JOINT INSTITUTE FOR NUCLEAR RESEARCH
Veksler and Baldin laboratory of High Energy Physics

FINAL REPORT ON THE INTEREST PROGRAMME

Radiation Protection and the Safety of Radiation Sources

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I am also extremely grateful to all my professors and teaching assistants - in the department of nuclear engineering - who taught me and gave me a solid base in this field.

ABSTRACT

Radiation sources widely exist around us. So, it's important to learn about them and know how to protect ourselves from their radiation. In this project, we explored some features about radiation and got a wealth of information about radiation detectors. Using ROOT software, we could analyze different spectra taken by BGO and NaI scintillation detectors and deduce the energy calibration curve using standard radiation sources (Co-60 and Cs-137). The resolution of BGO and NaI detectors was successfully calculated. Then, we managed to identify the unknown sources of radiation in the spectrum using the energy calibration curve. Furthermore, we could

calculate the attenuation coefficient of different materials and the range of alpha particles in the dry air using plastic and pixel detectors.

1. BGO detectors

Bismuth Germanium Oxide detectors are a type of scintillation detectors commonly used in nuclear physics and medical imaging applications. They are made of a crystal composed of bismuth germanate ($Bi_4Ge_3O_{12}$), which exhibits excellent scintillation properties.
BGO crystals have a high density and high atomic number, which makes them efficient in converting incident radiation into scintillation light. They emit photons in the visible range when gamma rays or other high-energy particles interact with the crystal. BGO detectors are particularly effective in detecting gamma rays due to their high density and large effective atomic number. They have a high stopping power for gamma rays, allowing for accurate energy measurement and identification of gamma-ray sources.

1.1. Energy resolution

Energy Resolution of a detector measures its ability to distinguish gamma-rays with close energies.

$$R = \Delta E_{FWHM} / E = 2.35 \times \sigma / \mu$$

Using root software, we could get the standard deviation (σ) and the mean energy (μ) at different voltages from 1200 V to 2000 V by fitting the peaks.

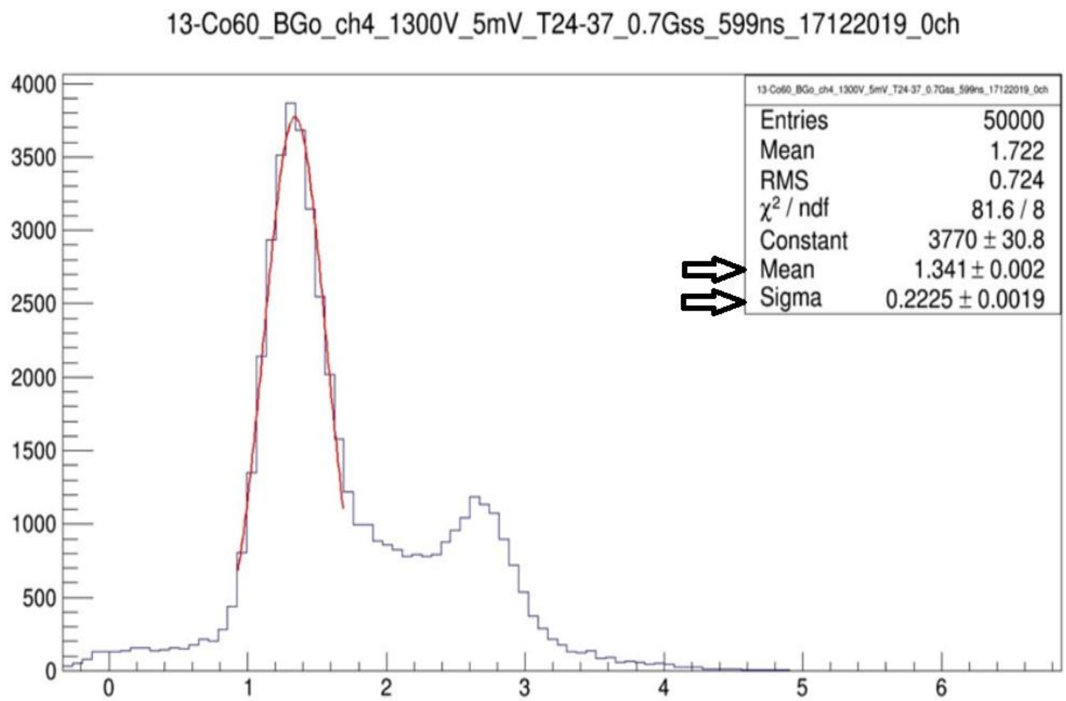

Figure 1. Spectrum of Co60 using BGO detector at 1300 applied voltage.

