RADIATION PROTECTION AND THE SAFETY OF RADIATION SOURCES

INTEREST: INTErnational REmote Student Training at JINR

(Wave 4)

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TYPES OF RADIATION

There are two types of radiation which are:

a. Non-Ionizing Radiation- Radiation that doesn't have enough energy to interact with the nucleus of an atom e.g. Ultraviolet, Radio waves, Infrared
b. Ionizing Radiation- radiation that has enough energy to dislodge orbital electrons in an atom e.g. gamma rays and X-rays.

RADIATION SPECTRUM

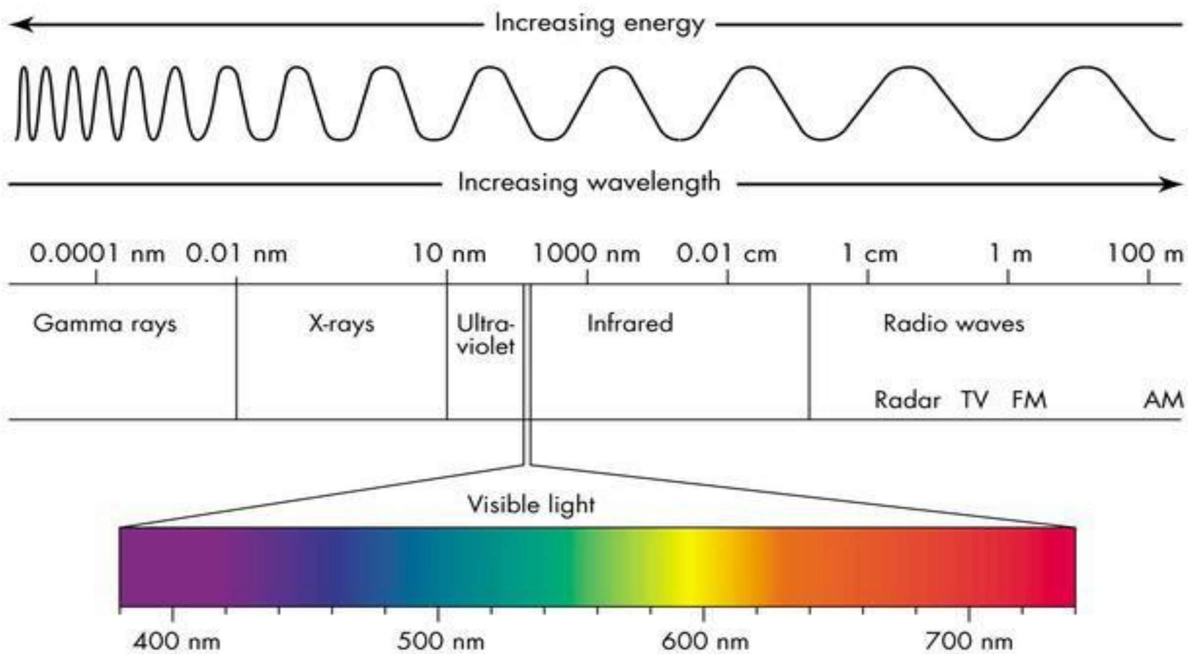

Figure 1. Electromagnetic Radiation Spectrum

As shown in the figure X-rays and Gamma rays have short wavelength hence they are more penetrating.

SHIELDING OF SOURCES

Since X-rays and gamma rays are very penetrative one must be shielded against them. Shielding depends on;

- Type of radiation (α, β, γ, X-rays, neutrons)
- Activity of the source
- Dose-rate which is acceptable outside the shielding material

RADIATION PROTECTION TERMINOLOGY

- **Activity (Bq)**
  Activity is the amount of radionuclide present.
  $$1\ Bq = 1\ disintegration\ per\ second\ (dps)$$
  $$1\ Ci = 3.7 \times 10^{10}\ dps$$
  $$1\ Ci = 3.7 \times 10^{10} Bq$$
- **Absorbed Dose (Gy)**
  It is the mean energy absorbed per unit mass in any medium by any ionizing radiation.
  $$D = \frac{Energy\ absorbed(J)}{mass(kg)}$$
- **Equivalent Dose (Sv)**
  It is the amount of energy absorbed per unit mass of a substance taking into account the radiation weighting factor (W_R).
  $$H_T = \sum_R W_R D_{T,R}$$
  Where $D_{T,R}$ = Absorbed dose
  The radiation weighting factor is dependent on the type of radiation.

- **Effective Dose (Sv)**
  It is a measure of the stochastic effect on health risk that a radiation dose internal or external to whole or part of the body will have. It is dependent on the tissue weighting factor.
  $$E = \sum_T W_T H_T$$
  Where W_T = Tissue weighting factor

OCCUPATIONAL DOSE LIMITS FOR RADIATION WORKERS

Table 1. Occupational dose limits for people working with radiation

Part of Body	Dose Limit (Sv/year)
Whole Body	0.05
Extremity	0.5
Skin or organ	0.5
Lens of eye	0.15
Fetus	0.005 Sv/gestation

EFFECTS OF RADIATION DOSE

DETERMINISTIC EFFECTS | **STOCHASTIC EFFECTS**

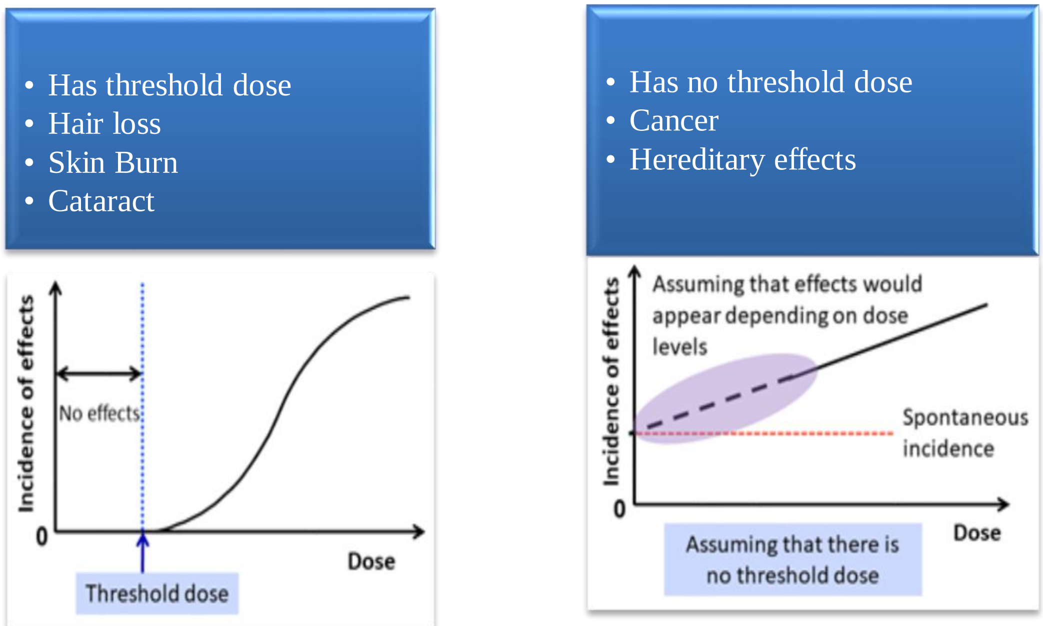

Figure 2. Deterministic and stochastic effects of radiation dose on people

TYPES OF DOSIMETERS

There are two types of dosimeters used in measuring radiation dose to people: Immediate read and delayed read.

