JOINT INSTITUTE
FOR NUCLEAR RESEARCH

Final Report on the INTEREST PROGRAM

# *Radiation Protection and Safety of Radiation Sources*


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- Participation Period:
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# ***Task One***

## ***BGO Detector, A Relation Between Voltage and Resolution***

A BGO (Bismuth Germanium Oxide) detector is an inorganic scintillation detector that converts incident radiation into light within the visible range. The detector is coupled with a photo-multiplier tube that converts the light output of the crystal into voltage pulses. These voltage pulses are to indicate radiation counts.

The resolution of a detector is its ability to differentiate between energy peaks, which depends on the FWHM (full wave at half maximum) value.

Where,

$$Resolution = {FWHM}/{Mean}$$

And,

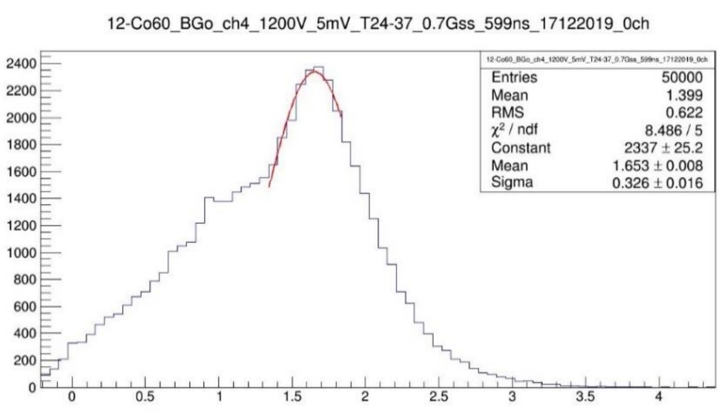
$$FWHM = \sigma \times 2.35 \quad \text{, σ : Standard Deviation}$$

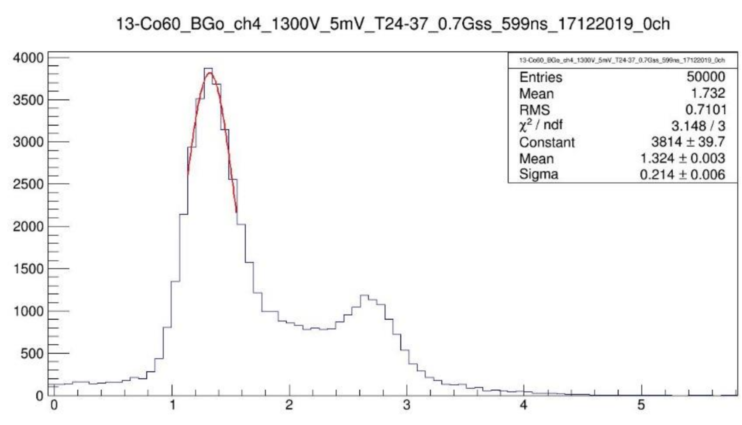
Therefore,

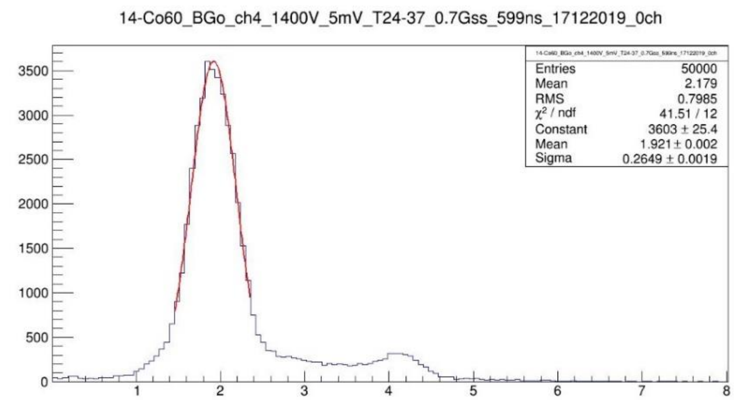
$$Resolution = {\sigma \times 2.35}/{Mean}$$

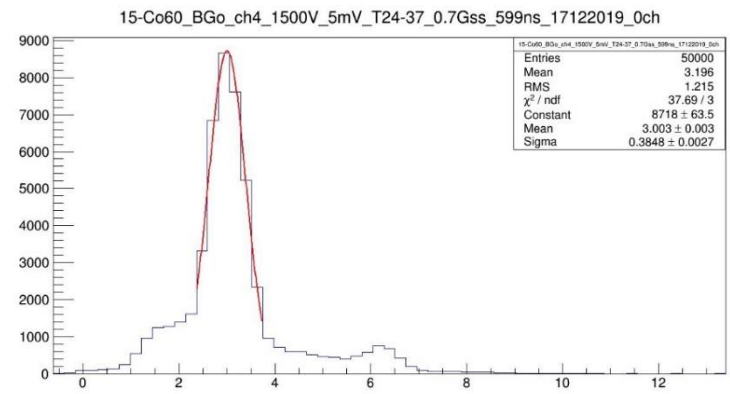
- ROOT is used to apply fitting to the given data at different applied voltages.
- Resolution is plotted against voltage using Excel.

