Nuclear Spectroscopy

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Aims: Investigate the radiation spectrum of Ba-133, Co-60, and NA-22. Investigate the linear absorption (attenuation) factor of Lead (Pb) and Polyethylene. Determine the half life of a neutron activated Indium foil.
Methods: A NaI scintillation detector in conjunction with a photomultiplier tube was employed to detect the radiation spectra for all investigations. By taking repeated measurements by either swapping out filters or simply waiting an appropriate amount of time, linear attenuation factors and half lives were able to be determined respectively. Cs-137 was used to both calibrate the NaI scintillation detector as well as to provide a source for attenuation investigations.
Results: Spectra of Ba-133, Co-60 and Na-22 generally are in agreement with literature, as well as the attenuation factor of lead. However the attenuation factor of Polyethylene was 560% lower than expected, possible due to the unknown polymerization or our sample. Our half life investigations into neutron activated Indium yielded a percentage error of 11% however further investigation leads this researcher to believe that much of the sample, or at least much of the radiation detected was instead due to Cd-111m a daughter nuclei of Indium. Considering this, our half life calculations yield a percent error of 1.0%
Conclusion: This investigation enlightened much of the techniques of Nuclear Spectroscopy and how one can use this to characterize materials.

I. INTRODUCTION

Nuclear spectroscopy is the study of how nuclei absorb and emit energy, a process that involves theses nuclei decaying by emitting γ, β, and α radiation. By this process, the nuclei decay into more stable types of nuclei. The amount of a radioactive substance, or equivalently the intensity of its radiation, can be modeled by:

$$I(t) = I_0 e^{-t/\tau} \tag{1}$$

where I_0 is the intensity at time 0, and τ is the decay rate. From this we can also define a half life, ie. the time when exactly half of the material is left. The calculation is as follows:

$$\begin{aligned} \frac{1}{2} I_0 &= I_0 e^{-t_{1/2}/\tau} \\ ln\left(\frac{1}{2}\right) &= \frac{-t_{1/2}}{\tau} \\ t_{1/2} &= -\tau ln\left(\frac{1}{2}\right) \end{aligned} \tag{2}$$

From this the half life can be seen to only depend on the decay constant, which should make sense.

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II. METHODS

A. Apparatus

A lead chamber constructed of lead blocks housed the sample holder and a sodium iodide (NaI) scintillation detector which composed of NaI, and a photomultiplier tube. This is then connected to a Multi Channel Scaler (MCS). Samples used in experimentation include Barium (Ba-133), Sodium (Na-22), Cobalt (Co-60), Cesium (Cs-137), and neutron activated Indium. All radioactive samples utilized were approximately 8 years old, with the exception of In-111 which was a fresh sample kept in a neutron bath until testing. All materials were provided by the University of Central Florida's physics department. The setup was calibrated with CS-137 as it has a well defined and well known radiation emission of 661.7 KeV.

B. Measurements

1. Radiation Emission Spectra

To begin, three Radiation spectra were investigated, these were Ba-133, Co-60, and Na-22. In each case the radioactive sample was placed in the sample holder, and then put into the lead chamber, in front of the NaI scintillation detector. Once the chamber was closed, data was allowed to collect for 5 minutes. This process was repeated three times, after which all three spectrum were averaged together.

2. Radiation Absorption Parameter

For this investigation Cs-137 was used due to its well defined peak at 667 KeV, and high intensity count. Two absorption parameters were investigated, that of Lead, and of Polyethylene, however the procedure was identical between them.

A range of thicknesses of filters were used in this investigation. For Lead: 0.250, 0.125, 0.062, and 0.032 inch filters were used. For Polyethylene, 0.0250, 0.062, 0.020, and 0.004 inches.

For each material, the radioactive substance with one filter was placed in the lead enclosure. The NaI scintillation detector was allowed to collect data for 1 minute. after which the energy peak at 667 KeV was investigated and it's Intensity in counts per second is recorded. The filter is then swapped out for one of a different thickness and the experiment is repeated. In this way a plot of Intensity vs Thickness can be constructed and evaluated.