1. **Immediate Read**

This dosimeters give you the readings immediately without having to take them to the lab for processing. Examples are:

- Ionization chamber
- Solid state detector
- Handheld Radiation detectors

2. **Delayed Read**

This type of dosimeters do not give you the reading automatically, they have to be processed in order for them to be read.

- TLD Badge
- Film Badge

RADIATION SOURCES COMMONLY USED IN THE LAB

- Gamma (γ) sources
    - ^{60}Co
        - Has 3 peaks of energies (1.17, 1.33 and 2.5 MeV)
    - ^{137}Cs
        - Has a single peak of energy (0.662 MeV)

Both ^{60}Co and ^{137}Cs are used for calibration and to check the resolution of a detector.

- Alpha (α) sources
    - ^{241}Am
        - Has energy of about 5.486 keV

EXPERIMENTAL SETUP

For the project, a detector, DRS, computer and high voltage power supply were used.

1. Detector: Scintillation detectors were used
    - BGO detector
    - NaI detector

2. DRS: converts signals from analogue to digital
    - Works as an oscilloscope
    - The maximum signal is ±1
    - Depends on temperature

3. Computer: displays the outcome data
    - One can manipulate threshold energy

4. HV Power Supply
    - Maximum power supply of 4 kV

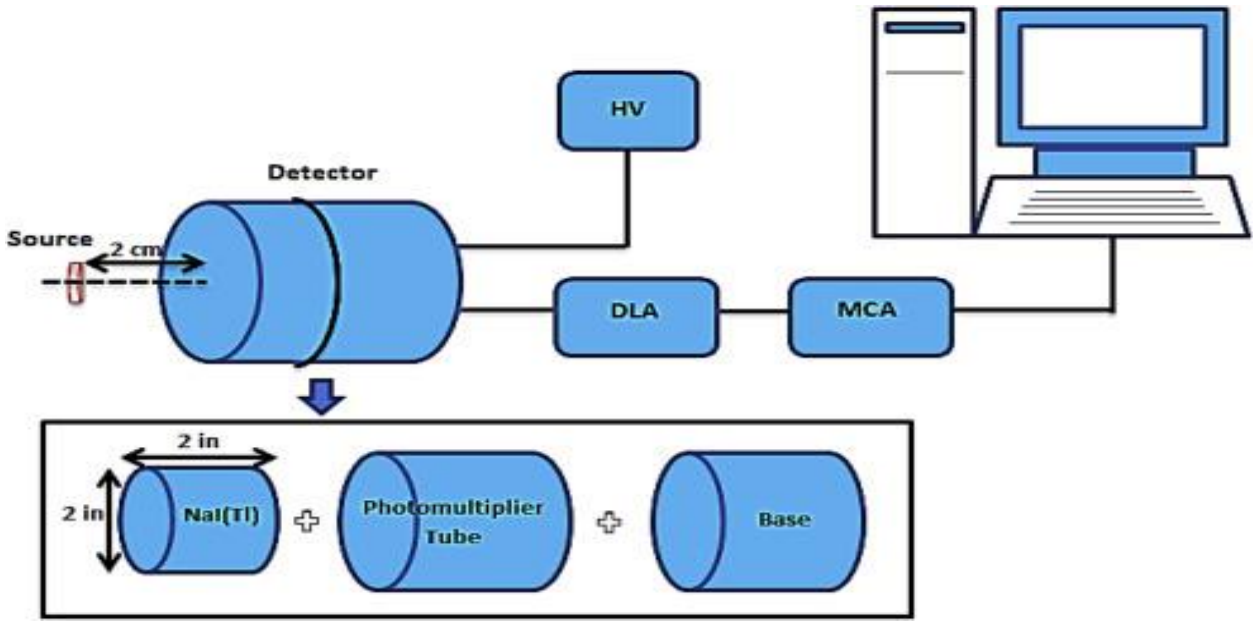

Figure 3. Schematic diagram of the experimental setup

PHOTOMULTIPLIER TUBE (PMT)

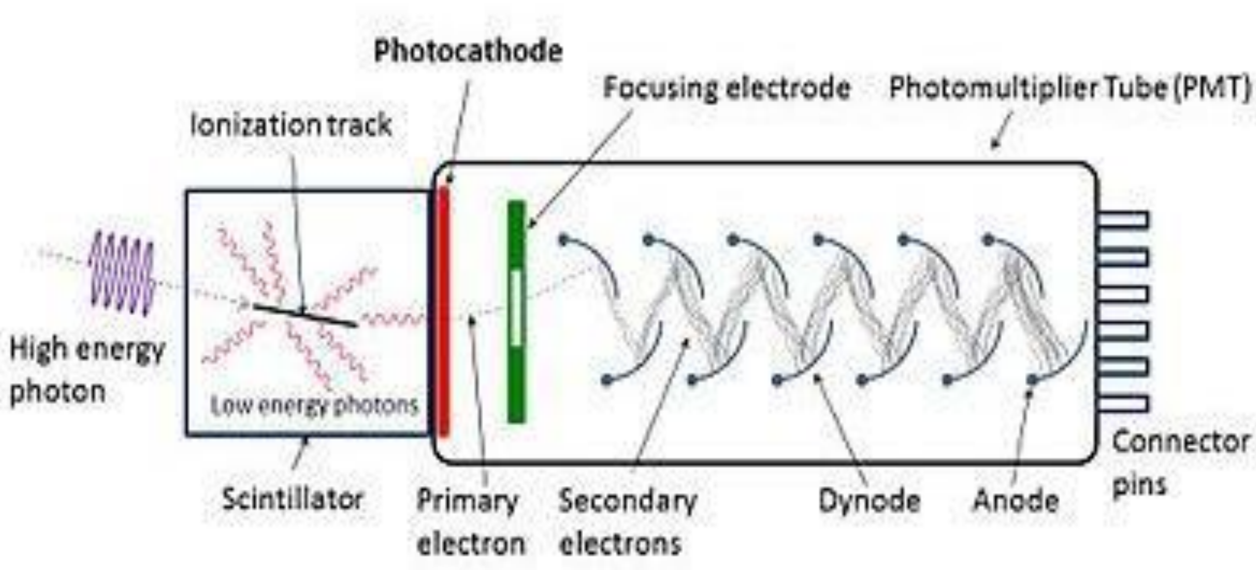

Figure 4. Photomultiplier tube

ASSIGNMENTS AND TASKS

In a detector there are 2 important factors which are;

- **Resolution**: -the ability of detector to separate peaks
- **Efficiency**: -measure of percentage of radiation that a given detector detects from the overall yield emitted from the source (whether the detector can collect all the radiation from the source or not).