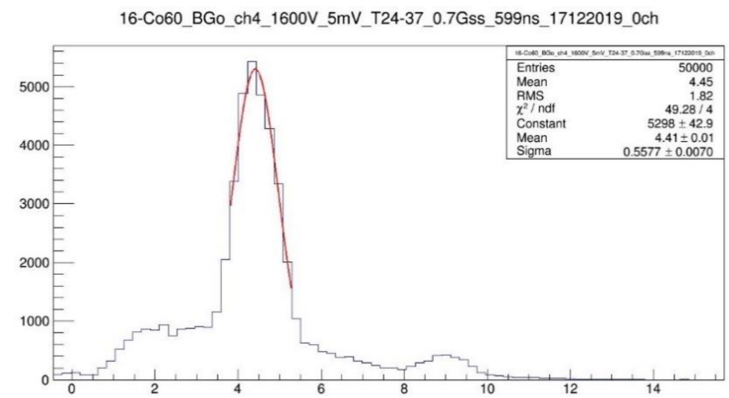
### ***Given Data:***

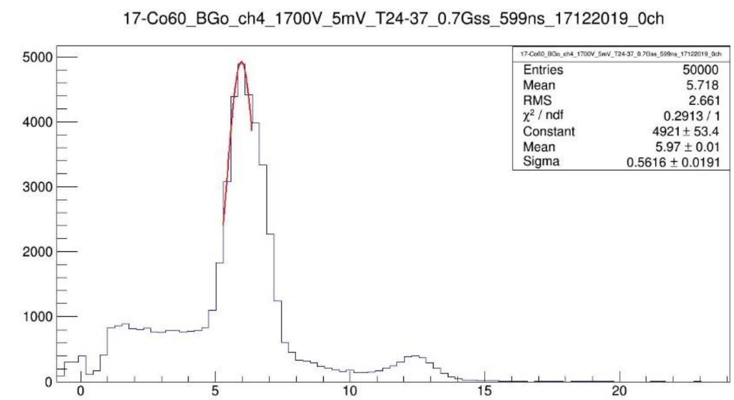


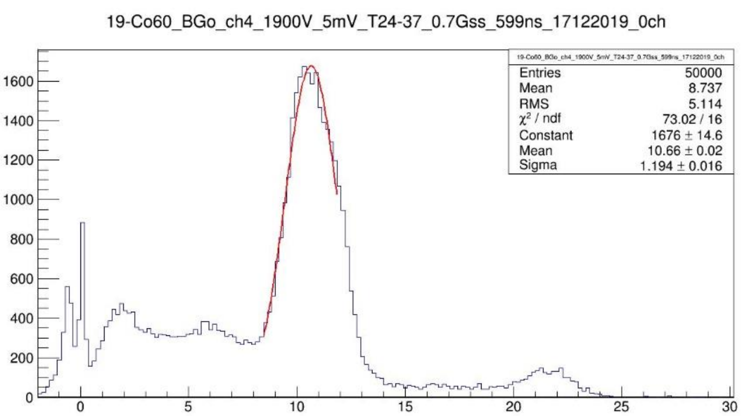



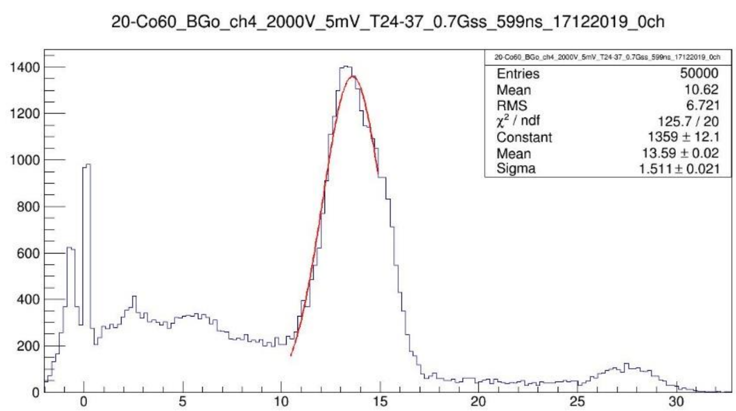

14-Co60_BGo_ch4_1400V_5mV_T24-37_0.7Gss_599ns_17122019_0ch
Entries 50000
Mean 2.179
RMS 0.7985
$\chi^2$ / ndf 41.51 / 12
Constant 3603 ± 25.4
Mean 1.921 ± 0.002
Sigma 0.2649 ± 0.0019


15-Co60_BGo_ch4_1500V_5mV_T24-37_0.7Gss_599ns_17122019_0ch
Entries 50000
Mean 3.196
RMS 1.215
$\chi^2$ / ndf 37.69 / 3
Constant 8718 ± 63.5
Mean 3.003 ± 0.003
Sigma 0.3848 ± 0.0027