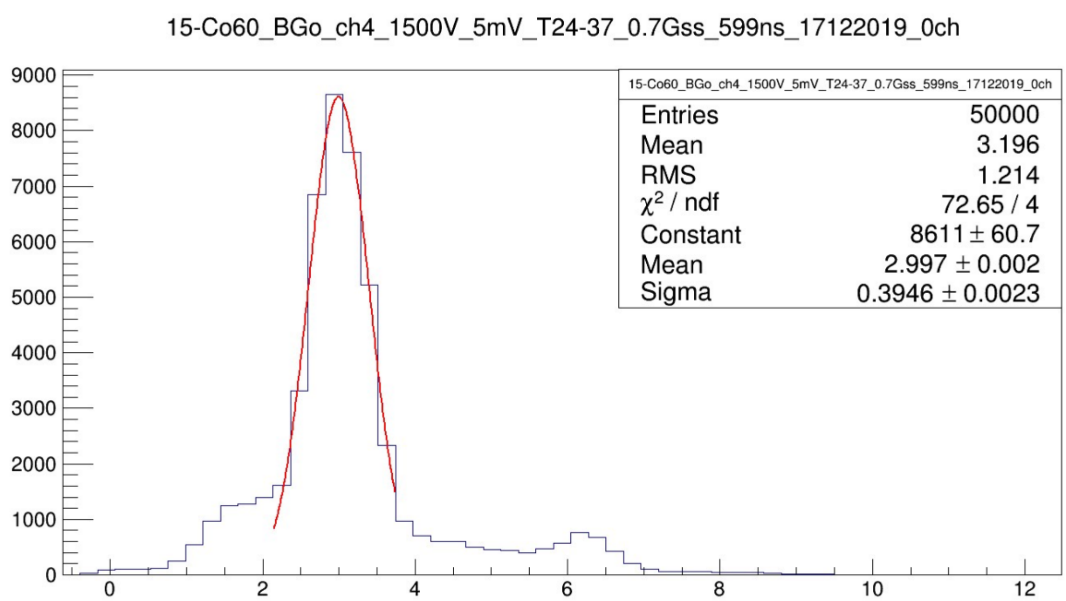

Figure 2. Spectrum of Co60 using BGO detector at 1500 applied voltage.

V	1200	1300	1400	1500	1600	1700	1900	2000
σ	0.3636	0.225	0.2647	0.3946	0.5595	0.7242	1.218	1.524
μ	1.649	1.361	1.921	2.997	4.418	6.125	10.67	13.64
R (%)	51.817	38.85	32.381	30.941	29.76	27.786	26.826	26.257

We got the relationship between resolution and voltage which shows that higher accelerating voltages provide better sharpness and resolution.

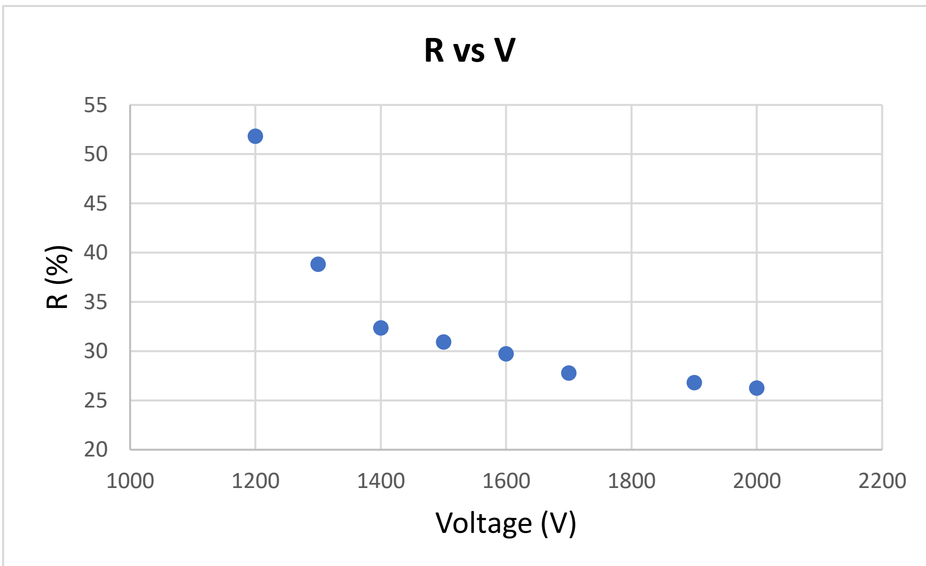

Figure 3. Relationship between the resolution and applied voltage

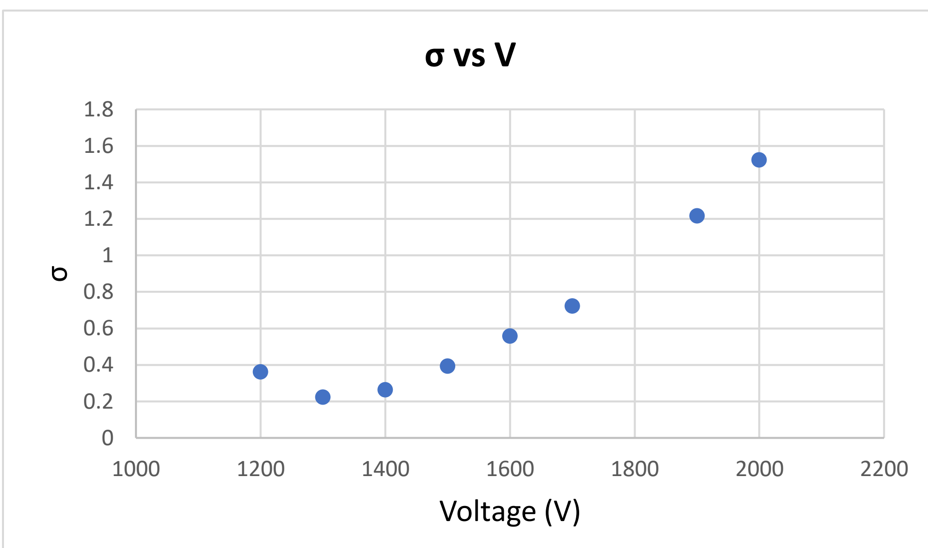

Figure 4. Relationship between the signal and applied voltage

1.2. Calibration of detectors

Calibrating detectors is an important step to ensure accurate measurements of radiation levels. The calibration process involves comparing the response of the detector to known radiation sources of specific intensities.

