JOINT INSTITUTE FOR NUCLEAR RESEARCH

Dzhelepov Laboratory of Nuclear Problems

FINAL REPORT ON THE INTEREST PROGRAMME

Radiation Protection and the Safety of Radiation Sources

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Task #1.1

BGO Detector, Resolution Vs Applied Voltage

BGO is an inorganic scintillator (crystal) that converts incident radiation into light within the visible range. It's coupled with a photon multiplier tube (PMT) that converts the light output of a BGO crystal into voltage pulses. Voltage pulses are processed such that they indicate radiation counts.

Resolution of BGO detectors is its ability to accurately determine the energy of the incoming radiation and separate between adjacent energy peaks.

$$Resolution = \frac{\sigma}{mean} \times 2.35 \longrightarrow \text{Equation. 1}$$

- ROOT is used to apply gaussian fitting to given data at different applied voltages.
- Resolution is calculated using equation 1.
- Resolution is plotted against voltage using Origin

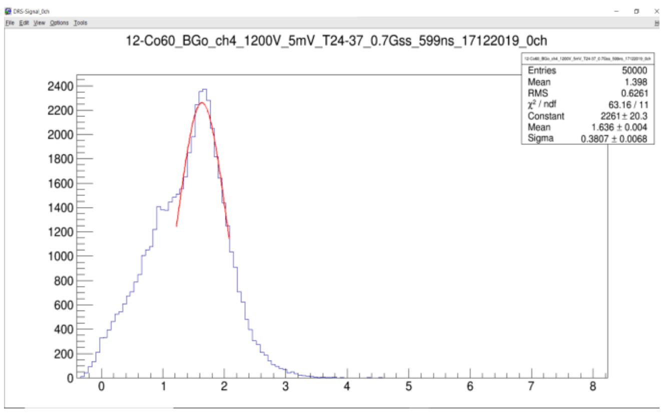


Figure 1, 1200 V applied

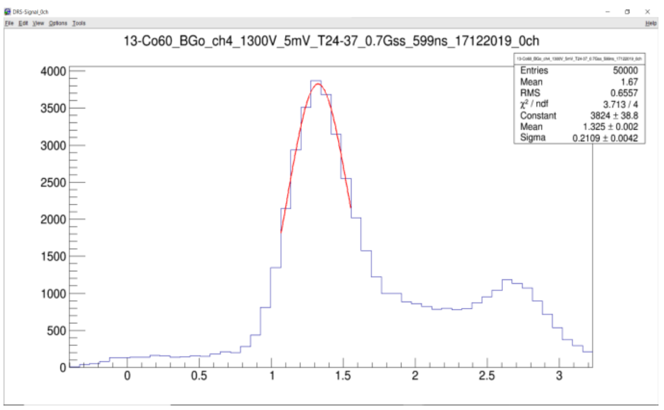


Figure 2, 1300 V applied

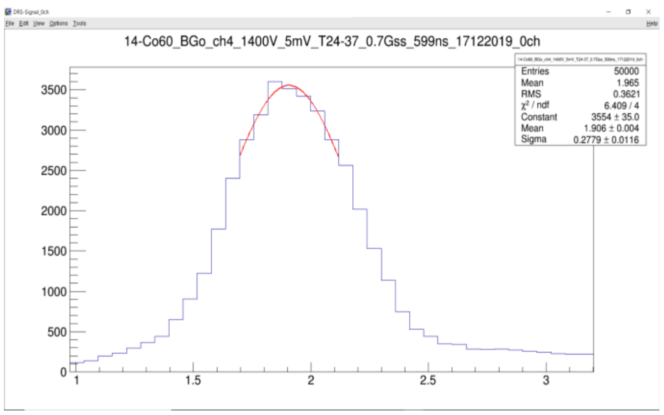


Figure 3, 1400 V applied