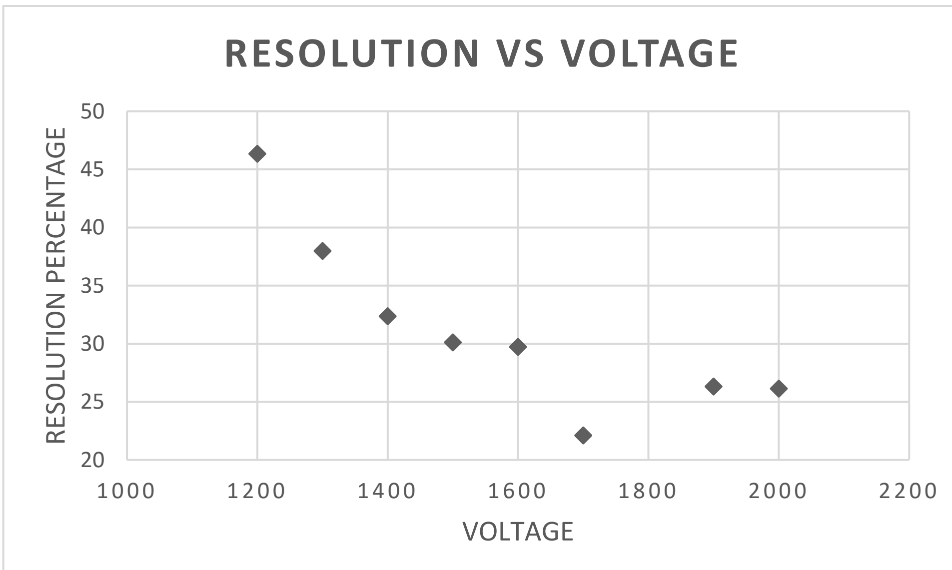

16-Co60_BGo_ch4_1600V_5mV_T24-37_0.7Gss_599ns_17122019_0ch
Entries 50000
Mean 4.45
RMS 1.82
$\chi^2$ / ndf 49.28 / 4
Constant 5298 ± 42.9
Mean 4.41 ± 0.01
Sigma 0.5577 ± 0.0070


17-Co60_BGo_ch4_1700V_5mV_T24-37_0.7Gss_599ns_17122019_0ch
Entries 50000
Mean 5.718
RMS 2.661
$\chi^2$ / ndf 0.2913 / 1
Constant 4921 ± 53.4
Mean 5.97 ± 0.01
Sigma 0.5616 ± 0.0191


19-Co60_BGo_ch4_1900V_5mV_T24-37_0.7Gss_599ns_17122019_0ch
Entries 50000
Mean 8.737
RMS 5.114
$\chi^2$ / ndf 73.02 / 16
Constant 1676 ± 14.6
Mean 10.66 ± 0.02
Sigma 1.194 ± 0.016


20-Co60_BGo_ch4_2000V_5mV_T24-37_0.7Gss_599ns_17122019_0ch
Entries 50000
Mean 10.62
RMS 6.721
$\chi^2$ / ndf 125.7 / 20
Constant 1359 ± 12.1
Mean 13.59 ± 0.02
Sigma 1.511 ± 0.021

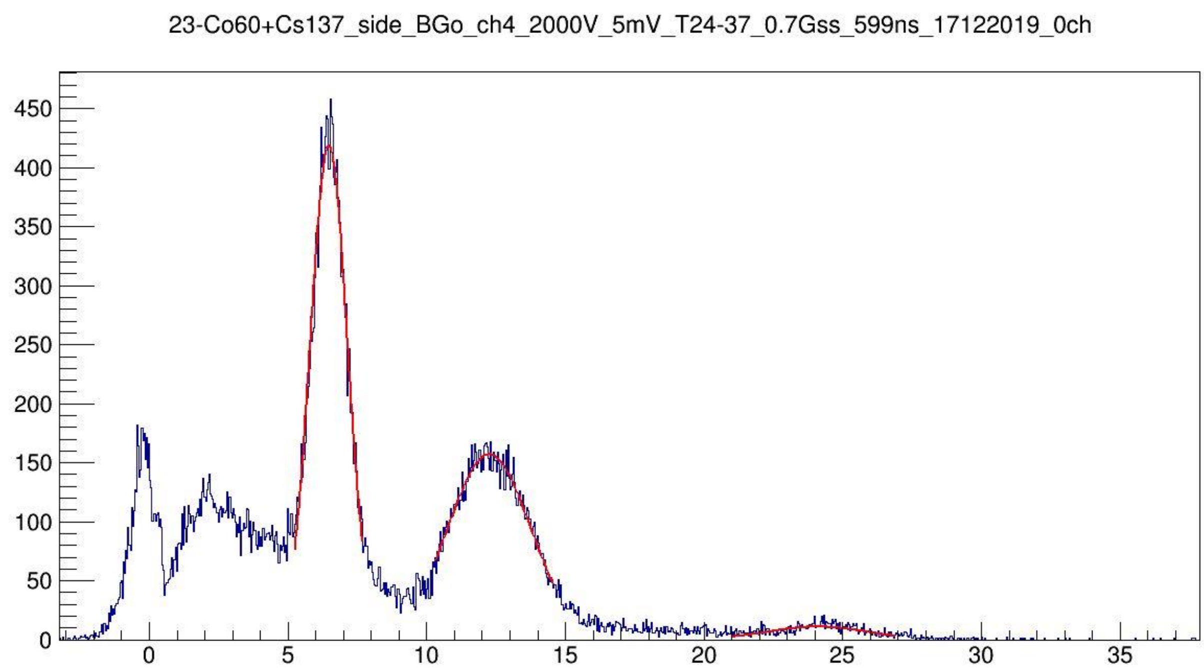
| Applied Voltage | σ | Mean | Resolution |
|---|---|---|---|
| **1200** | 0.326 | 1.653 | **0.4635** |
| **1300** | 0.214 | 1.324 | **0.3798** |
| **1400** | 0.2649 | 1.921 | **0.3237** |
| **1500** | 0.3848 | 3.003 | **0.3011** |
| **1600** | 0.5577 | 4.41 | **0.2972** |
| **1700** | 0.5616 | 5.97 | **0.2211** |
| **1900** | 1.194 | 10.66 | **0.2632** |
| **2000** | 1.511 | 13.59 | **0.2613** |