To calibrate the BGO detector we used a signal of Cs137 that we know it has a peak of 662 KeV and Co60 that has two peaks at 1173 KeV and 1332 KeV taking their average (1252.5 KeV) - as the BGO has low resolution. -

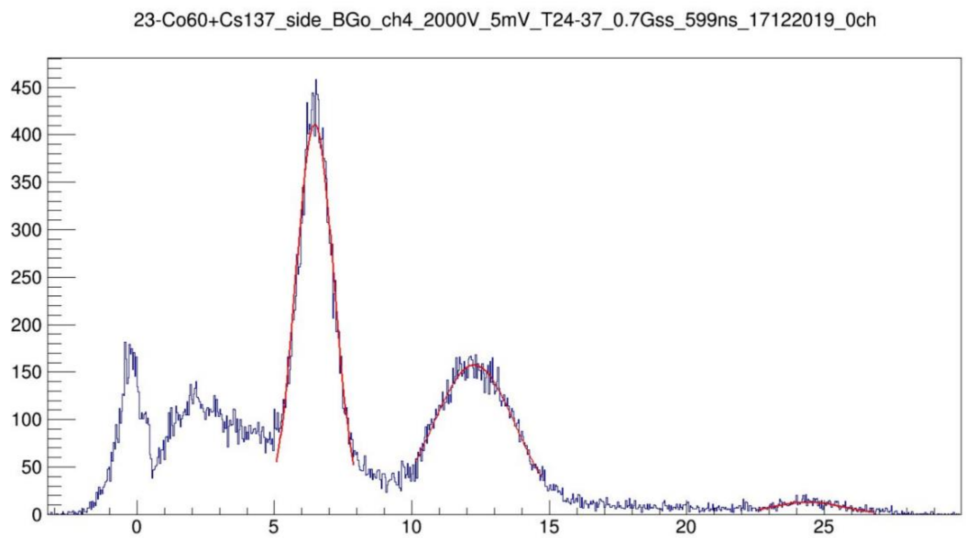

Figure 5. Signal of known sources (Cs137 +Co60) taken by BGO detector

By fitting the peaks of the signal, we get

Mean = Channel number	6.46693	12.2614	24.3972
Peak (KeV)	662	1252.5	2505

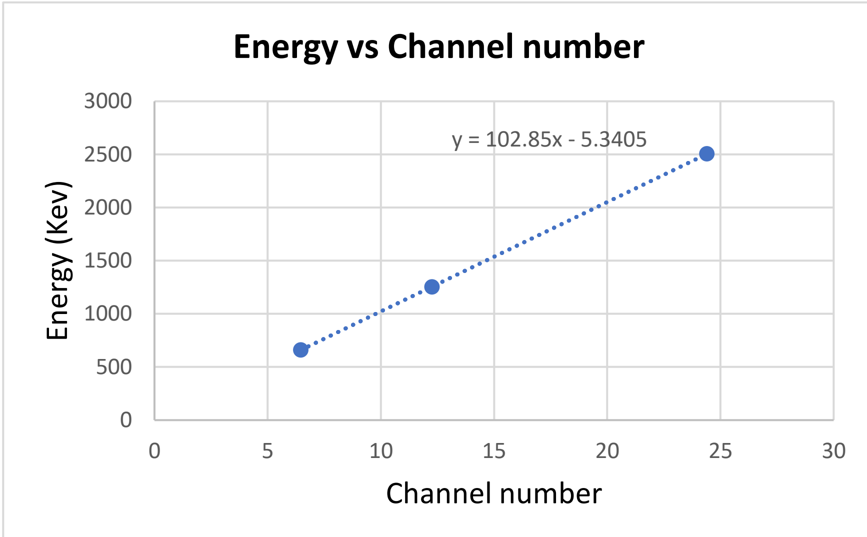

Figure 6. Calibration curve of BGO detector

This is the calibration curve of BGO which is almost linear, as expected, since radiation energy has a direct proportionality relationship with channel number. From this relationship, one can determine the corresponding energy of any unknown source when the channel numbers of its radiation energies are known.

2. NaI detector

Sodium iodide detector (NaI) is also a type of scintillation detectors but has higher resolution. For the same element Co60, doing the same analysis will give the following data:

2.1. Resolution of NaI

V	900	1000	1100	1200	1300
σ	0.6081	0.986	1.53	2.08	2.557
μ	23.68	40.64	65.74	98.28	137.4
R (%)	6.035	5.7	5.469	4.97	4.373

we will note that the resolution has become much better.

