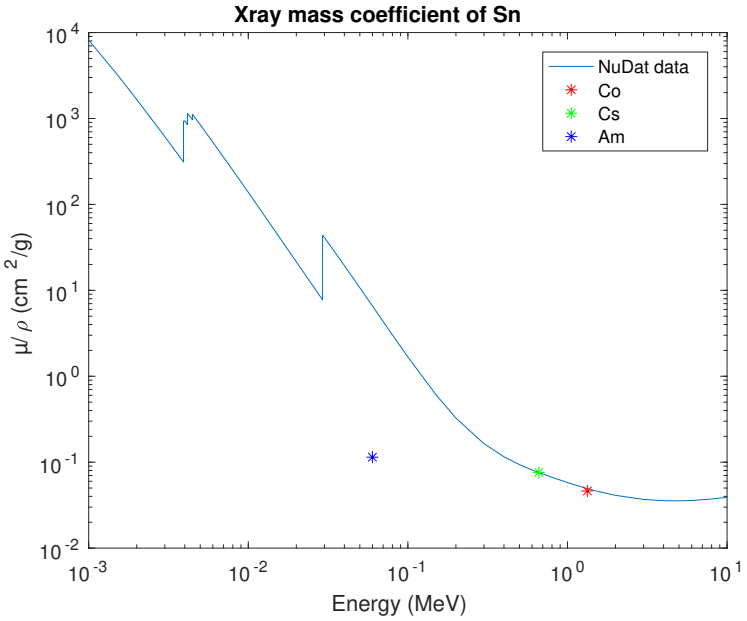

Figure 7: Comparison to NuDat data on xray mass coefficient for tin.

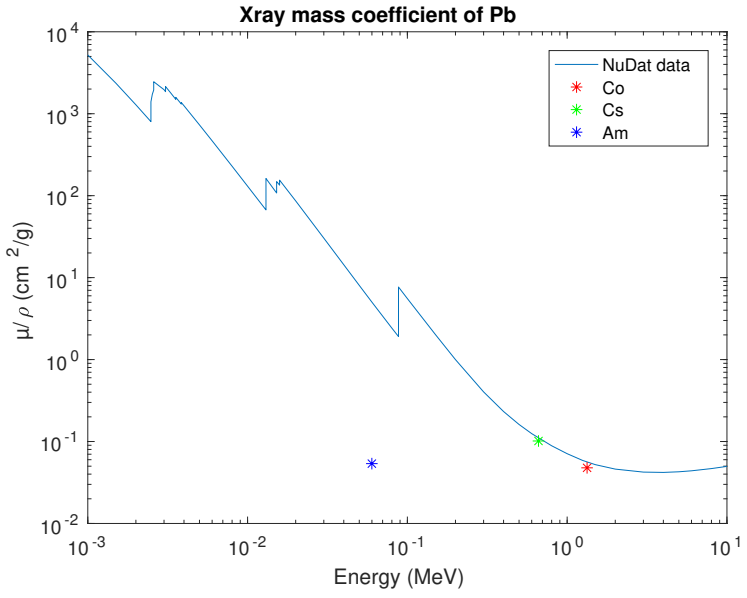

Figure 8: Comparison to NuDat data on xray mass coefficient for lead.

From Figure 7 and Figure 8 we can see that our measurements for cobalt and caesium closely fit previous results, but our values for americum are very far from the correct result.

4 Discussion and error sources

4.1 Goodness of fit

Our measurements with caesium radiation resulted in very good values, with almost no deviation from the model. However, both our cobalt and americum measurements had some inconsistent values. For cobalt, it seems that our measurements had minor inconsistencies, but not enough for us to suspect anything wrong with our measuring technique.

However, the measurements for americum varied a lot, and it greatly affected the accuracy of the radiation absorption coefficient for low energies. This is discussed further in Section 4.2.

4.2 Measurement errors

For our calculations, we discarded the measurement of Am radiation without plates. This is due to the fact that the radiation intensity was almost two orders of magnitude larger than when we added plates of either tin or lead.

One possibility for this result could be background radiation. For Co and Cs, the intensity is in the range 10^4 to $10^5 \frac{counts}{90s}$, but for Am it is around $10^3 \frac{counts}{90s}$. To determine if this would be a likely source of error, we conducted a measurement of radiation intensity without any radioactive material in the chamber. There were no plates of tin or lead in the chamber either.

From Figure 9 and Figure 10 we can clearly see that the background radiation is a significant part of the total radiation. As we added more plates, we estimated that around 30-40% of the radiation was background radiation.