## ***Task Two***
## ***Part I: Energy Calibration For BGO***

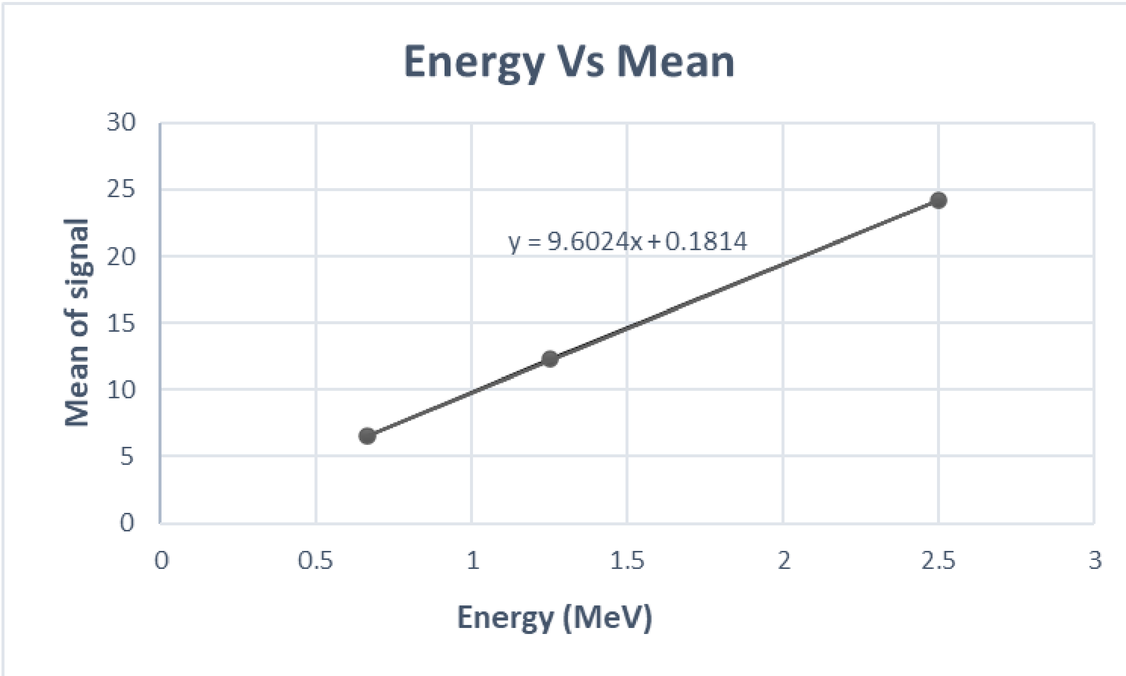
The calibration results in a relationship between the number of a given channel (the mean of a peak) and its corresponding energy. Therefore, to obtain the relation, a source of known energy peaks (in this case, Cobalt and Cesium) will be used.

- The first peak on the spectrum is noise that originated due to the resolution of the detector, so it's not a peak of energy from either element.
- Cesium-137 has one energy peak, which is the first from the left. While Cobalt-60 has two peaks.
- Mean is plotted against energy peaks, and the graph is linearly fit by Excel.




| Element | Energy (MeV) | Mean |
|---|---|---|
| Cs-137 | 0.662 | 6.48 |
| Co-60 (First Peak) | 1.25 | 12.27 |
| Co-60 (Second Peak) | 2.5 | 24.16 |

By using the given data, the graph becomes:




Therefore,

The equation, as shown, is: $y = 9.6024x + 0.1814$

Where, $y$ is the PMT signal

$x$ is the energy of the source

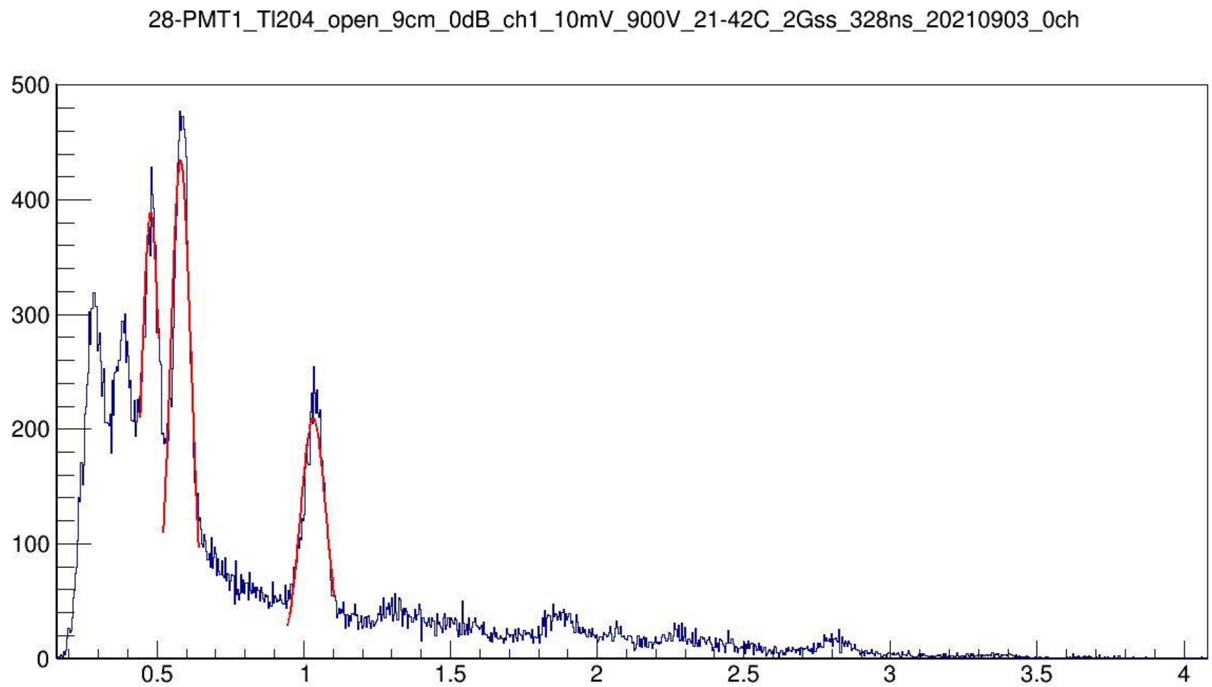
## ***Part II: The Identification of Unknown Sources***

After obtaining the calibration equation of the BGO detector, it can now be used to identify unknown sources based on the energy of their peaks.

Where,

$$y = 9.6024x + 0.1814$$

y: The PMT signal
x: The energy of the unknown source




- First Peak Mean: 0.4797
- Second Peak Mean: 0.5814
- Third Peak Mean: 1.0333

Therefore,

- Energy of first peak: 0.0342 MeV = 34.2 KeV
  Might be: $Mg^{28}$, $I^{125}$ or $Te^{125m}$
- Energy of second peak: 0.04166 MeV = 44.166 KeV
  Might be: $Rh^{103m}$, $I^{129}$, or $Pb^{210}$
- Energy of third peak: 0.08872 MeV = 88.72 KeV
  Might be: $Pb^{109}$, $Cd^{109}$, $Lu^{176m}$, $Ag^{109m}$, or $Nd^{147}$

# Task Three

## Part I: NaI Detector: A Relation between Resolution and Applied Voltage

Sodium Iodide detector is a scintillation detector that converts radiation into photons, and it is coupled with a photomultiplier and an electronic circuit, as the BGO detector discussed earlier.

In terms of resolution, the NaI detector has more resolution than the BGO detector, as it can differentiate between peaks easily. As with BGO detector, the maximum resolution that we can achieve is 23%. So, when analyzing the peaks of Cobalt-60, the overlapping of its two peaks is inevitable.
To ensure accuracy, the surface must be thoroughly cleaned. If the crystal and photomultiplier didn’t have good contact, the resolution will not be as desired. Oil is used in cleaning to improve the resolution of the detector.

Now, a relation between the resolution of the detector and applied must be plotted, same as the first task.

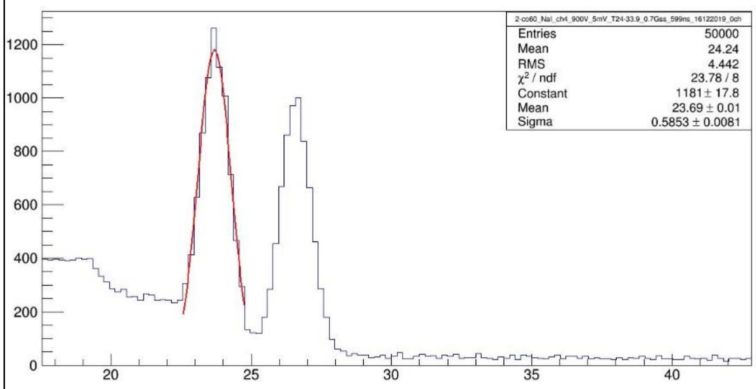
Equation Used:

$$Resolution = {}^{\sigma\ \times 2.35}/_{Mean}$$

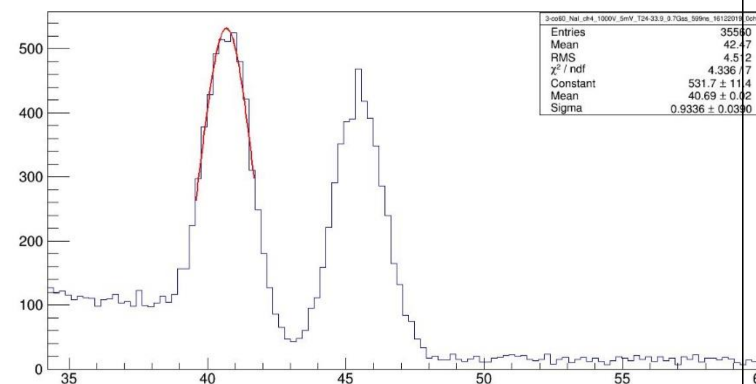
- ROOT is used to apply fitting to the given data at different applied voltages.
- Resolution is plotted against voltage using Excel.