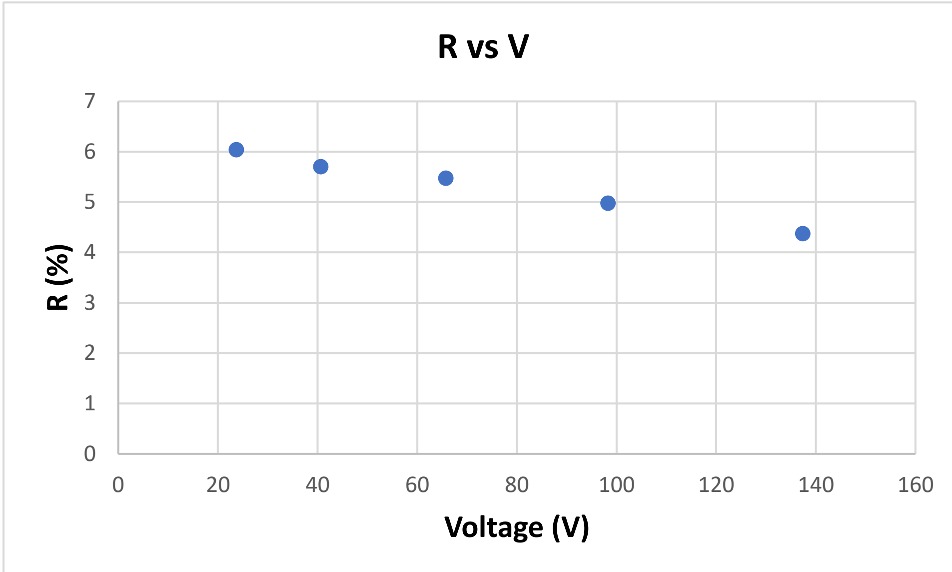

Figure 7. Relationship between the resolution and applied voltage

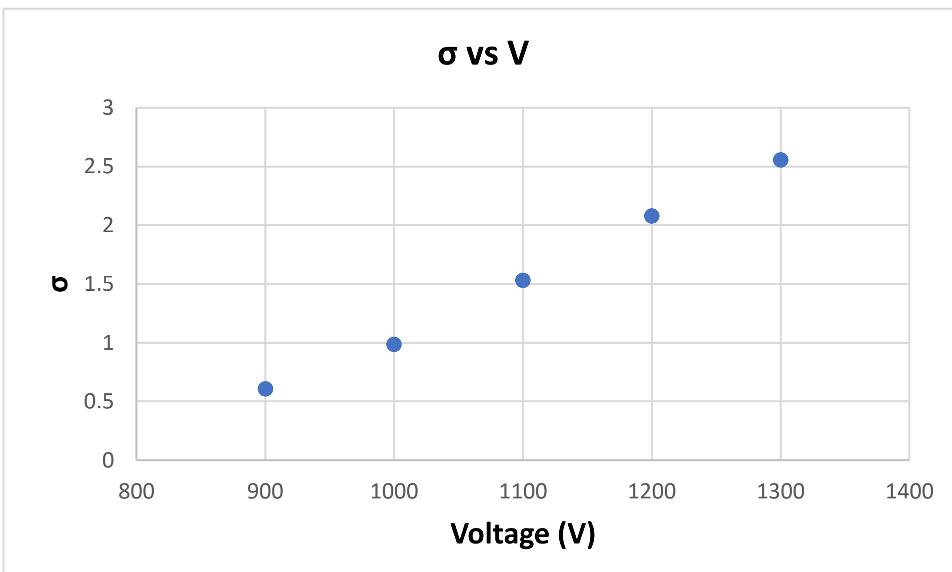

Figure 8. Relationship between the signal and applied voltage

2.2. Calibration of NaI

Note that Nai detector can discriminate between the two peaks of Co 60 (1173 & 1332 KeV), so we have here four points for calibration compared to three points in the case of BGO detector.