Assignment 1.A: APPLIED VOLT WITH RESOLUTION FOR BGO DETECTOR USING A CO-60 SOURCE

Resolution of detector;

$$R = \left(\frac{\sigma}{mean}\right) \times 2.35$$

Table 2 Calculated resolution from the mean and sigma after peak fitting

Applied Voltage (V)	Sigma (σ)	Mean	Resolution (%)
1200	0.47	1.58	69.9
1300	0.29	1.39	49.0
1400	0.29	1.92	35.5
1500	0.47	2.98	37.1
1600	0.67	4.40	35.8
1700	0.83	6.09	32.0
1900	1.30	10.63	28.7
2000	1.62	13.60	28.0

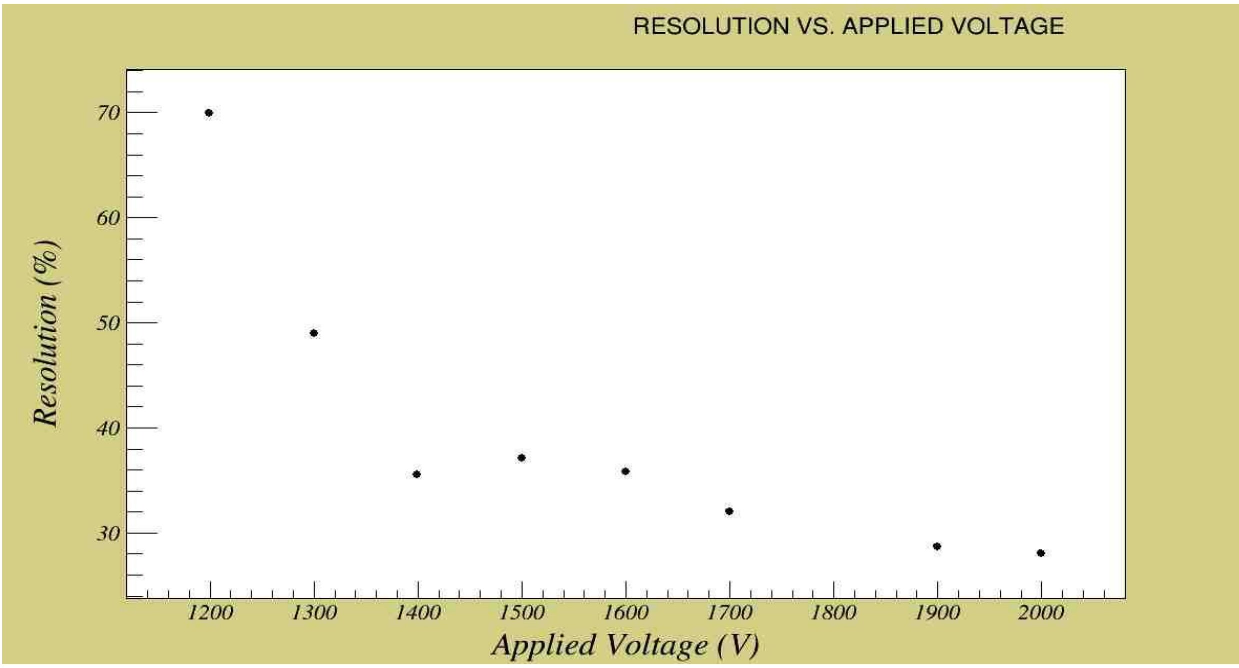

Figure 3. The relation between resolution and applied voltage for a BGO detector

N.B. When the applied voltage is increased, the noise also increases resulting in poor resolution. When calibrating one has to decrease the applied voltage to minimize the noise. In order to get a good resolution and calibration, a number of measurements should be made so as to get the optimum applied voltage.

Assignment 1.B: <u>ENERGY CALIBRATION FOR A BGO DETECTOR</u>

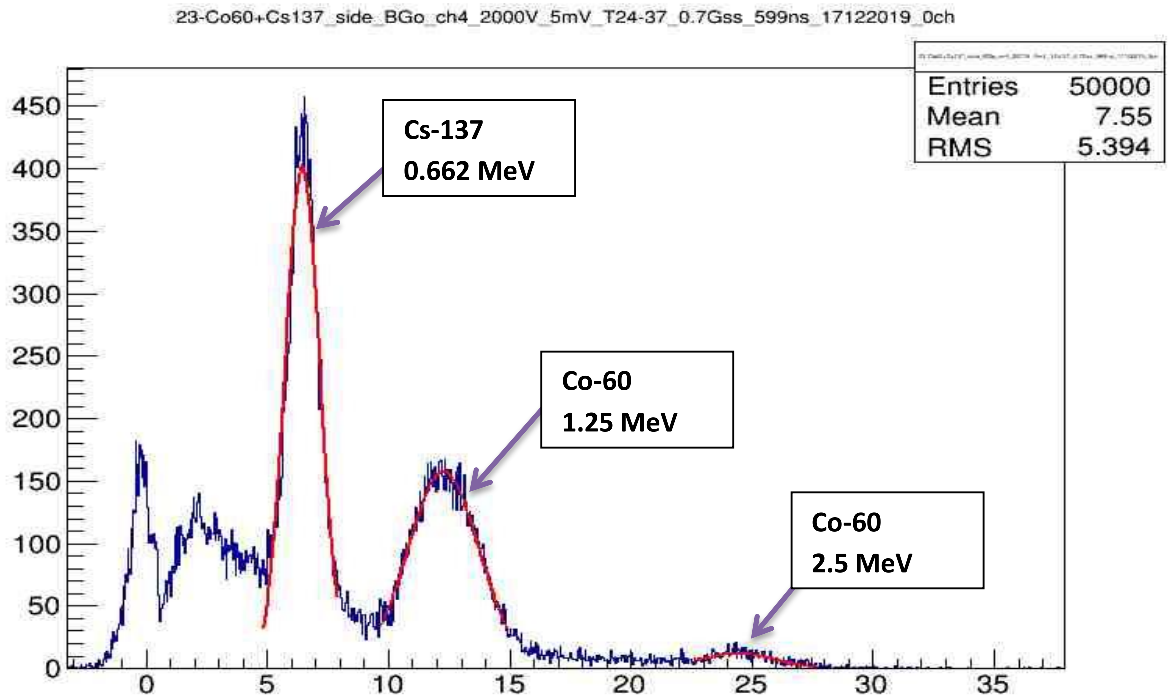

Figure 4. Cs-137 and Co-60 spectrum from measurements with BGO detector at 2000 V and threshold voltage of 5 mV