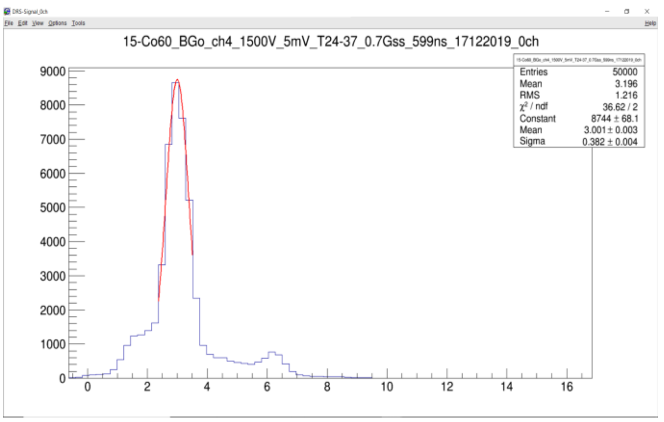


Figure 4, 1500 V applied

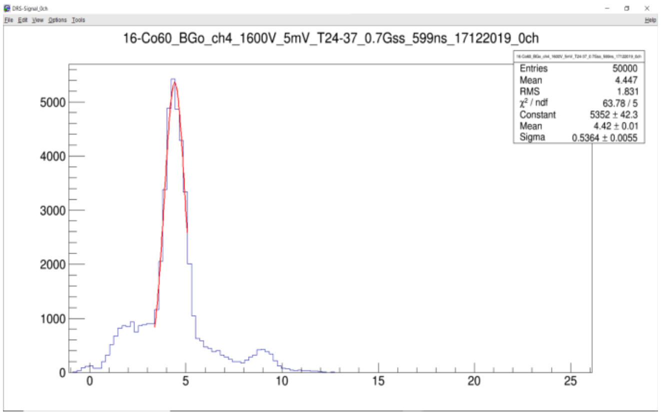


Figure 5, 1600 V applied

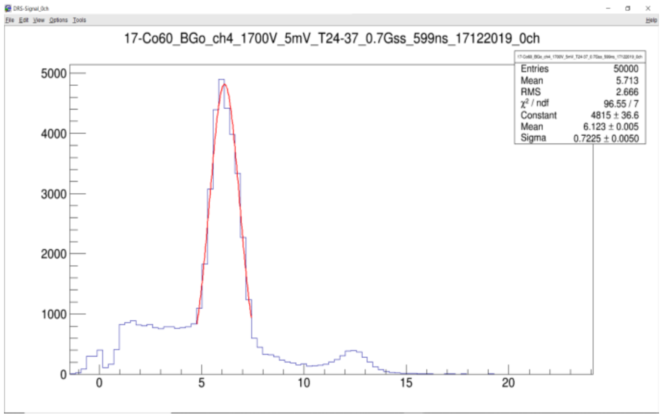


Figure 6, 1700 V applied

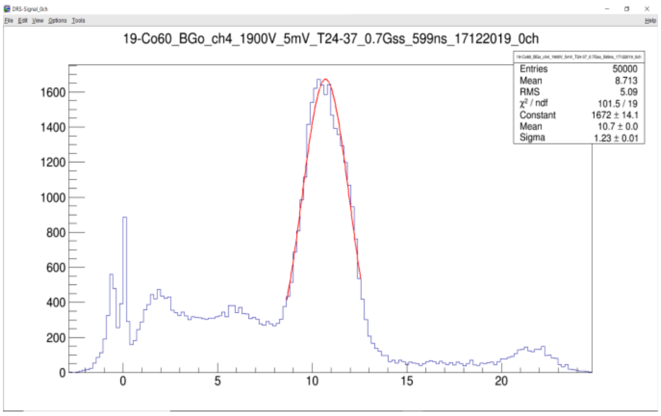


Figure 7, 1900 V applied

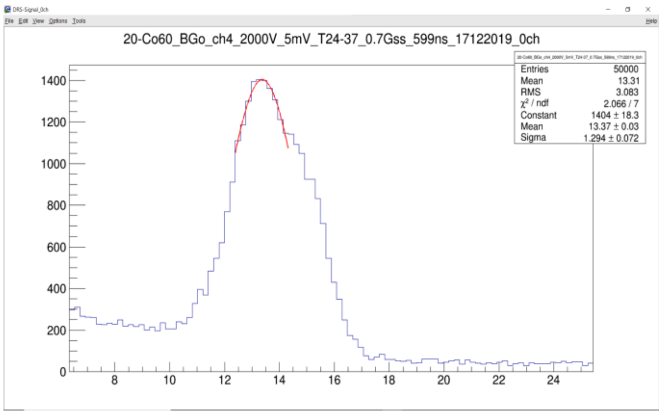


Figure 8, 2000 V applied

Applied Voltage	σ	mean	Resolution
1200	0.3807	1.636	0.5468
1300	0.2109	1.325	0.374
1400	0.2779	1.906	0.3426
1500	0.382	3.001	0.2991
1600	0.5364	4.42	0.28519
1700	0.7225	6.123	0.27729
1900	1.23	10.7	0.27014
2000	1.294	13.37	0.2274

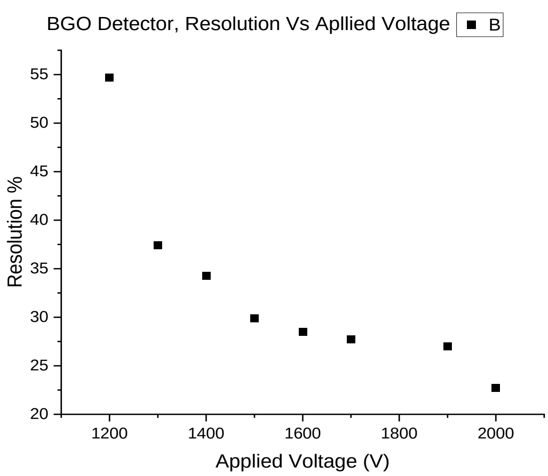


Figure 9, The relation between resolution and applied voltage for BGO detector. Resolution improves with increasing voltage

Task #1.2

Energy Calibration For BGO

The calibration results in a relationship that associates a given channel number (mean of a peak "PMT signal") with its corresponding appropriate energy. For this purpose, a source of known energy peaks (^{60}Co & ^{137}Cs) is used to firstly obtain the relation.

- A gaussian fitting is made to the peaks using ROOT to obtain their mean.
- Mean is plotted against energy of peaks, then a linear fitting is made to the data using Origin.