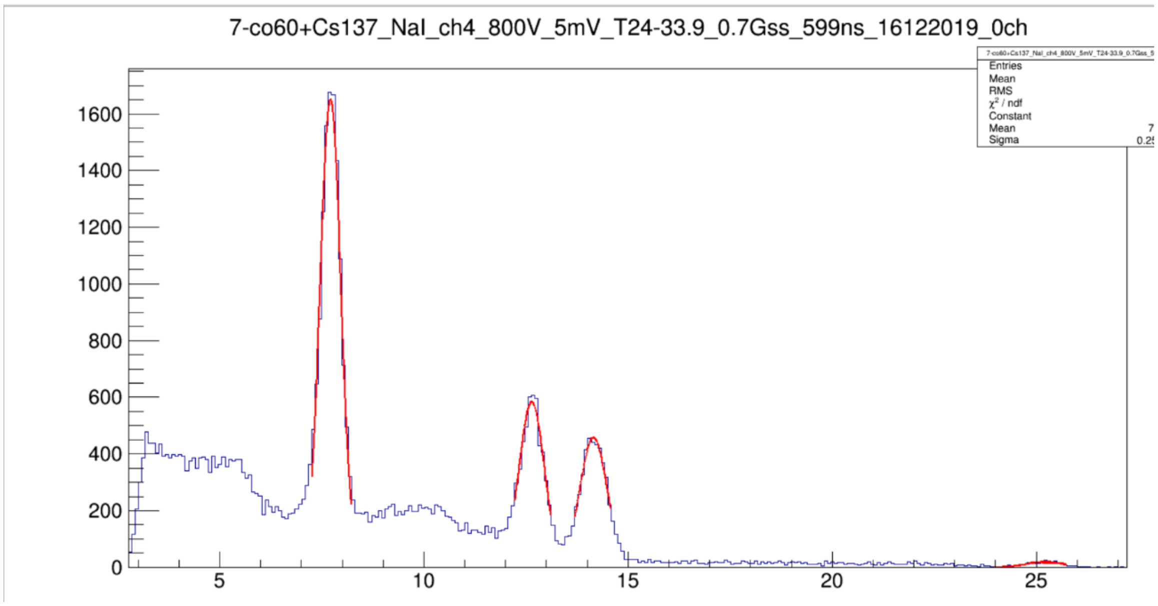

Figure 9. Signal of known sources (Cs137 +Co60) taken by NaI detector

Mean = Channel number	7.708	12.634	14.147	25.195
Energy	662	1173	1332	2505

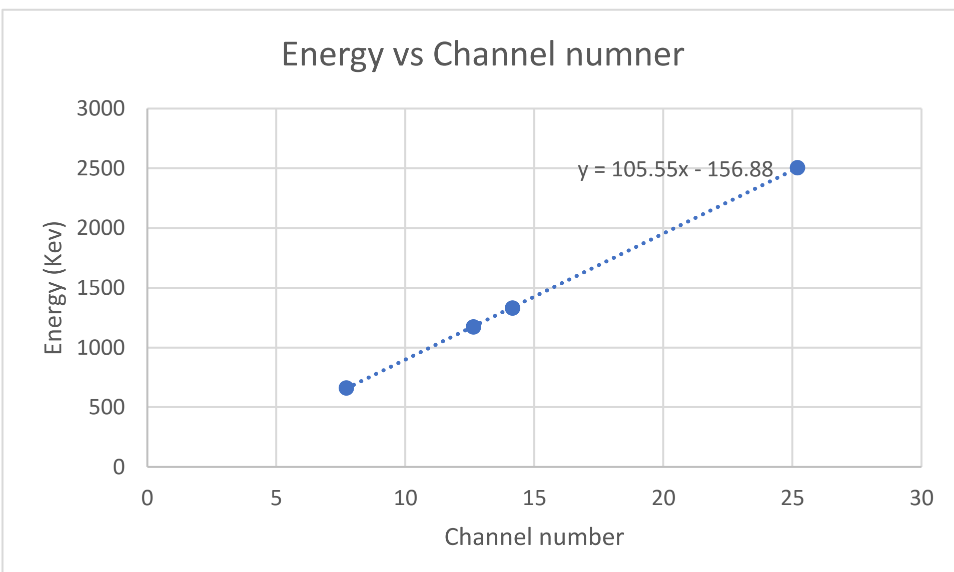

Figure 10. Calibration curve for NaI detector

3. Determination of unknown source using NaI

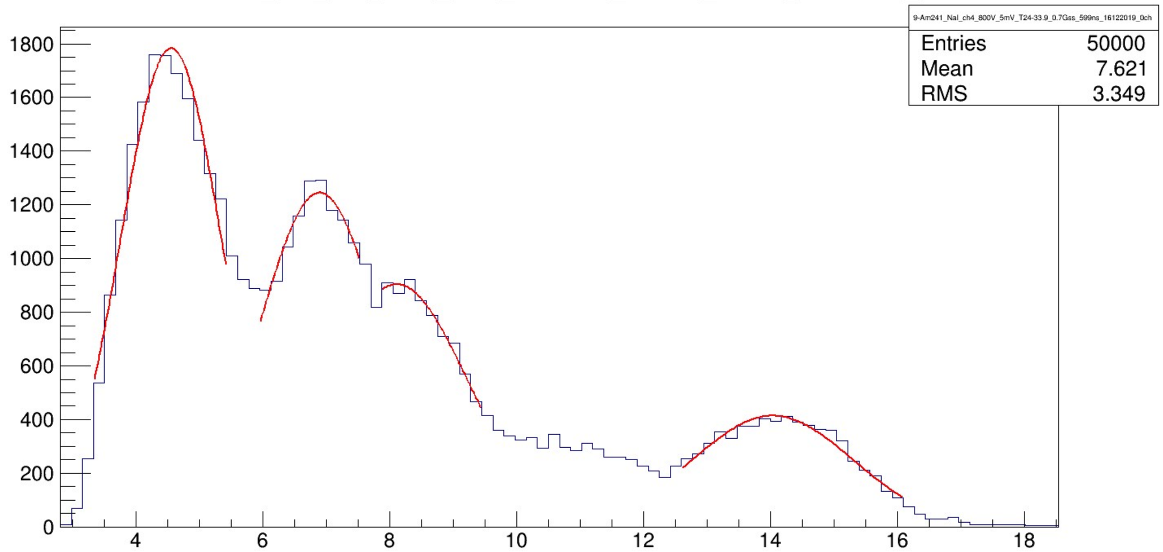

Figure 11. Signal of unknown sources by NaI detector

By fitting the peaks, we can get:

Channel number	4.5	6.9	8.1	14

using the equation: y =105.55 x - 156.88 where x is the channel number and y is the energy

Energy (KeV)	318.095	571.415	698	1320.82

4. Gamma Attenuation coefficient

Attenuation coefficient for gamma rays represents the extent to which gamma radiation is attenuated or weakened as it passes through a particular material. The attenuation coefficient is influenced by the energy of the gamma rays and the properties of the material they encounter.

$$I = I_0 \exp(-\mu x)$$

I is the intensity after attenuation.

I_0 is the intensity before attenuation.

μ is the attenuation coefficient (cm^{-1}).

x is the thickness of the shield (cm).

For sitting up we will use: BGO detector, 2000 V, Cs-137 (source).

4.1. Using Al as a target:

x	0	0.15	0.3	0.45	0.75	0.9	1.08	1.26
I/I_0	1	0.75573	0.71623	0.70569	0.68596	0.67155	0.66103	0.63939

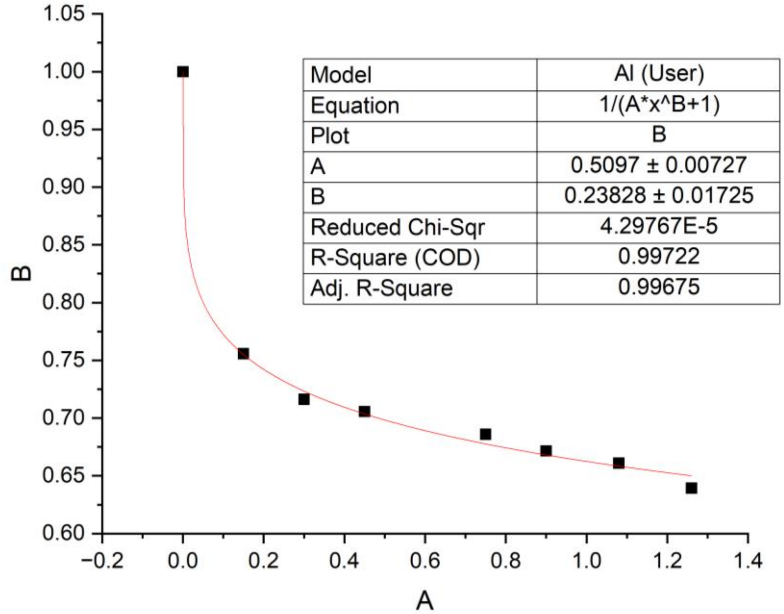

Figure 12. Attenuation of gamma by Al

Fitting the plot will give: $\mu_{Al} = 0.23828\ cm^{-1}$

4.2. Using Cu as a target:

x	0	0.2	0.25	0.4	0.8	1	1.2
I/I_0	1	0.73931	0.7357	0.68065	0.58611	0.53827	0.48042

