

Absorption of Gamma Radiation

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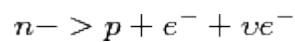
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1. Introduction

The objective of this experiment is to investigate the radiation spectrum of gamma rays using various radioisotope sources. Moreover, through testing with lead and tin shielding plates of various thicknesses, the linear absorption coefficient is to be determined for both these materials as a function of energy and compared to NIST database values.

2. Experimental Setup

The measurements are being carried out using ^{137}Cs , ^{60}Co and ^{241}Am radioisotope sources. ^{137}Cs , ^{60}Co are characterised by the fact that they initially decay by β^- radiation. This means that within their nucleus, a neutron is converted to a proton, with a resulting pair of an electron and an anti-neutrino being created outwith the nucleus as depicted in the following reaction:



The radioactive sources used are 'sealed source', meaning that they are covered by a layer of plastic which acts to stop electrons and helium particles from reaching the detector, but allows photons to pass through.

The samples are being examined in a lead cave to reduce background radiation, and a NaI scintillator and photomultiplier tube combination is used for gamma detection. When the gamma radiation interacts with the scintillator, proportional light is produced which is then converted to electrons and amplified by the photomultiplier. The resulting information is analysed by the computer program 'Tukan8k'

Initially, each radioisotope source is tested individually and the resulting spectra are analysed. Following this, the ^{137}Cs and ^{60}Co sources are used together with both lead and tin plates of varying thickness to directly shield the source from the detector in order to determine each material's influence on the radiation being emitted. The ^{241}Am source is tested in the same way but on it's own.

3. Results

3.1 Caesium-137

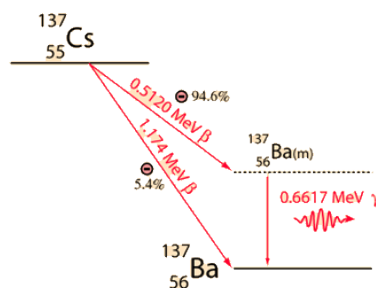


Figure 1. ^{137}Cs decay path [1]

In this report, we will just analyse the spectrum of ^{137}Cs and explain the interesting observed phenomena. ^{137}Cs initially decays through β^- where, as stated earlier, a neutron is converted to a proton in the nucleus and an electron is produced and emitted along with an antineutrino. Roughly 95% of this β^- decay results in a metastable energised state (662keV) of ^{56}Ba , with the remaining 5% decaying to stable base ^{56}Ba . The energised ^{56}Ba then de-excites through gamma emission to it's stable base state. The decay path is represented in Figure 1 and it's resulting effect can be seen as

the main photoelectric peak indicated on the gamma spectrum in Figure 2. For this main photo peak, the gamma photo fully transfers it's energy to eject a bound electron in the crystal of the scintillator.