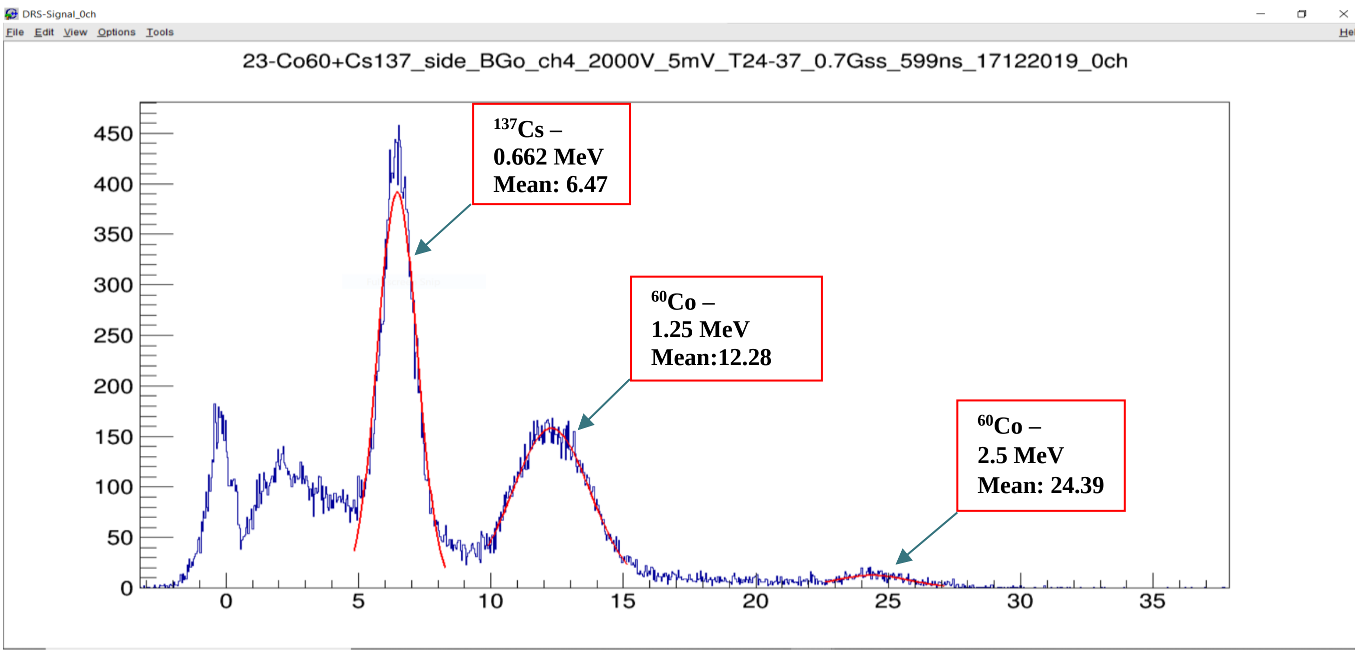


Figure 10, ^{137}Cs & ^{60}Co spectrum measured by a BGO detector at applied voltage 2000 V.

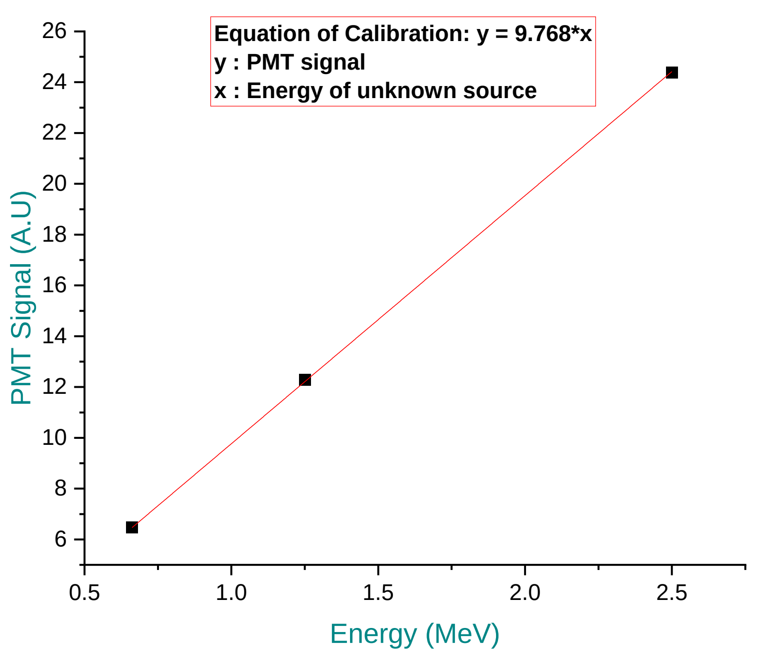


Figure 11, Calibration Function for a BGO detector.

Task #1.3

Identification of Unknown Sources

After obtaining the calibration equation for a BGO detector:

PMT signal = 9.76837 * Energy of unknown source ⟶ Equation. 2

PMT signal (Mean of peaks in measured spectrums) can now be used to obtain energy of those peaks which consequently will allow us to identify the source nuclei based on their energy.