This severely impacts the accuracy of our results for Am. However, background radiation was non-existent for higher energy channels, and thus it did not affect the measurements for Co and Cs, which were both measured around $1000keV$.

However, even after adjusting for the background radiation, we did not obtain a good measurement of the X-ray mass coefficient in the $60keV$. The adjusted result was closer to the NuDat value, but was still wrong by more than an order of magnitude.

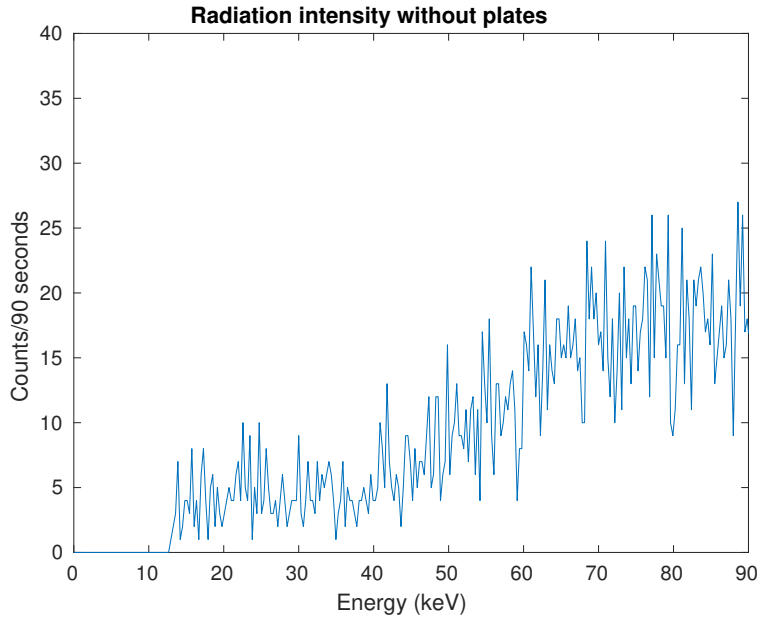

Figure 9: Background radiation in the same spectrum as Am radiation peaks.

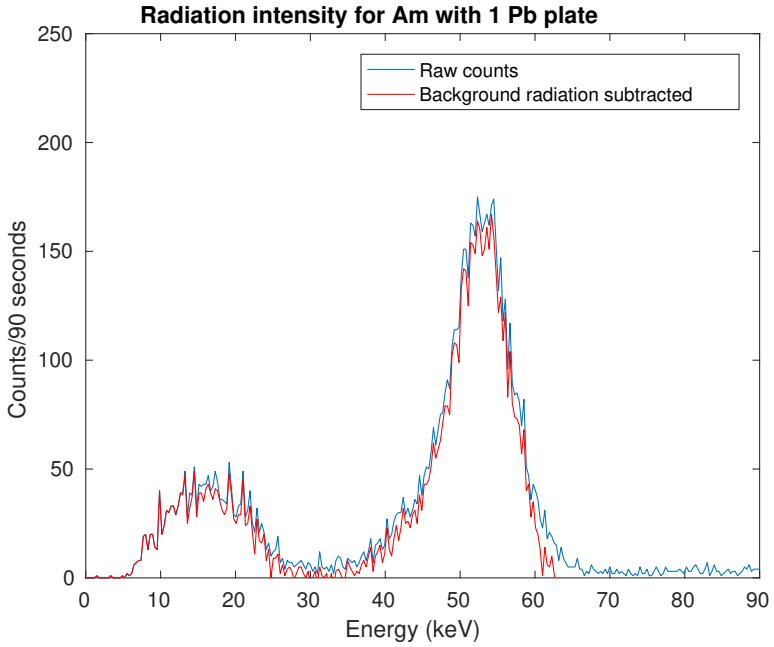

Figure 10: Comparison between measurement with and without background noise. Am has two characteristic peaks at $13.9keV$ and $59.54keV$, both of which can be seen in the graph.

4.3 Accuracy of results

Discarding the americum measurements, the rest of our experiment data correlates with literature values. The sought after result that lead has a higher radiation absorption coefficient was found by our measurements.

The reason for lead having a higher radiation absorption coefficient is because of its higher density (due to the higher atomic number). The gamma photons which enter the lead plate will be absorbed by the many electrons present in the lead. With tin having atomic number 50, and lead having atomic number 82, this difference is quite apparent.

Bibliography

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[6] M. S. Basunia, NuDat, 2006: *Nuclear Data Sheets 107, 3323*, Decay Scheme, ^{241}Am.

[7] National Institute of Standards and Technology: *Gamma attenuation of tin and lead.*