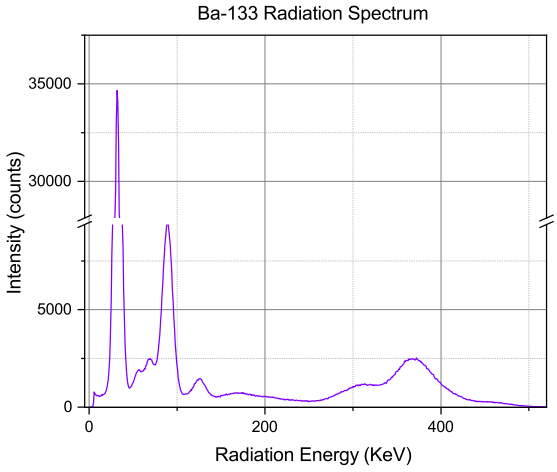


FIG. 1. Caption

3. Half Life of Neutron Activated Indium

To Investigate the half-life of the neutron activated Indium foil, the foil was placed into the lead enclosure. Then the NaI scintillation detector was allowed to collect data for 10 seconds, after which the counts per second of the largest intensity peak is recorded, and the spectrum is saved. Leaving the foil in the enclosure, this was repeated every 5 minutes for a total of 55 minutes, allowing for an Intensity vs. Time graph to be ploted and investigated. A total of 55 minutes was chosen as that is approximately the half life of Indium-116, which is the expected product of neutron activated Indium.

III. DATA

A. Radiation Emission Spectra

In this experiment we examined the radiation spectra of 3 radioactive samples, Ba-133, Co-60, and Na-22. The spectrum of Ba-133 (Figure 1) show several prominent peaks whose values can be found in Table I.

The data analyzed is the average of 2 batches of data collection where the detector was allowed to collect for 5 minutes. The peaks were fit with Origin[1] peak analyzer and are compared to the values reported by the Brookhaven National Laboratory's National Nuclear Data Center[2]. As can be seen the data collected is generally both precise and accurate accepting for the peak at 126.4 KeV. This peak does not correspond to a known γ emission of Ba-133. The best explanation we can posit is that this peak, which appears as a shoulder to the much more prominent 89.49 KeV, is due to some reflection of the 89.49 KeV radiation within the lead housing. This might lead to a shift in the wavelength of the radiation and thus a shift in energy, but that is purely speculative. It should also be pointed out that the Literature value of 31.289 KeV, is actually a waited average of several peaks in close proximity, which our detector did not have the precision to differentiate.

The radiation spectrum of Co-60 (Figure 2) has four prominent peaks found in Table II. These were also fit with Origin[1] and compared to values[3] reported by Brookhaven National Laboratory. It appears that this spectrum is much noisier than the Ba-133 spectrum, however the noise is the same, it is just that the intensity is much less. This is due to the fact that Co-60 has a much lower half life than Ba-133, so the amount of sample was much lower, and so too is the intensity. Again this data appears to be generally accurate and precise, with the exception of the very first peak of 239 KeV, with a percent error of 31.2%. The relatively high percentage error, leads to the conclusion that the literature value of 347.14 KeV does not correspond to the recorded data of 239 KeV. Again we speculate this is some sort of back reflection radiation due to the chamber.

The radiation spectrum of Na-22 (Figure 3) has three prominent peaks found in Table III. Again data was analyzed with Origin[1] and compared to Brookhaven National Laboratory's data[4]. All peaks measured exhibit a high degree of accuracy and precision. The peak located at 201 KeV is not well defined as it is amid a sea of back reflection radiation due to the chamber, but it is nonetheless measurable.