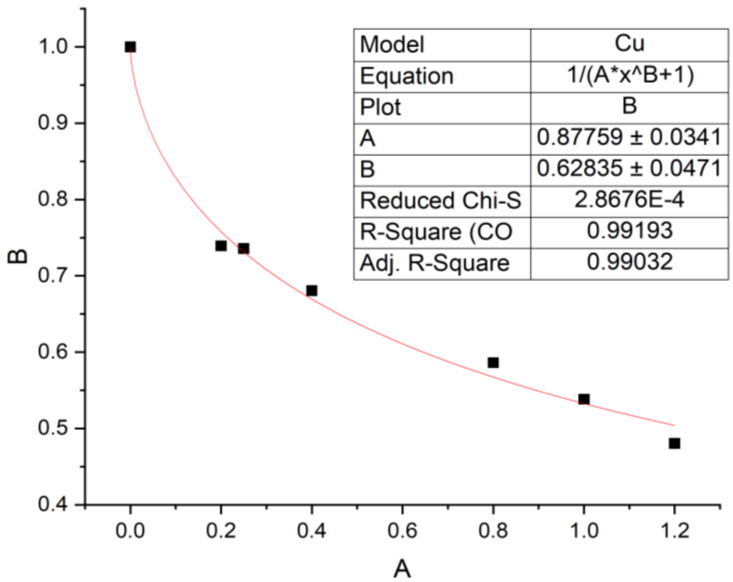

Figure 13. Attenuation of gamma by Cu

Fitting the plot will give: $\mu_{Cu} = 0.62838\ cm^{-1}$

5. Alpha range in air

The range is defined as the distance an alpha particle can travel before it loses all its energy through ionization and other interactions with the air molecules.

Changing the distance from the detector will give us the following results which shows that the range of alpha in air = 3.5 cm (alpha loses its energy at 3.5 cm).

For setting up: plastic detector, 1000 V, Pu239 (source) of Energy 5 MeV.

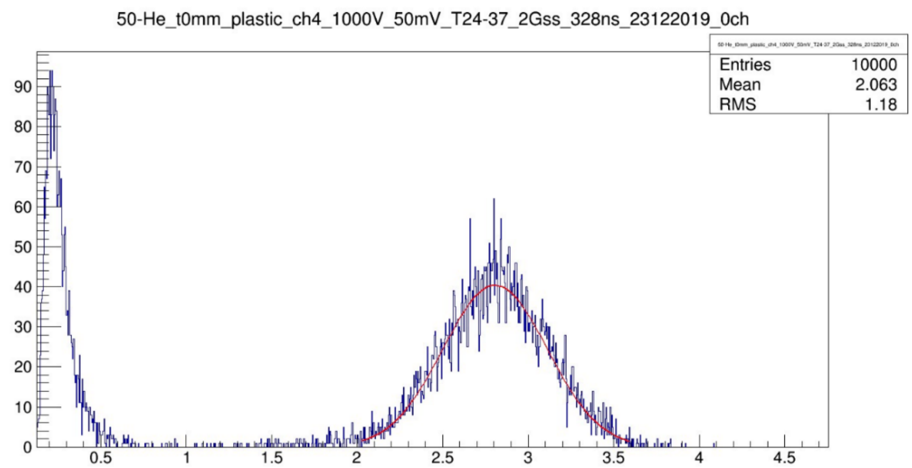

Figure 14 Energy spectrum of alpha at distance = 0 cm from the plastic detector

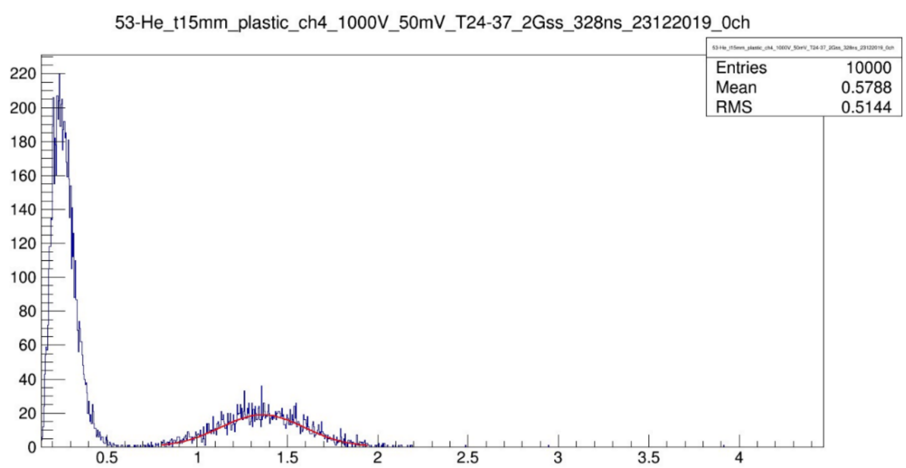

Figure 15. Energy spectrum of alpha at distance = 1.5 cm from the plastic detector

Distance (cm)	0	0.5	1	1.5	2	2.5	3
Mean = Channel number	2.807	2.15	1.71	1.362	1.04	0.7998	0.2673
Energy (MeV)	5	3.826	3.0494	2.4259	1.8526	1.4248	0.476