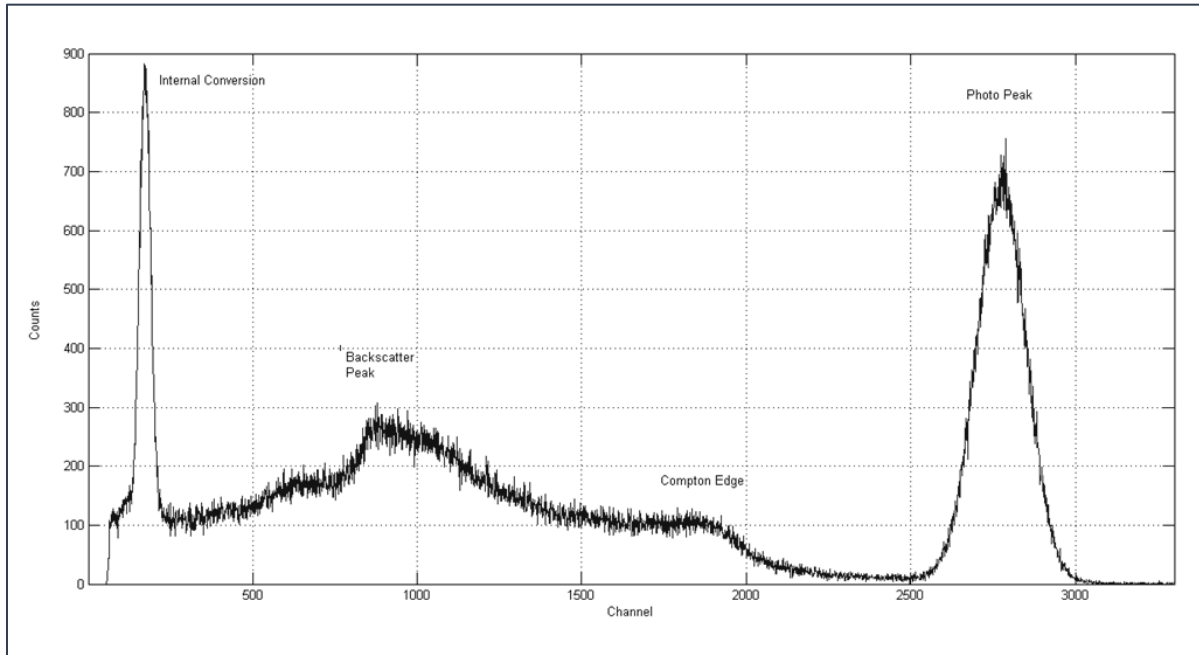


Figure.2 ¹³⁷Cs gamma spectrum

As can be seen on Figure 2, there are additional peaks which can also be explained. Unlike with the main photo peak, some of the photons being emitted will not transfer their energy fully to a bound electron in the scintillator. When the photons collide with a free or loosely bound electron, they will transfer a proportion of their energy to this electron. Depending on the angle of incident contact, the energy levels given to the electron will vary. This phenomenon is known as the Compton Scattering Effect. The maximum energy that a photon can transfer to an electron through Compton Scattering and then not cause further detectable interactions is represented by the Compton Edge peak shown on Figure 2. A further peak, known as the Backscatter Peak is caused by a large angle photon scatter off the lead cave wall which is then subsequently detected. The final peak indicated in Figure 2 is caused by Internal Conversion. This is a phenomenon resulting from an electron from the inner electron shell being emitted after receiving energy from a photon. This then creates a hole in the inner electron shell which is filled by an outer electron jumping in and releasing energy in the form of a photon representing a 'characteristic X-ray'. The low energy peak representing this Internal Conversion can be seen clearly on Figure 2.

3.2 Linear attenuation coefficient of Lead and Tin

In the second part of the experiment we examine the ability of gamma radiation to penetrate lead and tin by calculating the linear attenuation coefficient for each energy peak from the combined ¹³⁷Cs and ⁶⁰Co spectrum results using the formula shown below:

$$\mu = [-\ln(I/I_o)]/x$$

Attenuation coefficient (μ) is a function of Intensity (I), which is calculated as the area underneath each energy peak on the spectrum. (I_o) represents the intensity with no lead or tin shielding and (x) represents the thickness of shielding in use (cm). Further to this, the error in attenuation coefficient ($\Delta\mu$) is calculated for variations in plate thickness and intensity errors using the following formula:

$$\Delta\mu = \mu \sqrt{\left(\frac{\Delta I}{I}\right)^2 + \left(\frac{\Delta I_0}{I_0}\right)^2 + \left(\frac{\Delta x}{x}\right)^2}$$

Table 1 below shows the resulting attenuation coefficients and errors for various tin shielding thicknesses. The shielding plates were placed in sequence to provide an exponential increase in thickness.