B. Radiation Absorption Parameter

In this investigation the absorption parameter of Lead (Pb) and Polyethylene were investigated. The absorption of a material is given by:

$$I(x) = I_0 e^{-\mu x} \tag{3}$$

TABLE I. Ba-133 Peak Energies

Peak Index	Peak Energy (KeV)	Standard Error	Lit. Values[2]	% Error
1	32.183	0.0089	31.289[a]	2.86
2	56.5	0.45	53.1622	6.3
3	71.9	0.48	79.6142	9.7
4	89.49	0.044	80.9979	10.5
5	126.4	0.43	XXX[b]	XXX
6	178	1.0	160.6120	11
7	302.1	0.61	302.8508	0.2
8	364.7	0.67	356.0129	2.4

[a] Weighted Average of 3 Energies from 30 to 35 KeV
[b] Peak does not correspond to known radiation energy of Ba-133.

TABLE II. Co-60 Peak Energies

Peak Index	Peak Energy (KeV)	Standard Error	Lit. Values[3]	% Error
1	239	3.0	347.14	31.2
2	885	3.8	826.10	7.1
3	1163	3.9	1173.228	0.9
4	1323	3.9	1332.492	0.7

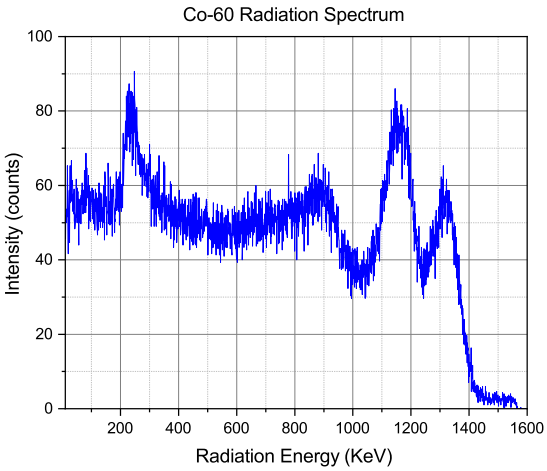


FIG. 2. Caption

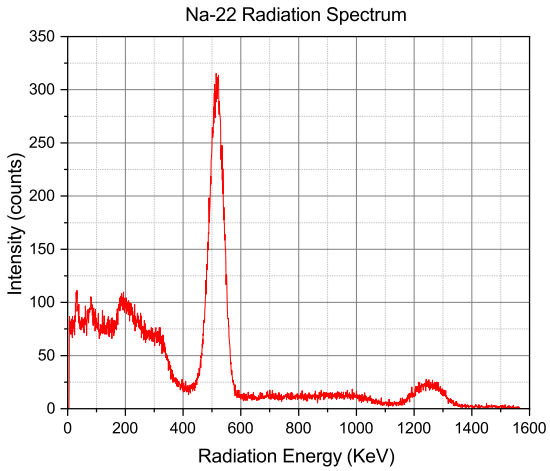


FIG. 3. Caption

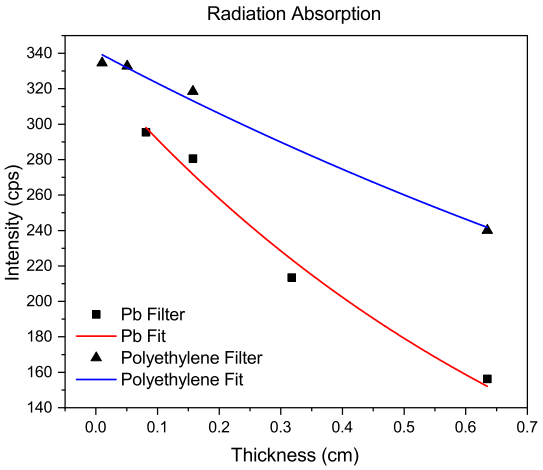
Where x is the thickness of the material, I_0 is the initial intensity and μ is the absorbance coefficient. This is calculated my measuring the intensity, in counts per second, after the radiation has passed through a filter of certain material and thickness. By choosing Cs-137 as the emitting source, the effect of there being less material at each measurement can be made negligible due to Cs-137's approximately 30 year half life, compared to the 2 hours the experiment was run in.