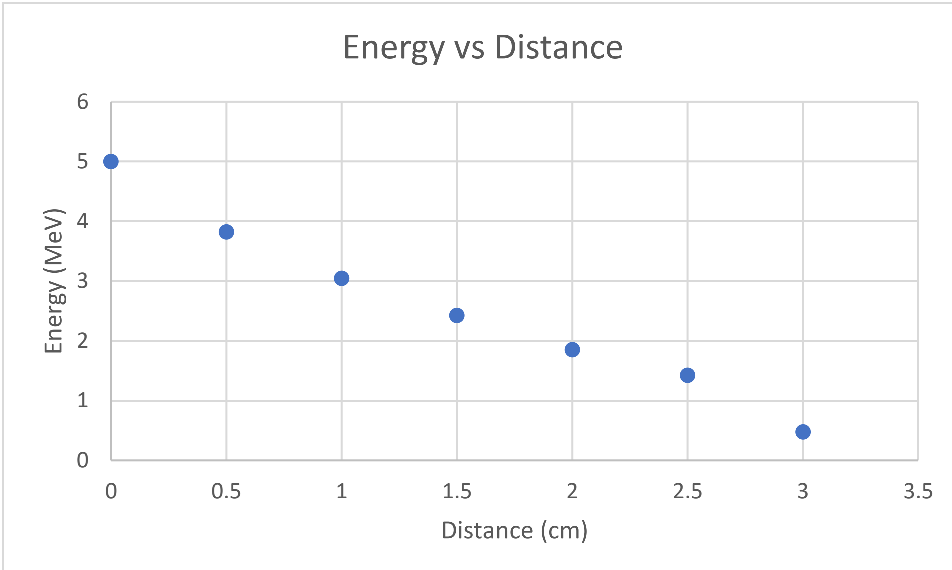

Figure 16. Energy of alpha in air with distance from the plastic detector

and by integrating (calculating area under the peak) we can get the number of counts per second:

Distance (cm)	0	0.5	1	1.5	2	2.5	3	3.5	3.8	4
Counts/Sec	440	390	360	340	320	300	280	260	260	260

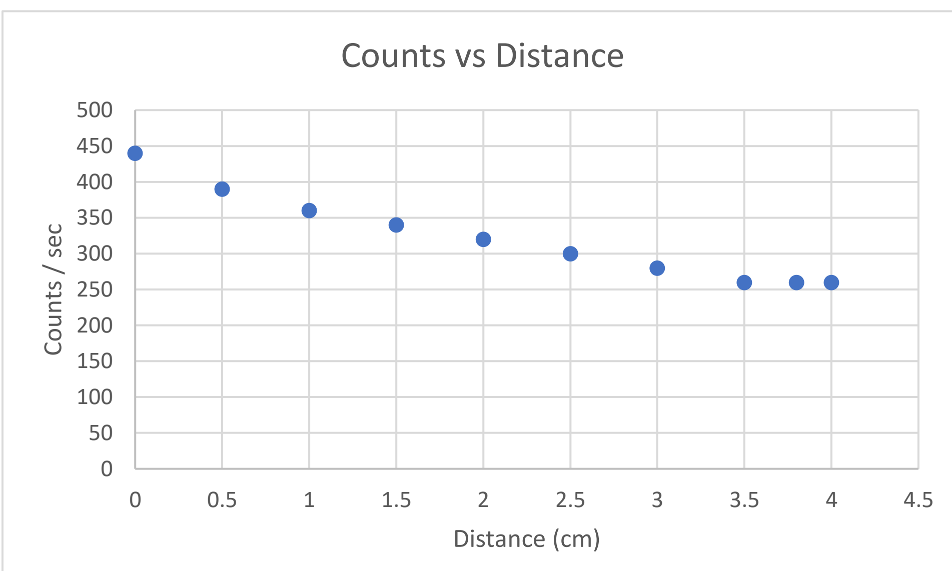

Figure 17. Number of counts per second with the distance from the plastic detector

6. Pixel detectors

Pixel detector is an advanced type of radiation detectors, it consists of 3 parts: Sensor (Si), Electronic chip, USB.

Determination of Alpha Range Particles in Air by Pixel Detectors:

For Setting up: Pixel detector. Am241 (Source) of energy 4 MeV.