Peak	Number of Plates	Thickness (cm)	Intensity	Error %	μ (cm-1)	$\Delta\mu$ (cm-1)
662 keV	0	0	82564	2.9		
	1	0.2	73270	4.5	0.5971	0.0289
	2	0.4	69026	4.6	0.4477	0.0213
	4	0.8	55628	4.8	0.4936	0.0242
	8	1.6	33916	7.3	0.5561	0.0411
1173 keV	0	0	16618	6.7		
	1	0.2	15360	8.2	0.3936	0.0350
	2	0.4	14876	8.4	0.2768	0.0247
	4	0.8	13357	9.3	0.2731	0.0267
	8	1.6	9802	11.1	0.3299	0.0381
1332 keV	0	0	16109	4.9		
	1	0.2	14965	5	0.3683	0.0202
	2	0.4	14134	6	0.3270	0.0206
	4	0.8	12272	6.2	0.3401	0.0220
	8	1.6	8831	7.7	0.3757	0.0298

Table. 1 Attenuation coefficient and error for 662keV peak (^{137}Cs) and, 1173keV and 1332keV peaks (^{60}Co) using Tin shielding.

Tables 2 and 3 show the average attenuation coefficient, average error in attenuation coefficient and attenuation coefficient divided by the density of the respective shielding material for each energy peak. The reason that Table 3 includes the 32 keV energy peak resulting from ^{241}Am decay, and Tables 1 and 2 don't, is because even with a single 0.2cm tin plate, the entire low energy ^{241}Am decay peak was attenuated. The density of Tin was taken as 7.31 g/cm³ and the density of lead was taken as 11.53 g/cm³.

Energy (MeV)	μ (cm ⁻¹)	μ/ρ (cm ² /g)	Error $\Delta\mu$
0.662	0.5236	0.0716	0.0288
1.173	0.3184	0.0436	0.0311
1.332	0.3528	0.0483	0.0232

Table 2. Average attenuation coefficient and error for Tin shielding

Energy (MeV)	μ (cm ⁻¹)	μ/ρ (cm ² /g)	Error $\Delta\mu$
0.032	5.8965	0.5195	5.5206
0.662	1.1171	0.0984	0.0856
1.173	0.6020	0.0530	0.0679
1.332	0.5608	0.0494	0.0415

Table 3. Average attenuation coefficient and error for Lead shielding

These resulting values are plotted against the National Institute for Standards and Technology (NIST) [2] curves for Lead and Tin linear attenuation and presented in Figures 3 and 4 below.