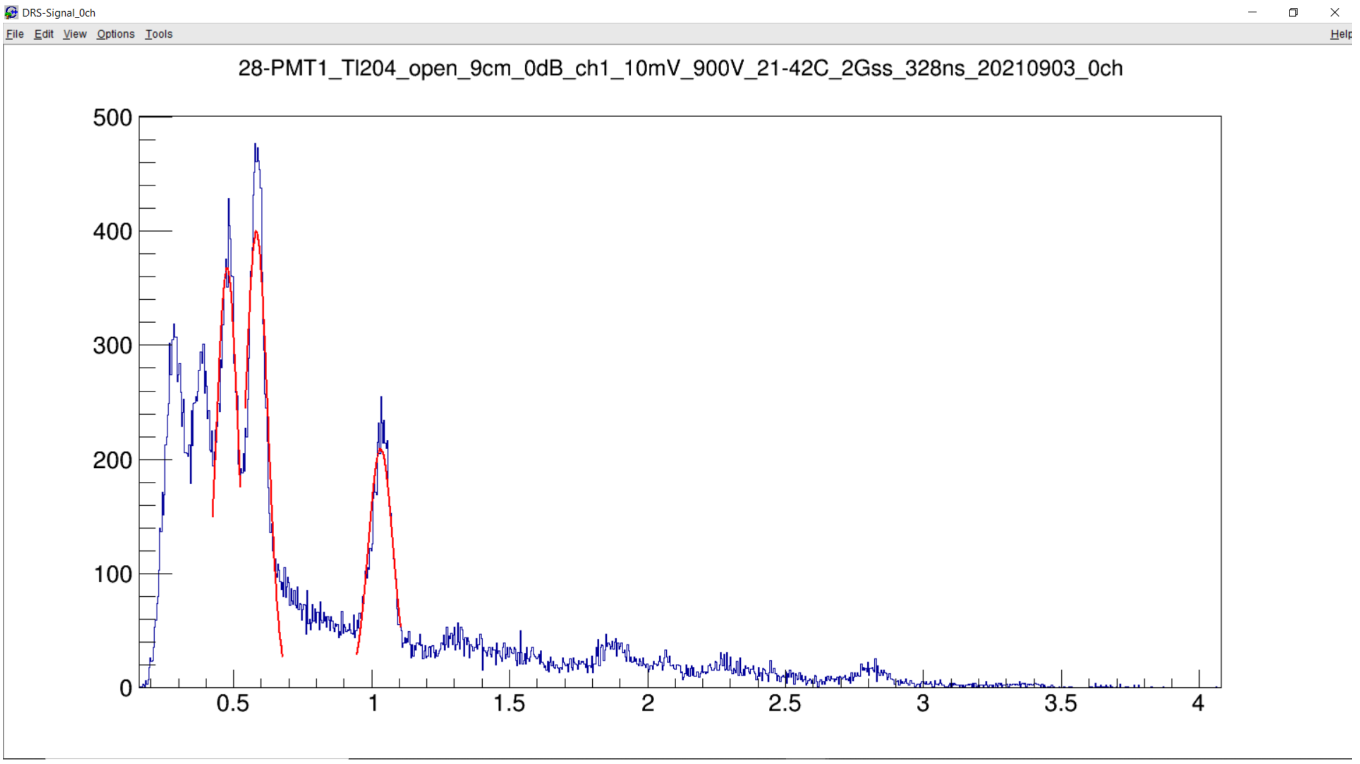


Figure 12, 1st peak mean: 0.47737, 2nd peak mean: 0.582936, 3rd peak mean: 1.03331

Using equation 2:

- Energy of the 1st peak = 0.04886 MeV = 48.86 KeV ⟹ ^{210}Pb (or) ^{104m}Rh
- Energy of the 2nd peak= 0.05967 MeV = 59.67 KeV ⟹ ^{127m}Te (or) ^{241}Am
- Energy of the 3rd peak= 0.10374 MeV = 103.74 KeV ⟹ ^{153}Sm (or) ^{155}Sm

*Nuclei are approximately identified based on their energy using data sheet available at:

https://www.cpp.edu/~pbsiegel/bio431/genergies.html

Task #2.1

The Relation Between Resolution and Applied Voltage for a NaI Detector

Main Idea:

Sodium Iodide (NaI) crystal converts radiation into photons based on the scintillation effect same as a BGO detector. It is also coupled with a photon multiplier tube (PMT) across which a voltage is applied. Same as the BGO detector, the applied voltage across the PMT increases the extractability of electrons from the photocathode which consequently increases the ability of the detector to separate between adjacent energy peaks (resolution), but also the noise will increase.

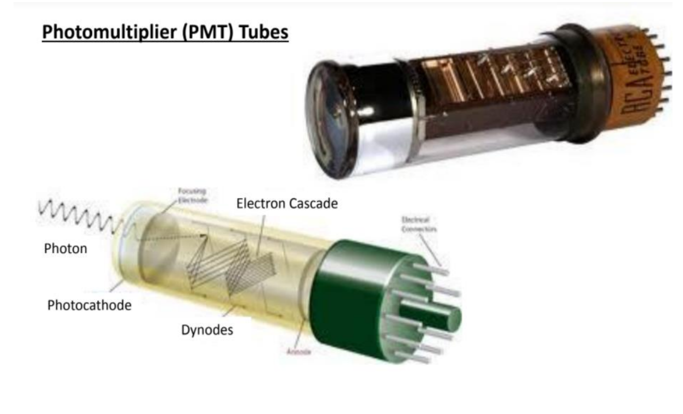


Figure 13, PMT

Requirements:

- Plot the relation between energy resolution against applied voltage.

Methods:

- ROOT is used to apply gaussian fitting to peaks of given data of ^{60}Co spectrum at different applied voltages.
- Resolution is calculated using equation 1.
- Resolution is plotted against voltage using Origin.