## Given Data:

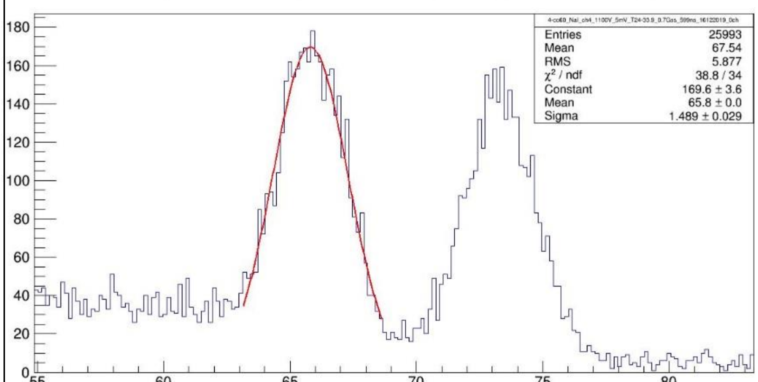
2-co60_NaI_ch4_900V_5mV_T24-33.9_0.7Gss_599ns_16122019_0ch



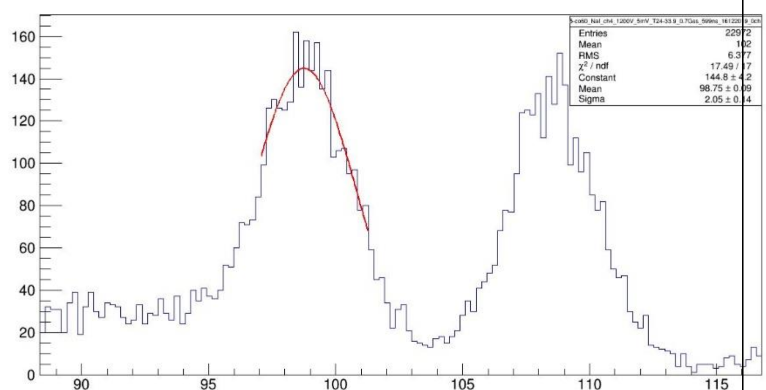

3-co60_NaI_ch4_1000V_5mV_T24-33.9_0.7Gss_599ns_16122019_0ch



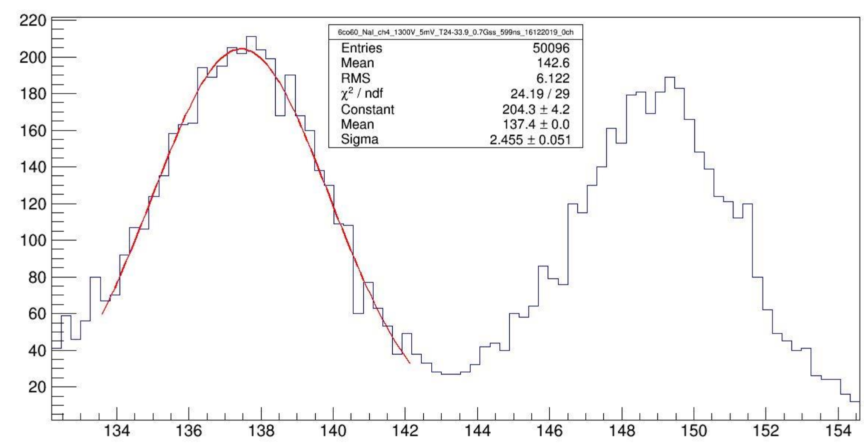

4-co60_NaI_ch4_1100V_5mV_T24-33.9_0.7Gss_599ns_16122019_0ch




5-co60_NaI_ch4_1200V_5mV_T24-33.9_0.7Gss_599ns_16122019_0ch

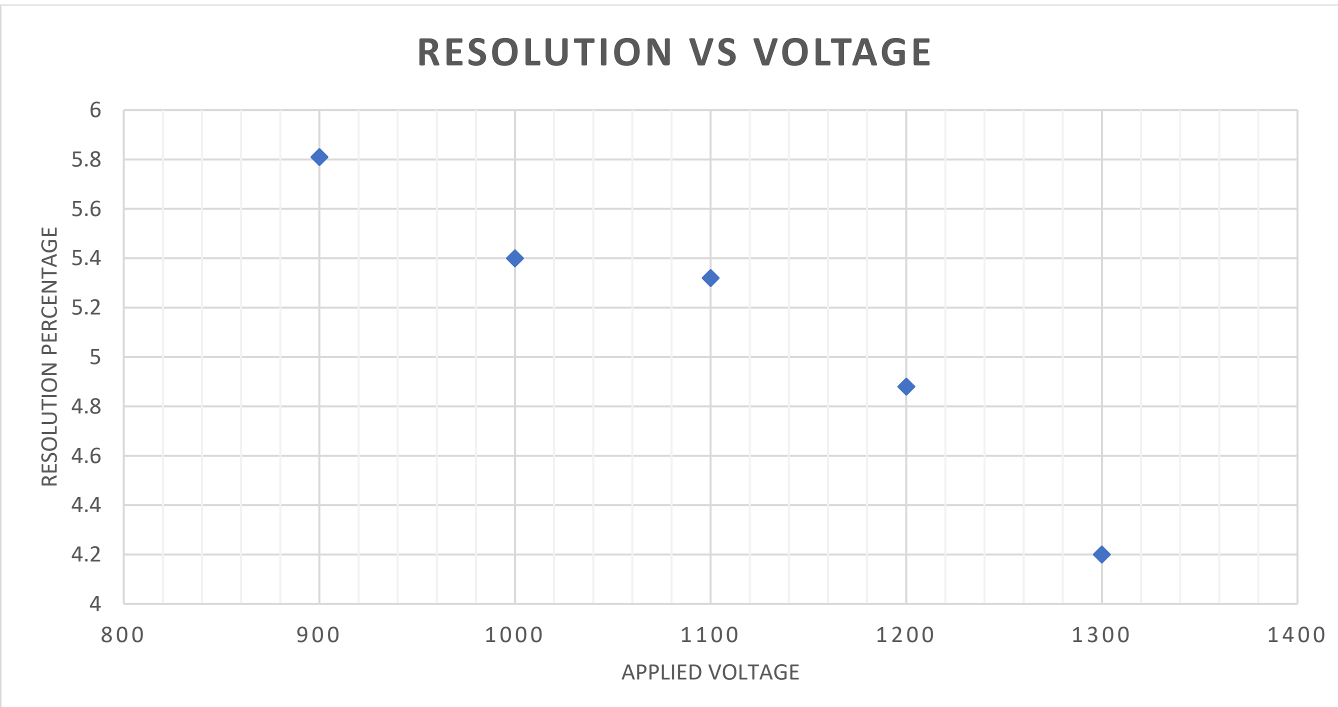



6co60_NaI_ch4_1300V_5mV_T24-33.9_0.7Gss_599ns_16122019_0ch



| Applied Voltage (v) | σ | Mean | Resolution (Percentage) |