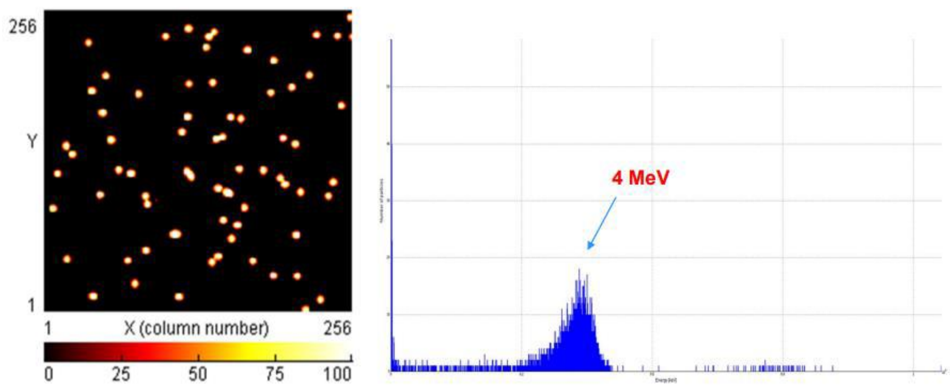

Figure 18. Alpha spectrum at 0 cm

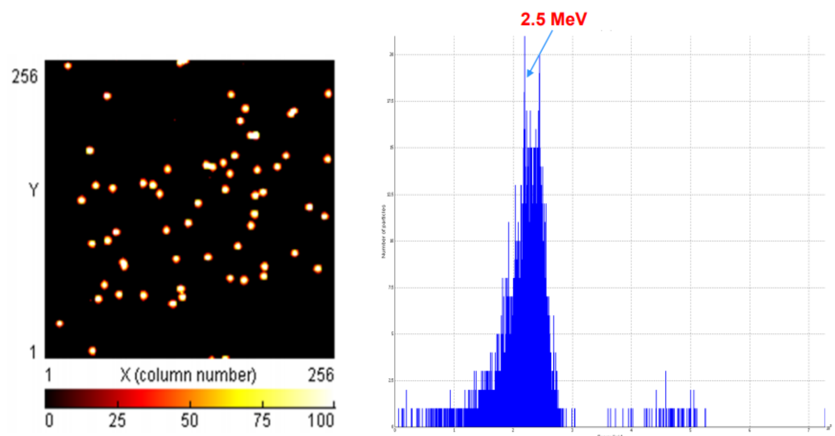

Figure19. Alpha spectrum at 1 cm

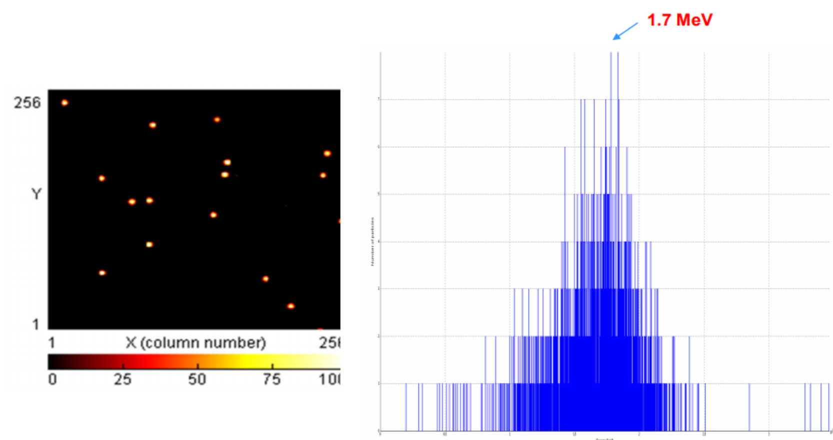

Figure 20. Alpha spectrum at 2 cm

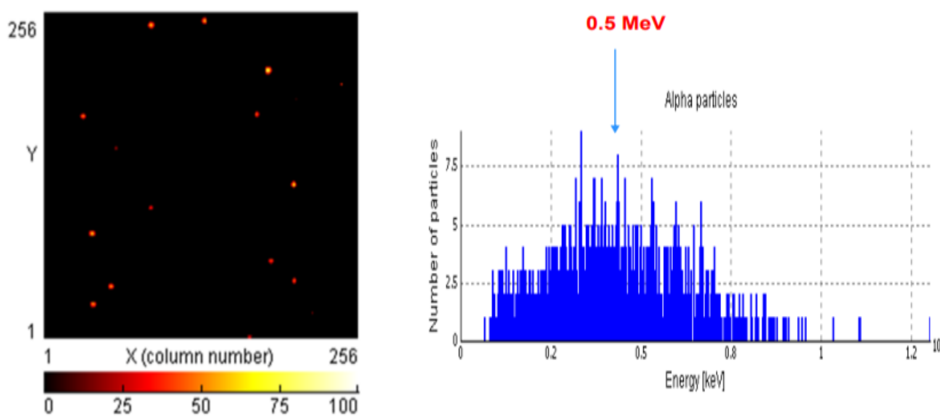

Figure 21. Alpha spectrum at 2.5 cm

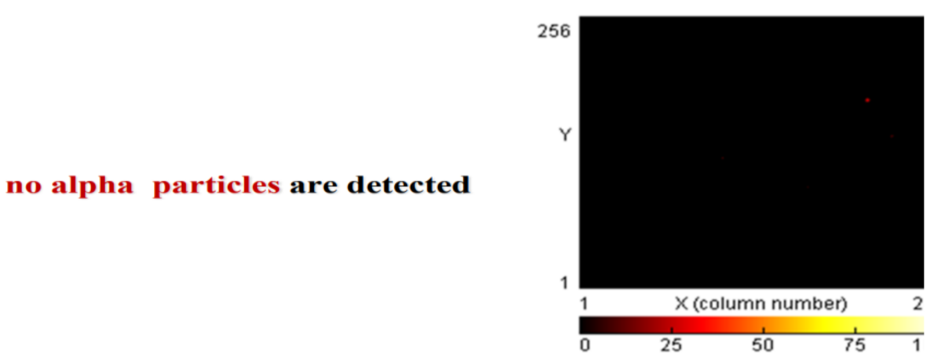

Figure 22. Alpha spectrum at 3 cm

Distance (cm)	0	1	2	2.5	3
Energy (MeV)	4	2.5	1.7	0.5	0

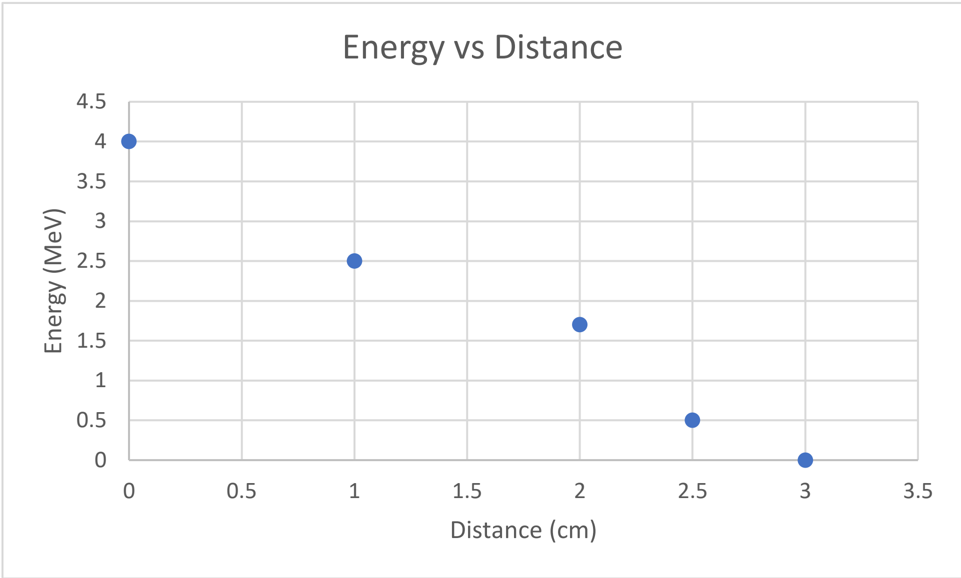

Figure 23. Energy of alpha with distance from the pexel detectors

REFERENCES

[1] Knoll, G. F., Radiation detection and measurement, 4th Edition, Wiley (2010).