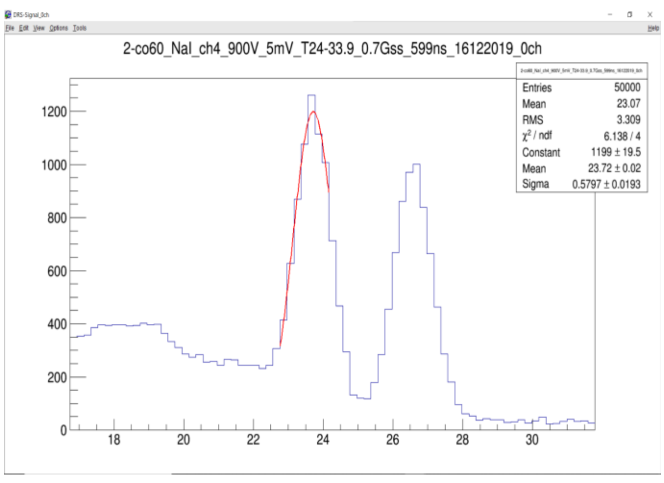


Figure 14, 900 V applied voltage

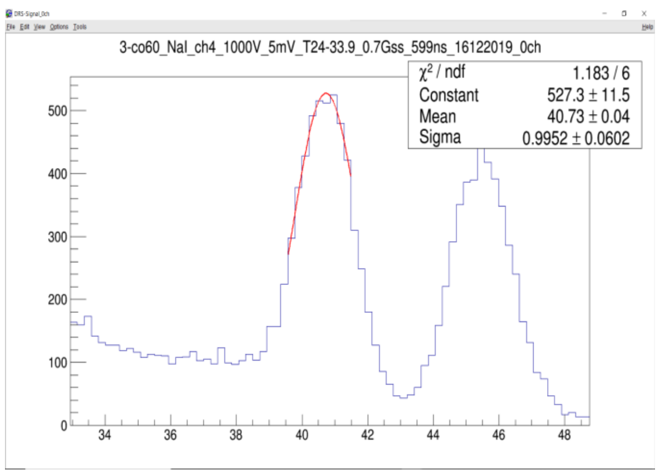


Figure 15, 1000 V applied voltage

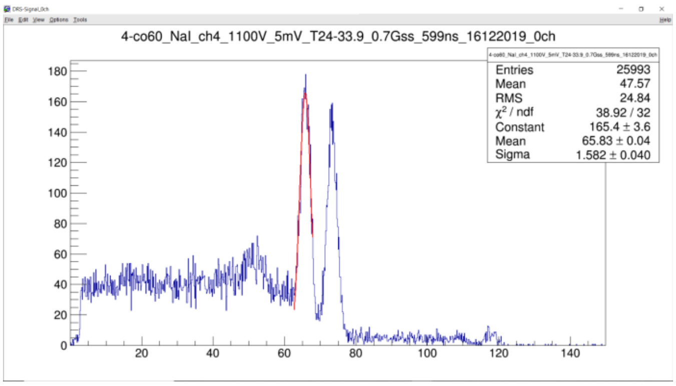


Figure 16, 1100 V applied voltage

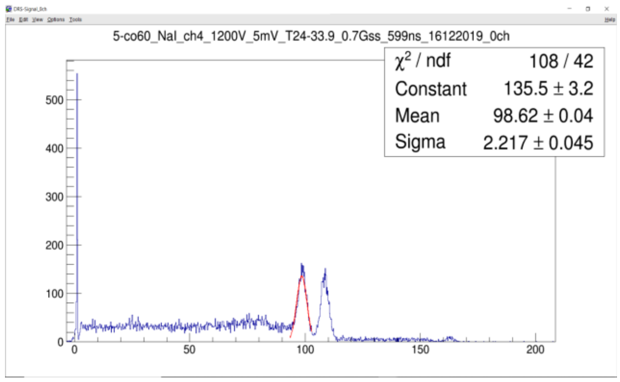


Figure 17, 1200 V applied voltage

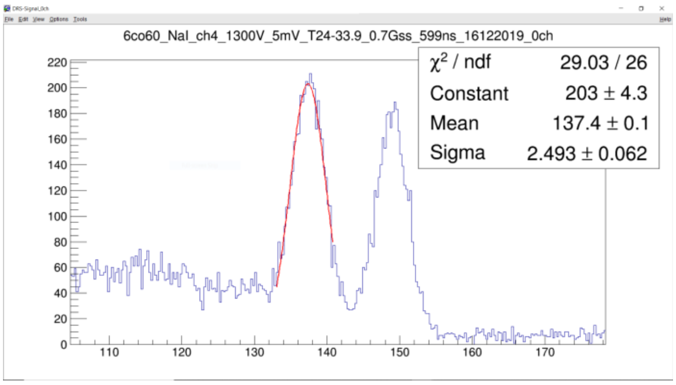


Figure 18, 1300 V applied voltage

$$Resolution = \frac{\sigma}{mean} \times 2.35$$

Results:

Applied Voltage (V)	Mean	σ	Resolution (%)
900	23.73	0.5797	5.7432
1000	40.73	0.9952	5.7420
1100	65.83	1.582	5.6474
1200	98.62	2.217	5.2829
1300	137.4	2.493	4.2639

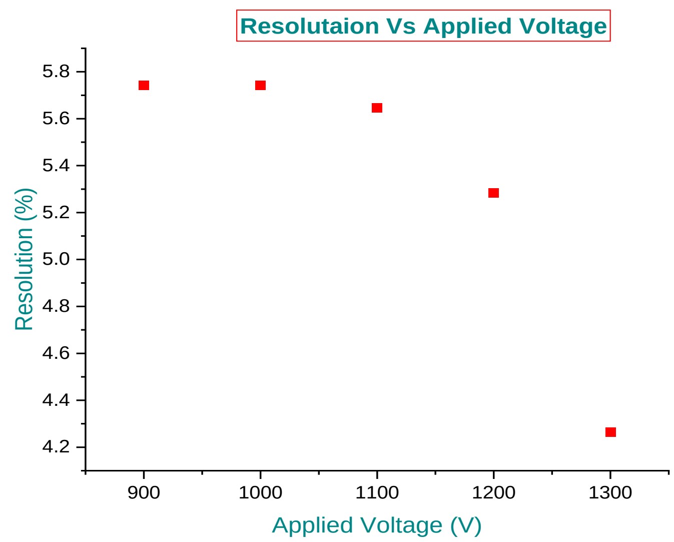


Figure 19, Relation between resolution and applied voltage for an NaI detector.

Resolution improves with increasing applied voltage

Task #2.2

Energy Calibration for NaI

Required is obtaining the energy calibration plot based on given date; given is the spectrum of ^{137}Cs and ^{60}Co measured by an NaI detector at a value of 800 V applied voltage.

Same as task #1.2, the following procedures are applied to fulfill the requirement:

- A gaussian fitting is made to the peaks using ROOT to obtain their mean.
- Mean is plotted against energy of peaks, then a linear fitting is made to the data using Origin.

Energy of Peak (MeV)	Mean [PMT Signal (Arbitrary Unit)]
0.662	**7.70323**
1.17	**12.6399**
1.33	**14.1545**
2.5	**25.1948**

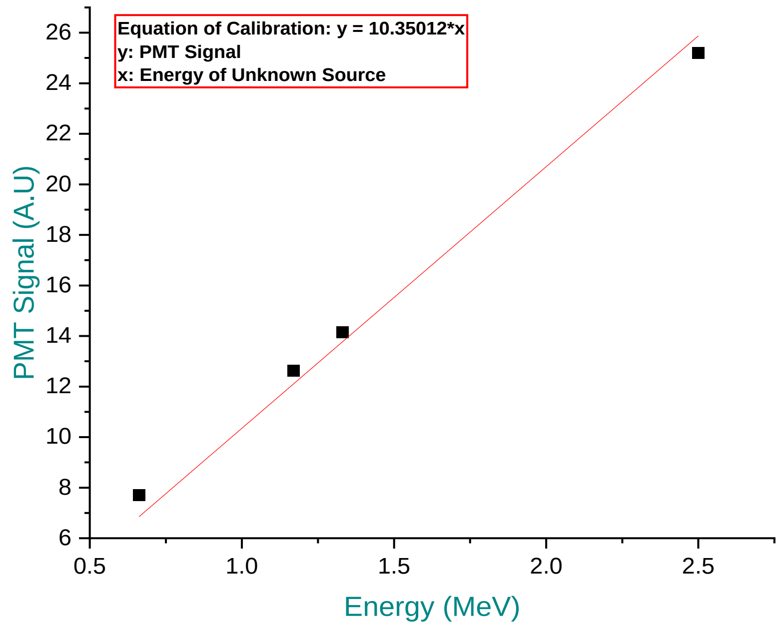


Figure 20, Calibration function for an NaI detector

Task #2.3

Identification of Unknown Source by NaI Detector

After obtaining the calibration equation for an NaI detector, it's now possible to identify nuclei based on their characteristic energies from:

PMT Signal (mean) = 10.35012 * Energy of Unknown source. → Equation 3.