Table 3. PMT signal taken from the fitting of each peak

PMT signal (A.U)	Energy (MeV)
6.46	0.662
12.27	1.25
24.38	2.50

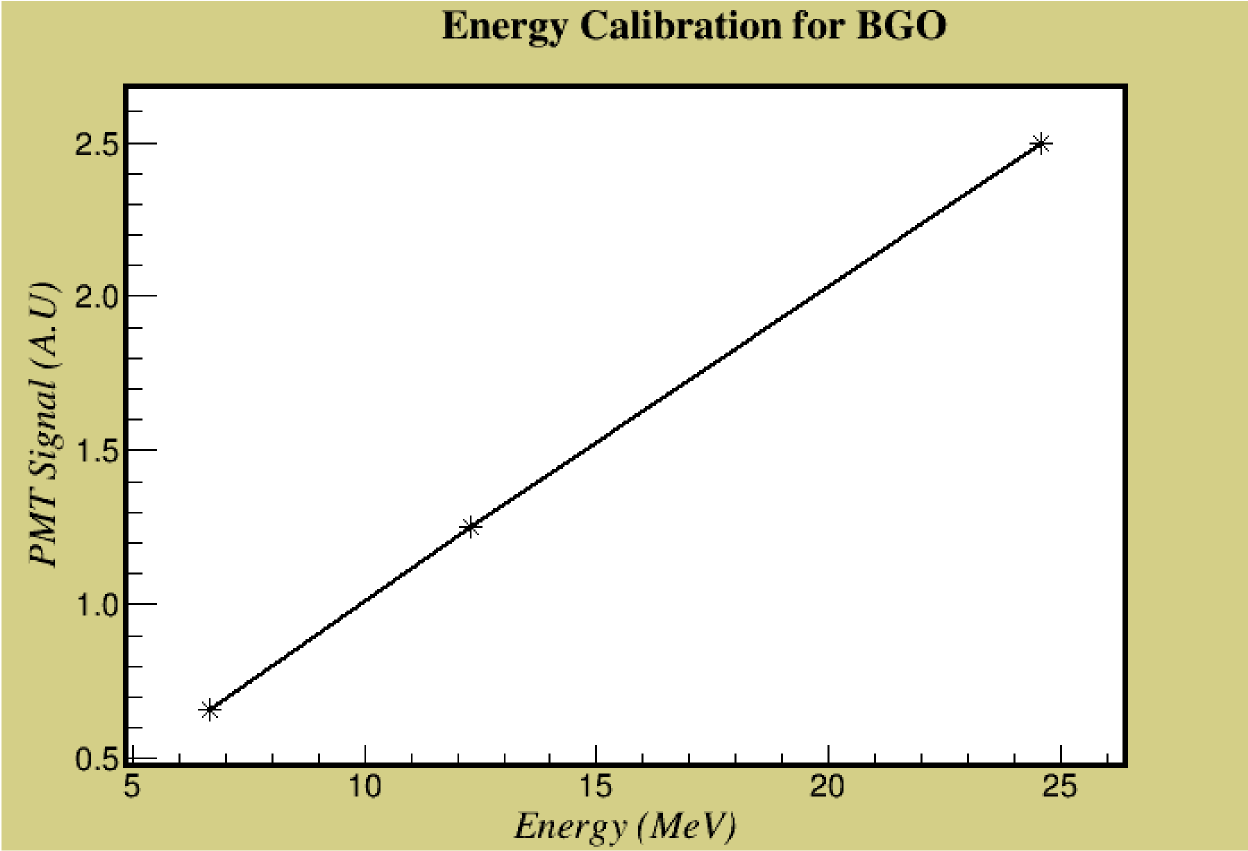

Figure 5. Energy calibration for BGO detector

The spectrum of Cs-137 and Co-60 with an applied voltage of 2000V and threshold voltage of 5mV were used to determine the energy calibration curve for a BGO detector. Only 3 peaks were visible since the resolution of a BGO detector is poor hence the 3 points plotted.

Assignment 2.A: APPLIED VOLTAGE WITH RESOLUTION FOR NaI DETECTOR

Resolution of detector;

$$R = \left(\frac{\sigma}{mean}\right) \times 2.35 \times 100\%$$

Table 4. Resolution calculated from the sigma and mean given from the fitting of the peaks using fit panel

Applied Voltage (V)	**Sigma (σ)**	**Mean**	**Resolution (%)**
900	0.64	23.65	6.36
1000	0.97	40.66	5.61
1100	1.56	65.76	5.57
1200	2.18	98.66	5.19
1300	2.63	137.35	4.50

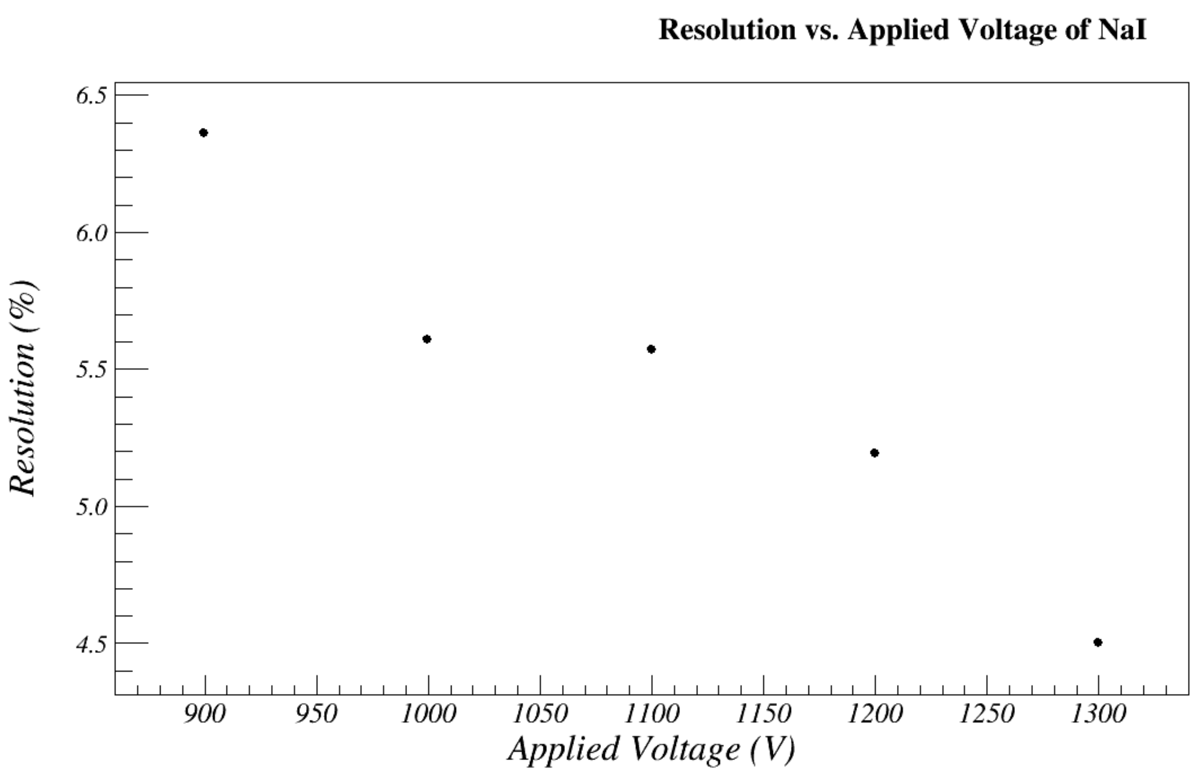

Figure 6. Graph showing the relationship between applied voltage (V) and the resolution (%) of a NaI detector.

The graph in figure 8 above shows that as you increase the applied voltage the resolution decreases, this is because when you increase the applied voltage the noise also increases.