|---|---|---|---|
| **900** | 0.5853 | 23.69 | 5.81 |
| **1000** | 0.9336 | 40.69 | 5.4 |
| **1100** | 1.489 | 65.8 | 5.32 |
| **1200** | 2.05 | 98.75 | 4.88 |
| **1300** | 2.455 | 137.4 | 4.2 |

Therefore, the graph becomes:



# ***Task Four: Attenuation Coefficient***

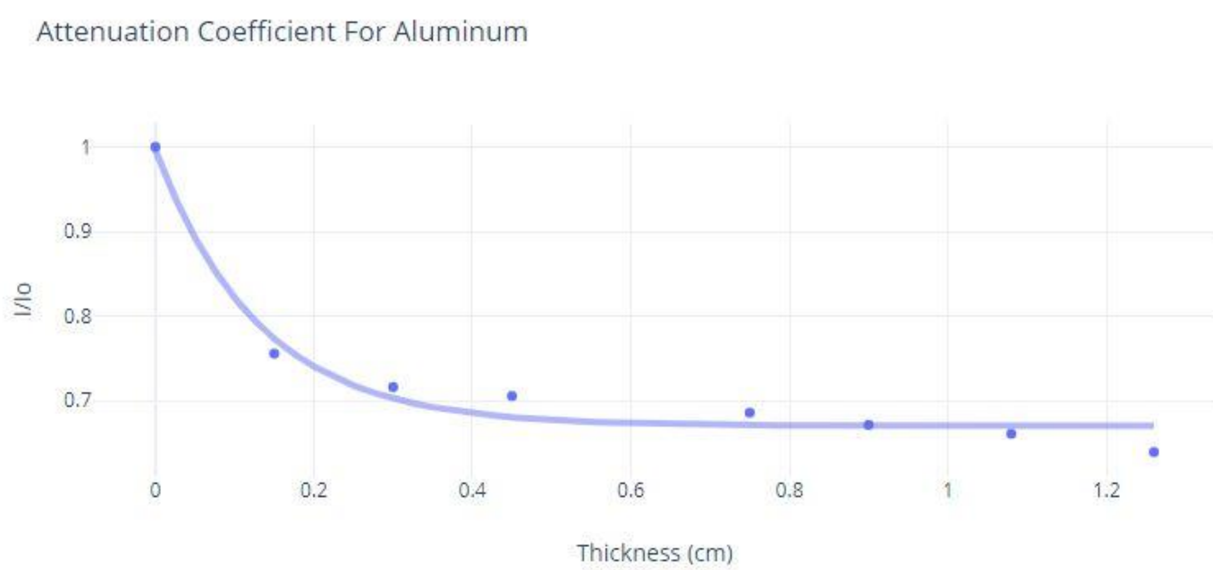
Attenuation coefficient is a measure of how easily a material can be penetrated by an energy beam.
It follows the following relation:

$$I = I_o\, e^{-\mu x}$$

It is required to determine the attenuation coefficient for aluminum and copper.