- Mean of measured spectrum peaks is calculated using ROOT to obtain energy of peaks using equation 3.

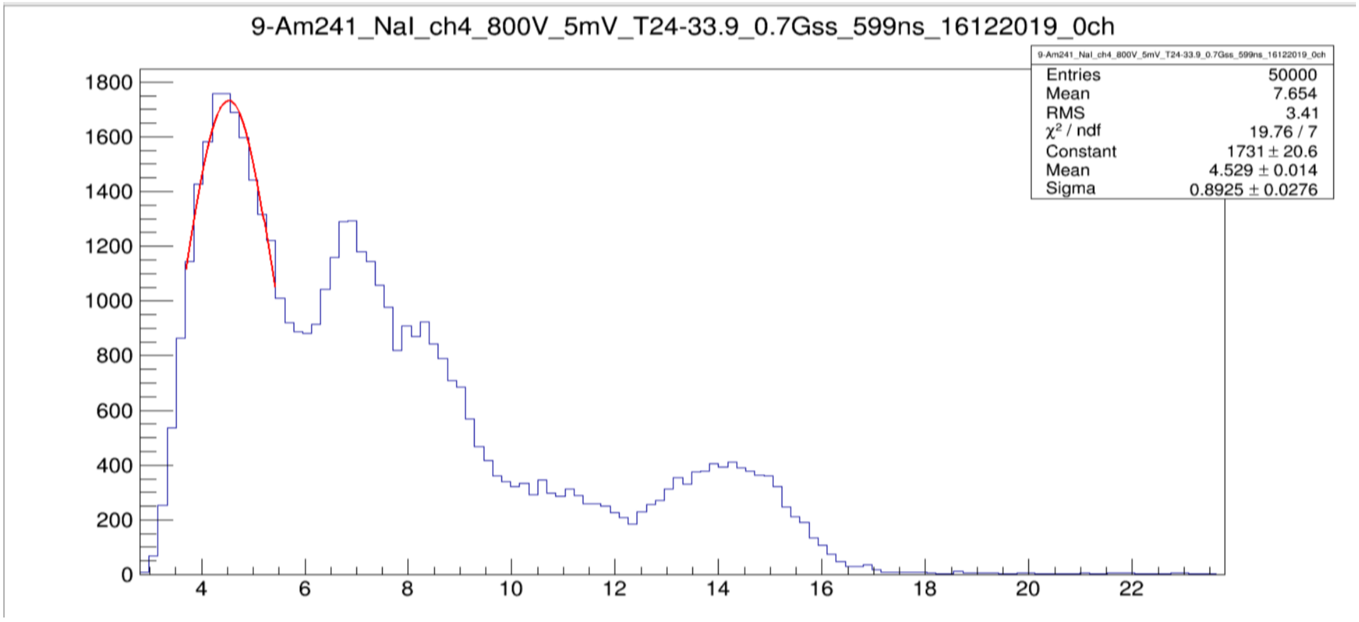


Figure 21, Unknown source spectrum.

Energy of the peak = 0.43 MeV → ^{241}Am approximately.

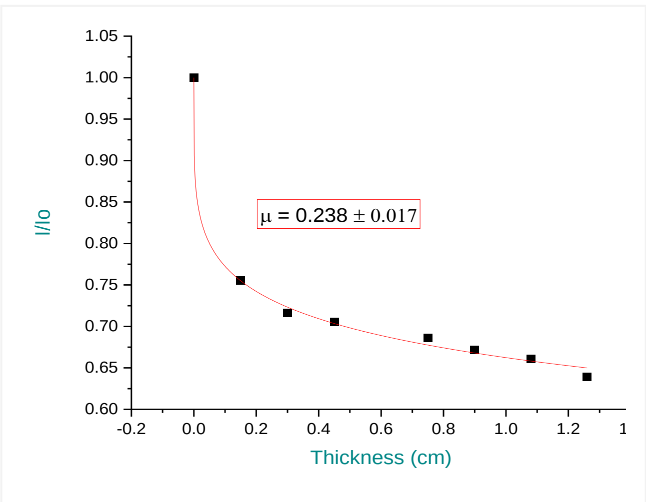
Task #3

Attenuation Coefficient.

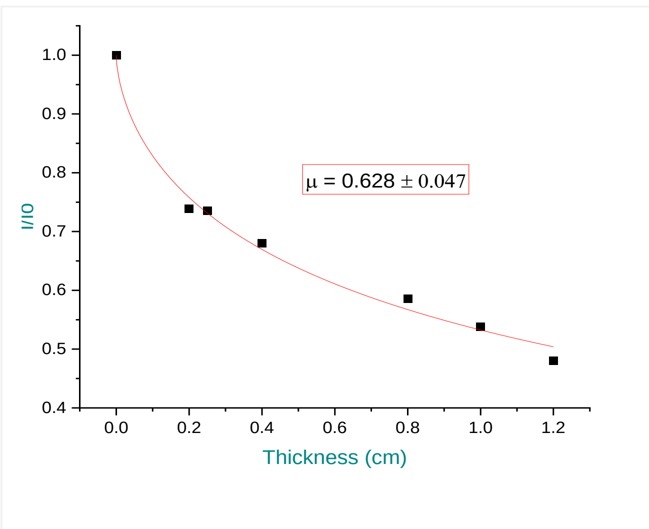
Attenuation coefficient (μ) describes how much would a material permit a beam of light to penetrate it, as, I = $I_o\, e^{-\mu x}$

Required is determining the attenuation coefficient for aluminum and copper.

Al



Cu



Task #4

Alpha Range in Air – Plastic Detector.