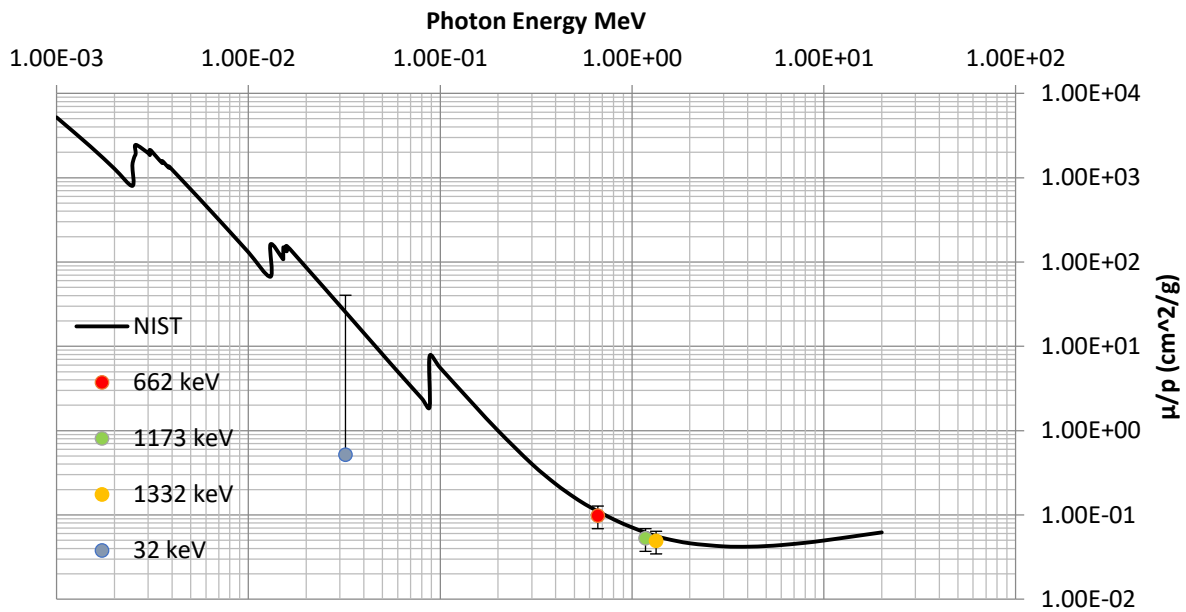


Figure 3. Attenuation coefficient over density in relation to energy (Lead)

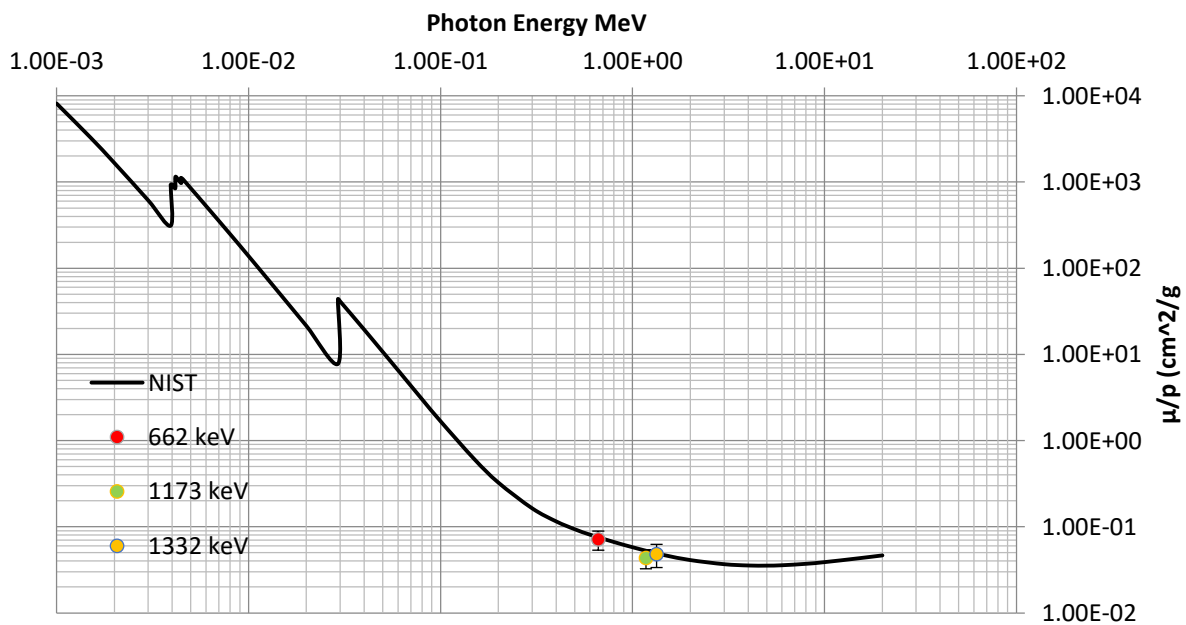


Figure 4. Attenuation coefficient over density in relation to energy (Tin)

4. Conclusion

As Figures 3 and 4 clearly show, the gamma attenuation coefficients which were measured and calculated for this report closely follow the data provided by NIST for both tin and lead. The one outlier is the attenuation value for lead for the 32keV peak from ^{241}Am which had a very high average error associated with it.

5. References

- [1] <http://hyperphysics.phy-astr.gsu.edu/hbase/nucene/fisfrag.html>
- [2] <http://physics.nist.gov/PhysRefData/XrayMassCoef/ElemTab/z82.html>
<http://physics.nist.gov/PhysRefData/XrayMassCoef/ElemTab/z50.html>