Assignment 2.B: **ENERGY CALIBRATION CURVE FOR NaI DETECTOR**

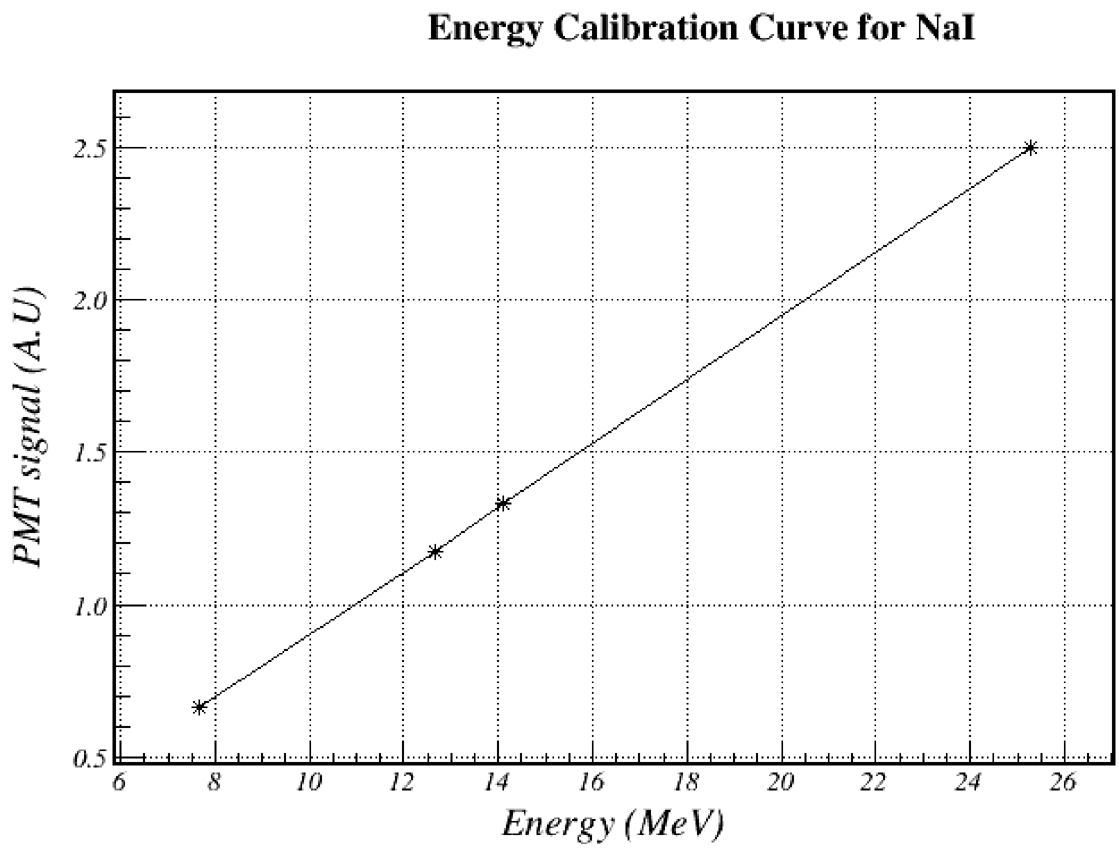

Figure 9. Graph showing the energy calibration of a NaI Detector

The spectrum of Cs-137 and Co-60 with an applied voltage of 800V and threshold voltage of 5mV were used to determine the energy calibration curve for a NaI detector. 4 peaks were visible since the resolution of a NaI detector is higher than that of the BGO detector hence the 4 points plotted.

N.B. To get the good resolution and good calibration one has to carry out a number of measurements.

Assignment 2.C: IDENTIFICATION OF UNKNOWN SOURCE

1. Unknown source using NaI detector with Cs-137 (Na-22)

Using the equation we got from the calibration curve of Cs-137 in a NaI detector one can find the energy of an unknown source:

$$y = 1.45953 + 9.50263x$$

where $\text{y} = \text{PMT signal (A.U)[mean]}$
$\text{x} = \text{Energy of unknown source}$

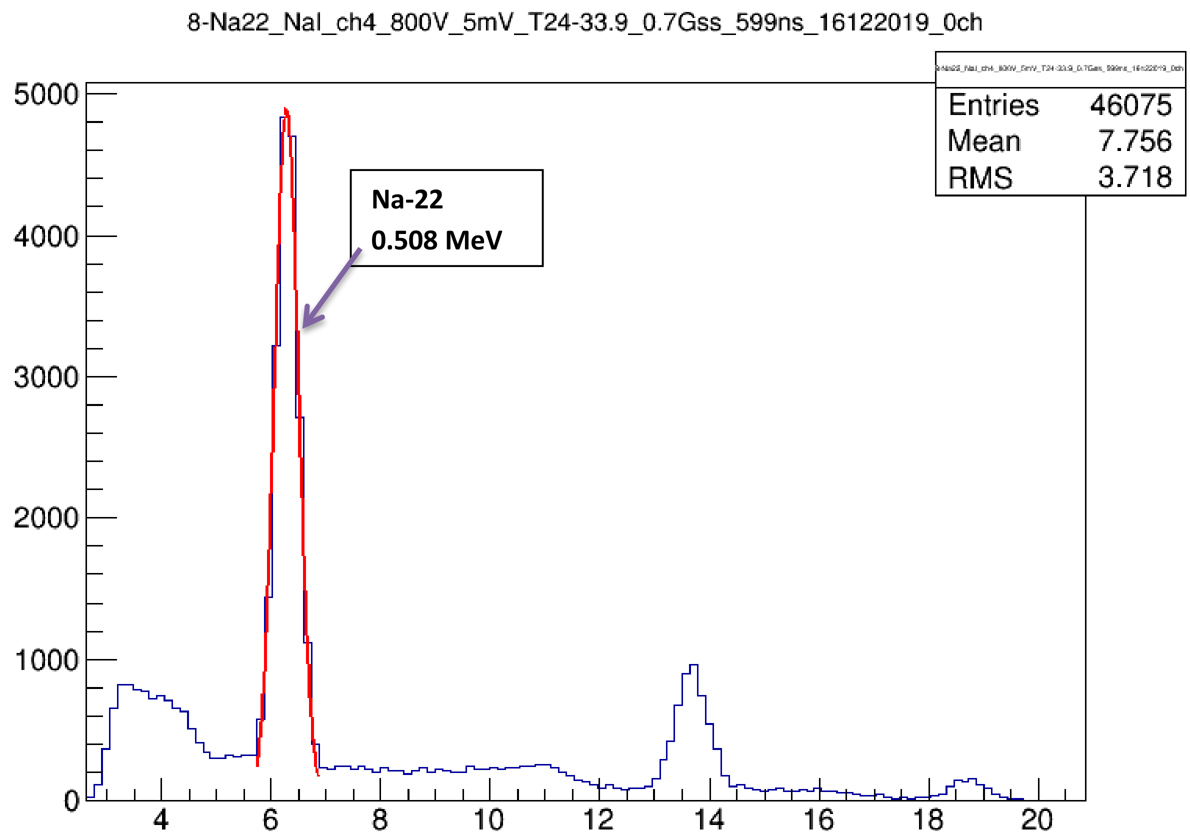

Figure 10. Na-22 spectrum

- **1st Peak:**
  Mean = 6.284

  Therefore;

$$Energy(x) = \frac{mean(y) - 1.45953}{9.50263}$$

$$Energy(x) = \frac{6.284 - 1.45953}{9.50263}$$

$$\underline{\underline{Energy(x) = 0.508\ MeV}}$$

- **2nd Peak:**
  Mean =13.68

  Therefore;

$$Energy(x) = \frac{mean(y) - 1.45953}{9.50263}$$

$$Energy(x) = \frac{13.68 - 1.45953}{9.50263}$$

$$\underline{\underline{Energy(x) = 1.29\ MeV}}$$

The energy of the first peak and the second peak is 0.508 MeV and 1.29 MeV respectively which corresponds to the energy of ^{22}Na (0.511 MeV and 1.274 MeV). Therefore the unknown source is ^{22}Na.