The plotted data can be found in Figure III B. From the exponential fit of the data the absorption coefficients can be found. For Pb the absorption coefficient was found to be $1.2 \pm 0.13\text{cm}^{-1}$. And for Polyethylene, 0.54 ± 0.040. To compare these with literature values, the XCOM: Photon Cross Sections Database[5] produced by National Institute of Standards and Technology was consulted. From this a percentage error of 3.1% for the Pb coefficient and 560% for Polyethylene.

While the measurement for Pb is both accurate and precise, Polyethylene is incredibly far from literature values. We offer two possibilities as for why. First the distribution of data points is quite sparse in the 0.3cm to 0.5cm region, which could be leading to a poor fit. Second the polymerization of our sample of polyethylene is unknown, which could be effecting the density and thus the attenuation of our sample.

TABLE III. Na-22 Peak Energies

Peak Index	Peak Energy (KeV)	Standard Error	Lit. Values[4]	% Error
1	201	1.5	216.012	6.9
2	516.4	0.36	511.0	1.1
3	1250	7.5	1274.537	1.9



C. Half Life of Neutron Activated Indium

The decay of the Indium sample can be found in Figure III C, in which radioactive intensity is measured in counts per second and time is measured in minutes. This data was plotted and fitted with Origin[1]. A half life $t_{1/2}$ is found to be 48 ± 2.5 minutes. Since all that was known about the sample was that it was a neutron activated Indium foil, its exact composition and therefore the decay schemes recorded were unknown. However by examining both the measured half life and excitation energy recorded (calculated to be approximately 424 ± 1.2 KeV), it would seem our sample of Indium decayed into Cd-111m via electron capture[6]. This is due to the fact that In-116m1, which is what we expected the sample to be has a half life of 54.29[6] minutes and an excitation energy of 127.267[6] KeV where as Cd-111m has an excitation energy of 396.214[6] KeV and a half life of 48.50[6] min. Certainly both processes are implied by the data, however it appears that Cd-111m is dominant. Using this a percentage error of 1.0% is found for the half life of our neutron activated sample.

IV. DISCUSSION

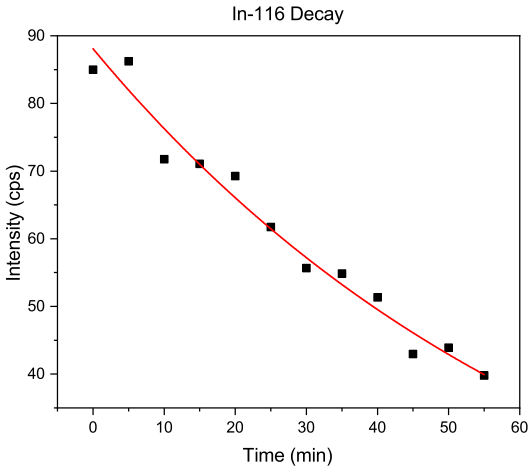
1. For the radiation spectra of Ba-133, Co-60, and Na-22, our calculated photo peaks were generally in good agreement with literature and they were generally precise as well.

2. A major indication of the different absorption coefficients is that the higher the coefficient, the more efficient at attenuating radiation the material is.

3. If we were to consider that the Indium sample was as we expected, a percentage error of 11% is found for the half life. However by analysing the energy spectra of our sample, It appears that it was mostly Cd-111m, which would yield a half life percent 1.0%.

V. CONCLUSION

Using a NaI scintillation detector the radiation spectra of Ba-133, Co-60, and Na-22 were all investigated and their radiation intensities were found to be in good agreement with literature. Afterwords the absorption coefficient of both Pb and Polyethylene in the 667 KeV range using a Cs-137 source were investigated. While the attenuation of Pb was found to be in good agreement with literature, The Polyethylene attenuation was found to be 560% smaller than that of literature. This is believed to be due to poor characterization of the sample. Finally the half life of Neutron activated indium was investigated, however due to the half life and radiation spectra investigations, this researcher is of the opinion that the sample had decayed to more Cs-111m, in which case values measured are in good agreement with literature.



VI. REFERENCES

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