Source: ^{239}Pu
Energy of α particles: 5.5 MeV
Applied Voltage: 2000 V

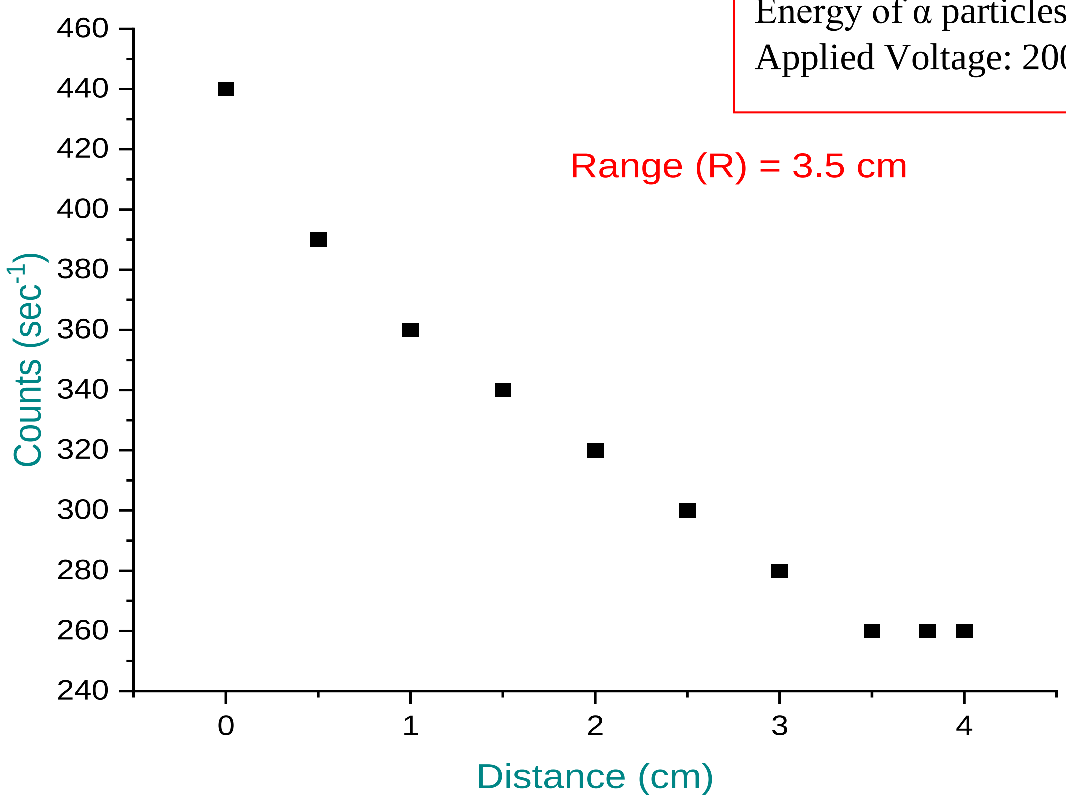


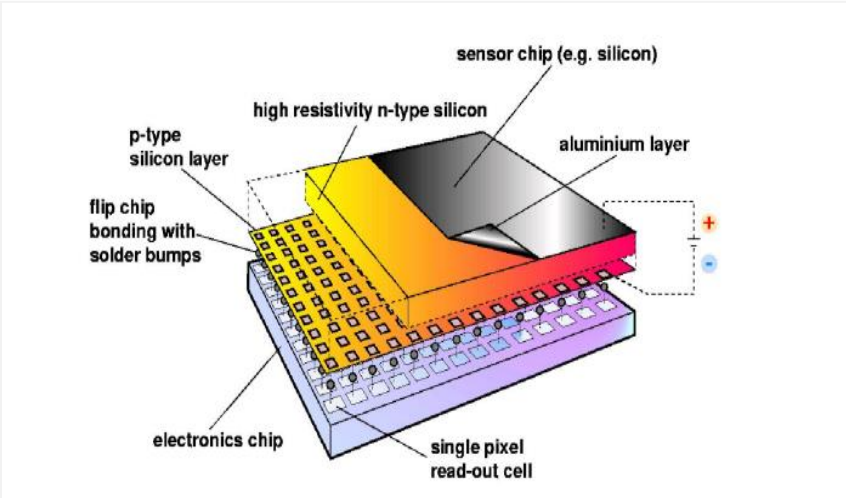
Figure 22, The range of alpha particles. Note: the counts don't reach 0 due to the background radiation.

Task #5

Pixel Detectors (PD)

- It is an advanced detector like a digital camera.
- It has high resolution.
- It is used for registration of different types of radiation

(Shown is a hybrid pixel detector)



Determination the range of Alpha particles with (^{241}Am) energy about 4 MeV in air using pixel detector.

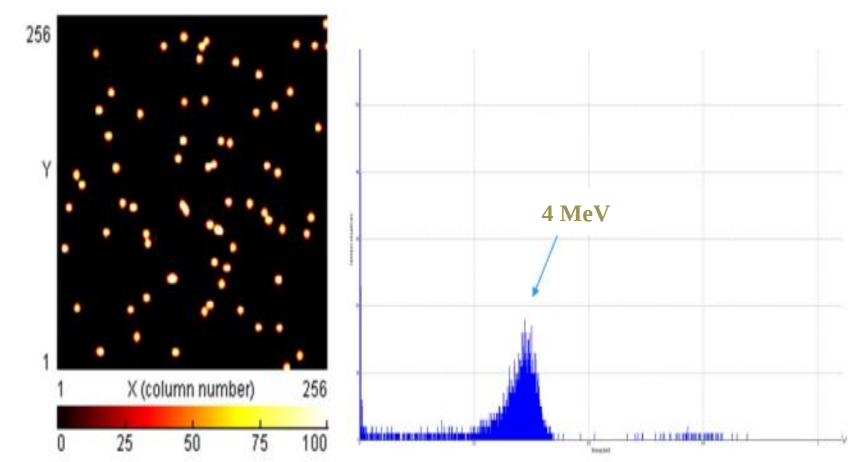


Figure 23, Absorption of α-particle energy at 0 cm in the air.