1) Aluminum

| **Thickness (cm)** | $I/I_o$ |
|---|---|
| **0** | 1 |
| **0.15** | 0.75573 |
| **0.3** | 0.71623 |
| **0.45** | 0.70569 |
| **0.75** | 0.68596 |
| **0.9** | 0.67155 |
| **1.08** | 0.66103 |
| **1.26** | 0.63939 |



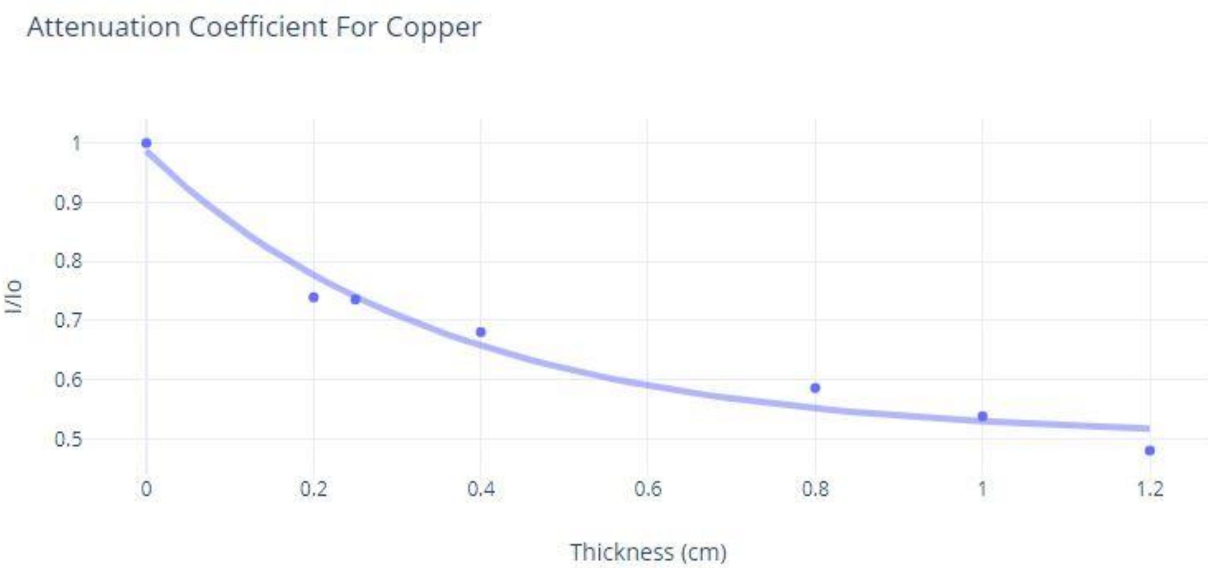

From Graph:

$$y = 0.8416e^{-0.249x}$$

Therefore, μ for aluminum = ***0.249 cm²/gm***

2) Copper

| **Thickness (cm)** | $I/I_o$ |
|---|---|
| **0** | 1 |
| **0.2** | 0.73931 |
| **0.25** | 0.7357 |
| **0.4** | 0.68065 |
| **0.8** | 0.58611 |
| **1** | 0.53827 |
| **1.2** | 0.48042 |




From Graph:

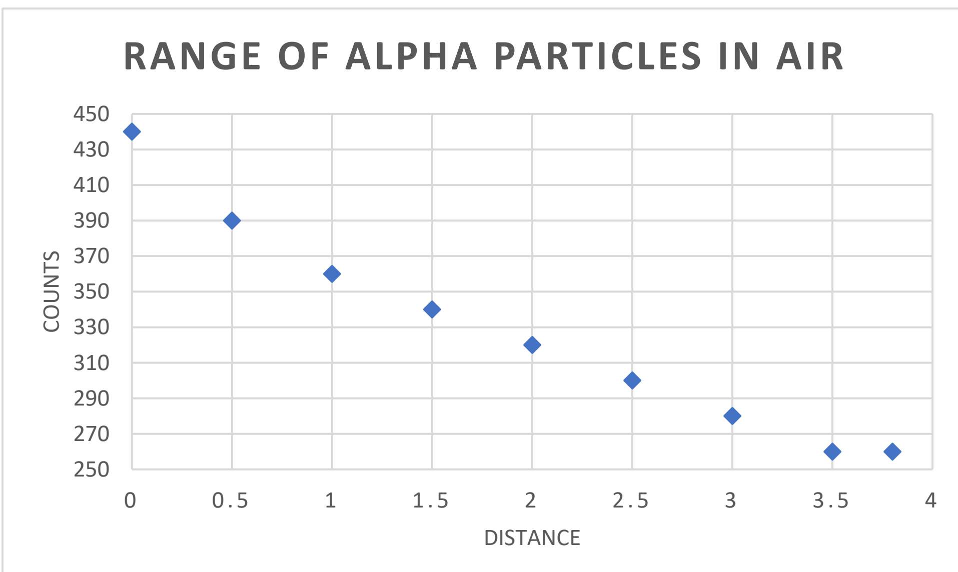
$$y = 0.8806e^{-0.517x}$$

Therefore, μ for copper = ***0.517 cm²/gm***

## ***Task Five: Alpha Range in Air***

In this experiment, we are required to find the range of alpha particles in air. We use $Pu^{239}$ as a source which emits alpha particles with energy 5.5 MeV. The detector used is a plastic detector with applied voltage of 2000 Volts.

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




Therefore, the range of alpha particles in air is equal to ***3.5*** cm.