2. Unknown source using NaI detector with Cs137 (Am-241)

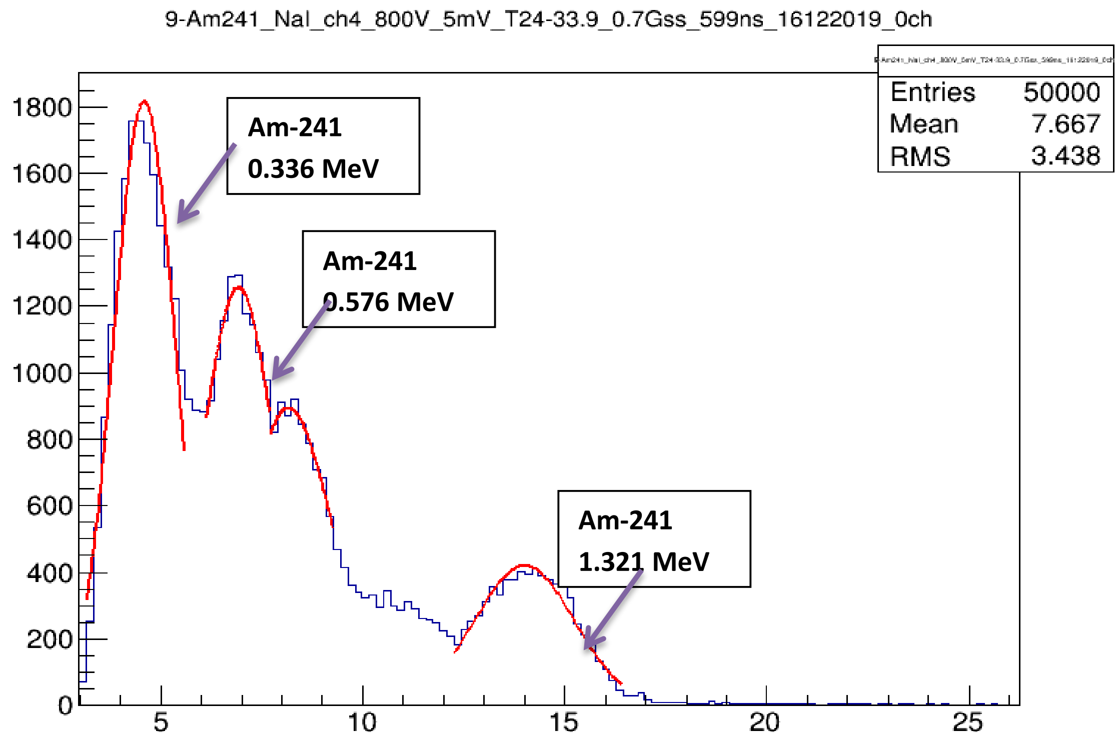

Figure 11. Am-241 spectrum

- **1st Peak:**
  Mean= 4.649

  Therefore;

$$Energy(x) = \frac{mean(y) - 1.45953}{9.50263}$$

$$Energy(x) = \frac{4.649 - 1.45953}{9.50263}$$

$$\underline{Energy(x) = 0.336\ MeV}$$

- **2nd Peak:**
  Mean= 6.93

  Therefore;

$$Energy(x) = \frac{mean(y) - 1.45953}{9.50263}$$

$$Energy(x) = \frac{6.93 - 1.45953}{9.50263}$$

$$\underline{\underline{Energy(x) = 0.576\ MeV}}$$

- **4^{th} Peak:**
  Mean= 14.01

  Therefore;

$$Energy(x) = \frac{mean(y) - 1.45953}{9.50263}$$

$$Energy(x) = \frac{14.01 - 1.45953}{9.50263}$$

$$\underline{\underline{Energy(x) = 1.321\ MeV}}$$

Assignment 3: ATTENUATION COEFFICIENT OF Cu AND Al

The attenuation coefficient is a constant that describes the fraction of absorbed or scattered incident photons in a beam per unit thickness of a material. The equation for calculating the attenuation coefficient is as follows:

$$I = I_0 e^{-\mu x}$$

Where x= the thickness of the material

I= the final intensity

I_0= Initial intensity

μ= attenuation coefficient

1. **Copper (Cu)**

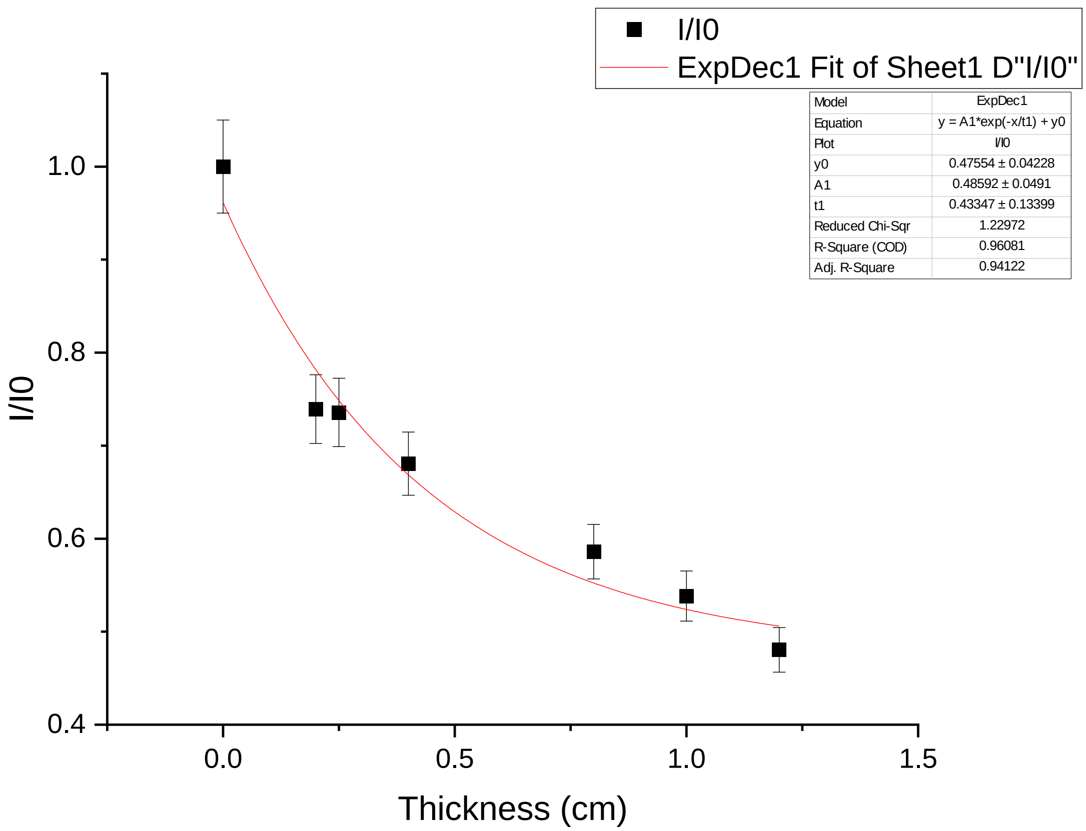

Figure 12. Determination of attenuation coefficient for Cu

The attenuation coefficient of copper (Cu) was determined to be **0.48592 ± 0.05 cm**.