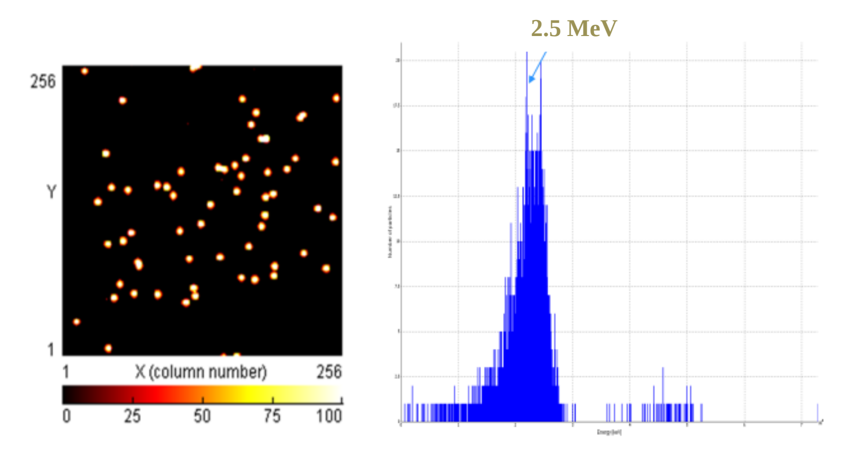


Figure 24, Absorption of α-particle energy at 1 cm in the air.

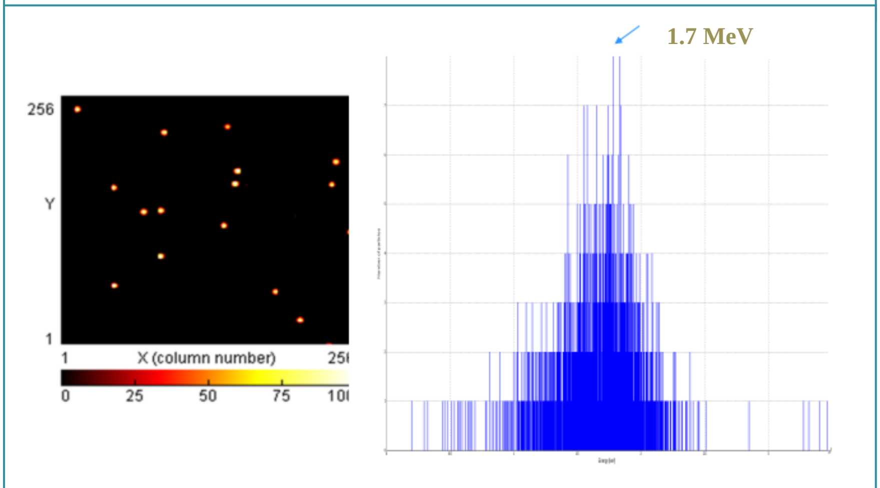


Figure 25, Absorption of α-particle energy at 2 cm in the air.

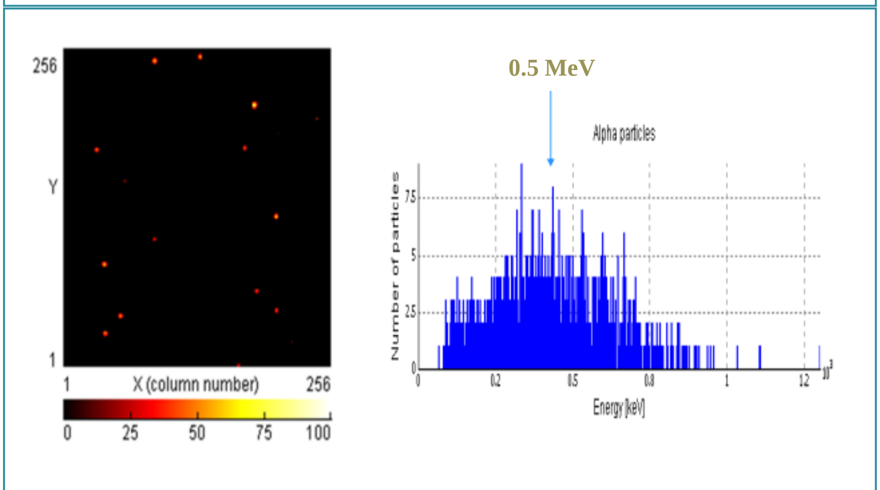


Figure 26, Absorption of α-particle energy at 2.5 cm in the air.

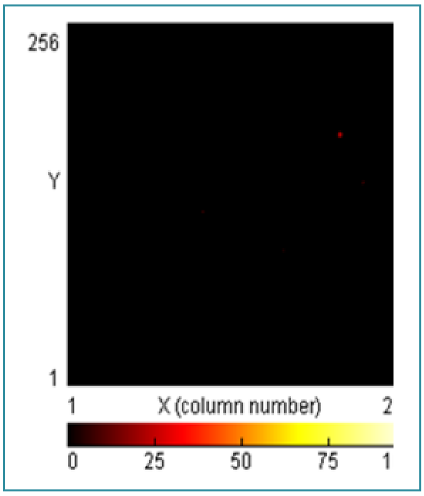


Figure 27, No α-particles are detected which means maximum of α-particle range is 3 cm in this case.

Conclusion

- Acquiring knowledge on radiation detection, protection, and safety.
- Acquiring the essential practical skills and basic tools for:
  - ➢ Analyzing spectrums obtained by BGO and NaI detectors and identifying unknown sources.
  - ➢ Evaluating the resolution of scintillation detectors.
  - ➢ Determination of attenuation coefficient for different materials.
  - ➢ Determination of α range in air.

References

[1] Attix, F.H., Introduction to Radiological Physics and Radiation Dosimetry, Wiley, New York (1986).

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

[3] Martin J.E., Physics for Radiation Protection, WILEY- VCH Verlag GmbH & Co. KGaA, Weinheim (2013).