2. Aluminum (Al)

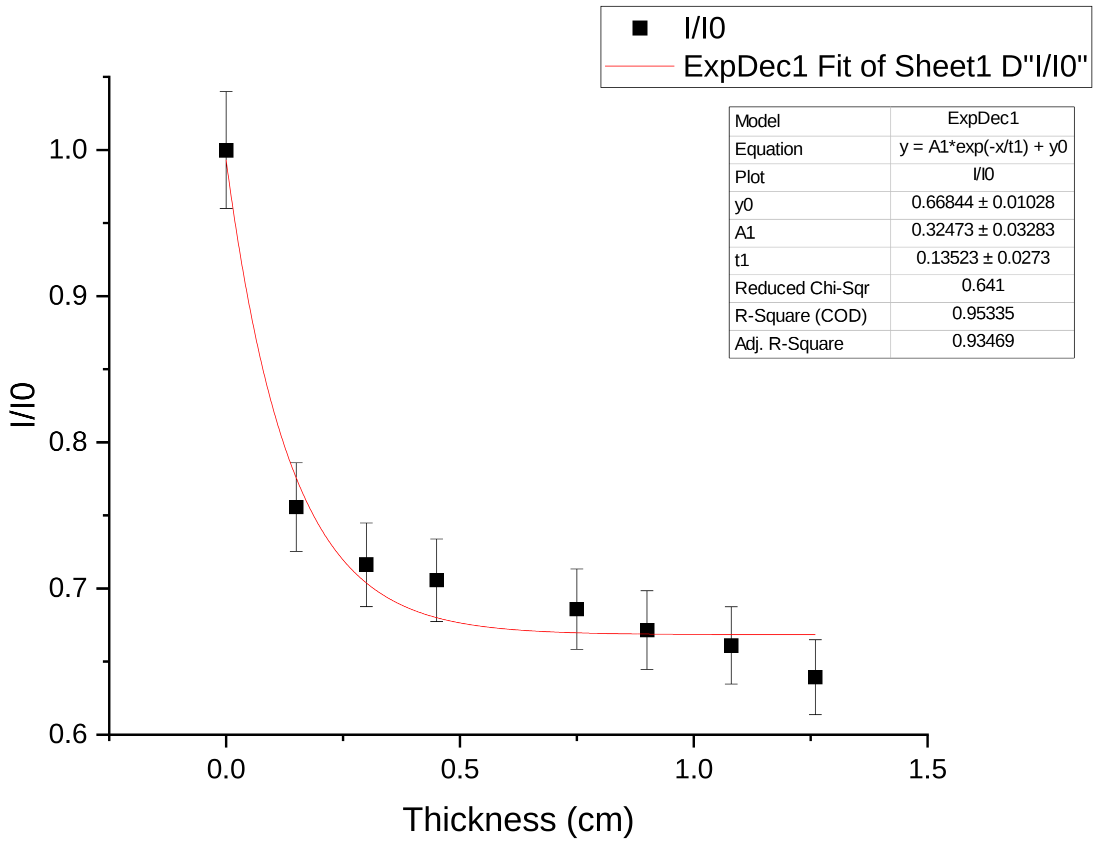

Figure 13. Determination of attenuation coefficient of Al

The attenuation coefficient of aluminium (Al) was determined to be **0.32473 ± 0.03 cm**.

Assignment 4: ALPHA RANGE IN AIR

Range is the distance that a particle travels from its source through matter. It is dependent upon a number of variables such as the particle type, its energy and the medium through which it travels. Range applies especially to charged particles i.e. electrons and alpha particles. This is because when charged particles pass through matter their energy is absorbed by the medium hence slowing them down.

A plastic detector with applied voltage of 2000V and threshold voltage of 50mV was used to determine the range of an alpha (α-) particle, ${}^{4}_{2}He$, in air.

The alpha source used: ${}^{239}Pu$ (Decay energy= 5.156MeV)

Detector used : Plastic detector

Applied Voltage : 2000V

Table 5. Number of counts per second of source at different distances from the detector

Counts per sec (d/s)	**Distance (cm)**
440	0.0
390	0.5
360	1.0
340	1.5
320	2.0
300	2.5
280	3.0
260	3.5
260	3.8
260	4.0

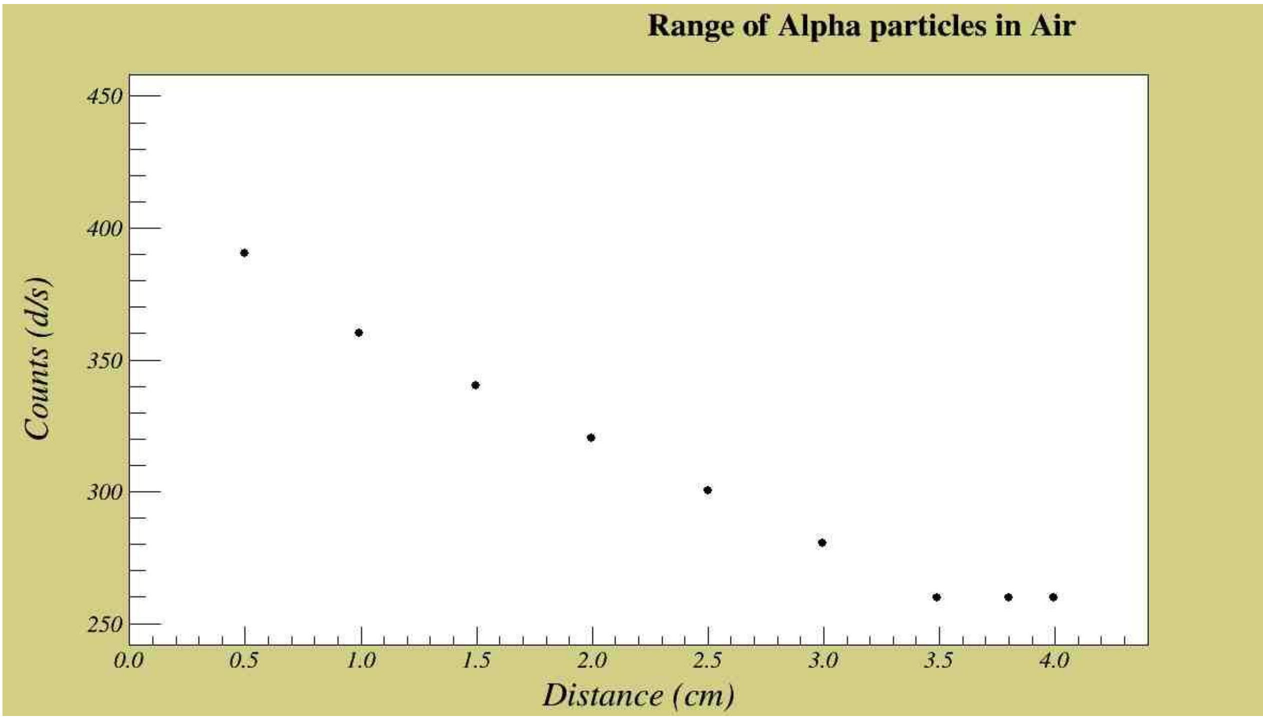

Figure 14. Range of alpha particle in air

Figure 14 shows a graph of counts per second plotted against the distance of the source from the detector in order to estimate the range of an alpha particle in air. From the figure it shows that the graph decreases until it reaches a point where the numbers of counts are consistent. This shows that the distance that an α particle can travel in air is about 3.5 cm.

Estimating the Range of α Particles in Air using SRIM Simulations

Simulations using SRIM software were done to estimate the range of alpha particles in air.

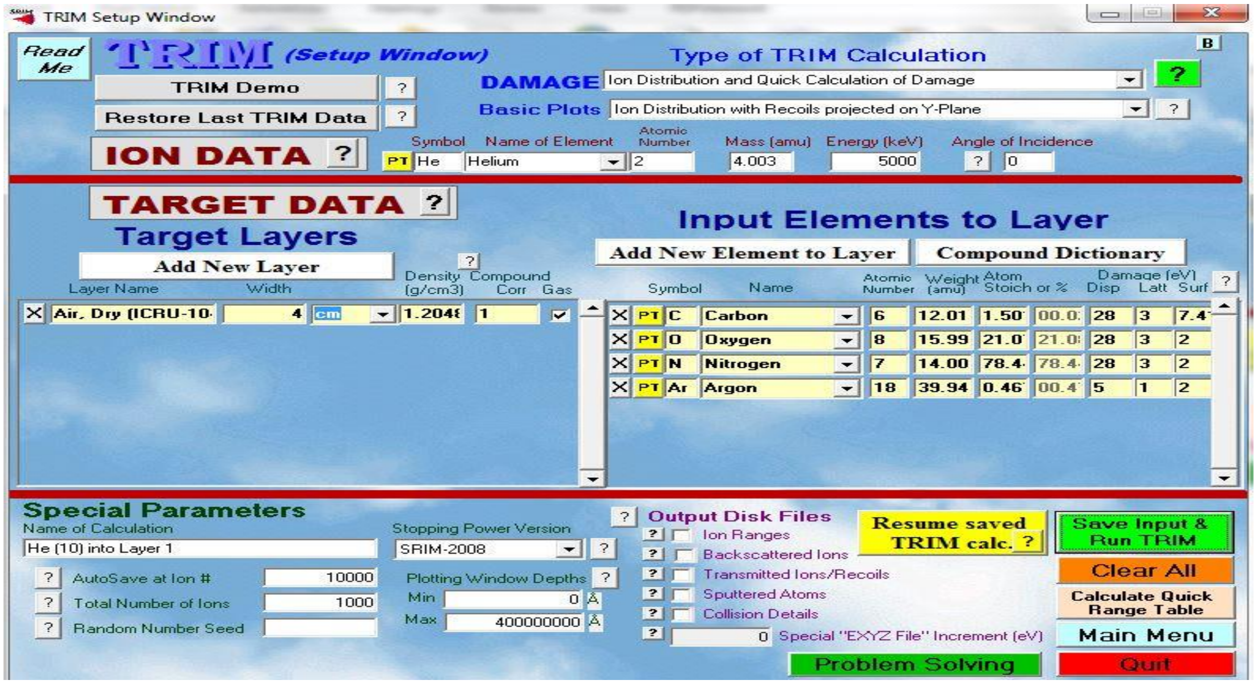

Figure 15 Parameters used for the simulation of an alpha particle in air using TRIM

Since the alpha energy of ^{239}Pu is about 5.156 MeV the energy was set to 5 MeV. The layer used was dry air and the total number of ions used was 1000. The width of the layer was set to 4 cm since it is already known that the range of an alpha particle is less than 4 cm.

Figure 16 below shows that the depth of He in air is about 38 mm (3.8 cm). The value corresponds to that taken from the graph (3.5 cm).

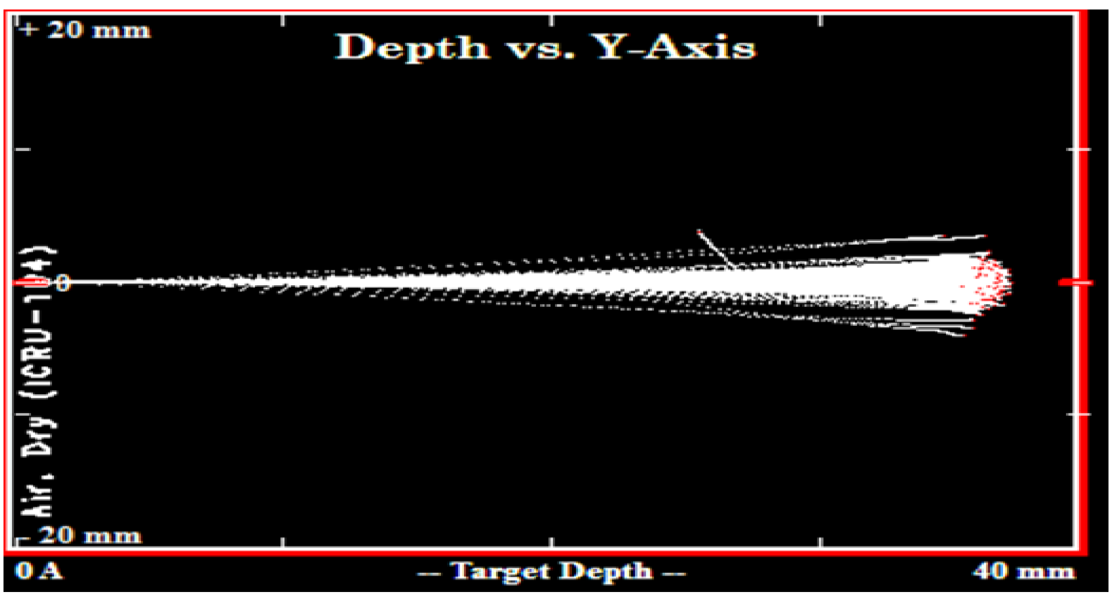

Figure 16. Depth of an alpha particle in air (TRIM)

PIXEL DETECTOR

- A pixel detector is a type of ionizing radiation detector consisting of an array of diodes based on semiconductor technology and their associated electronics**.**
- It is like a digital camera
- It comprises of two main components which is the Sensor (with size of 1.5×1.5 cm) and an electronic chip. It has 256 x 256 pixels, with each pixel size being 55µm x 55µm.

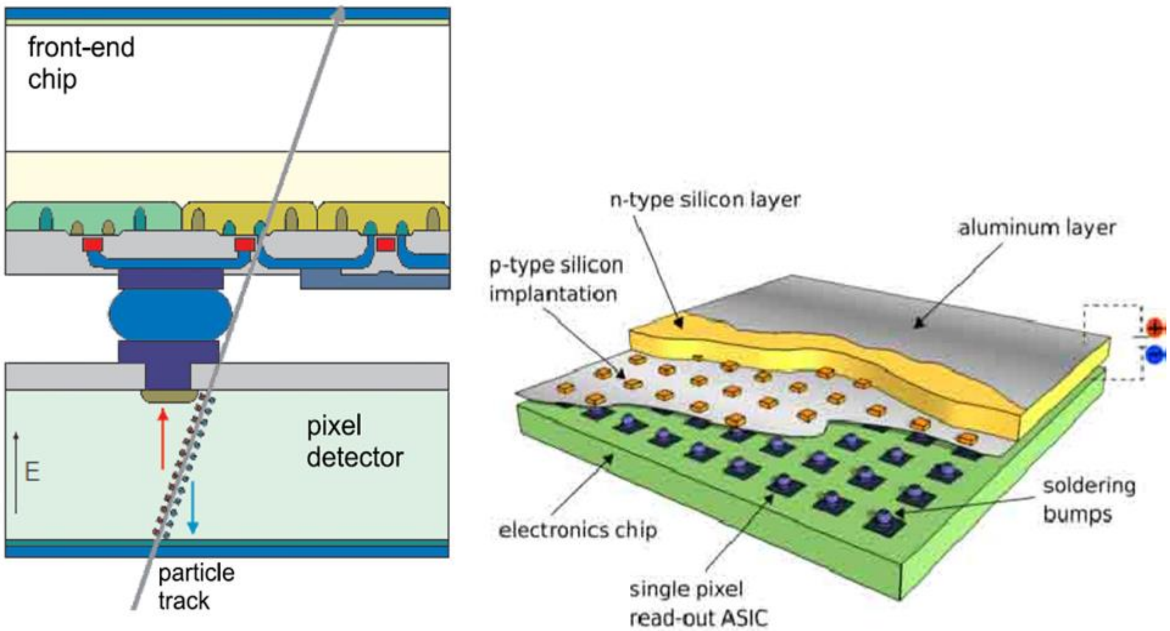

Figure 17. Pixel detector

Advantage of a Pixel Detector

- It is very small
- Has a very high resolution
- It can be used for every type of resolution
- Portable and doesn't need a power supply

Application of a Pixel Detector

- NASA uses a pixel detector to see the type of cosmic radiation from this stars
- One can identify the type of radiation and the number of particles.

Determination of Alpha particles (Am-241) in air with energy of about 4 MeV using pixel detector

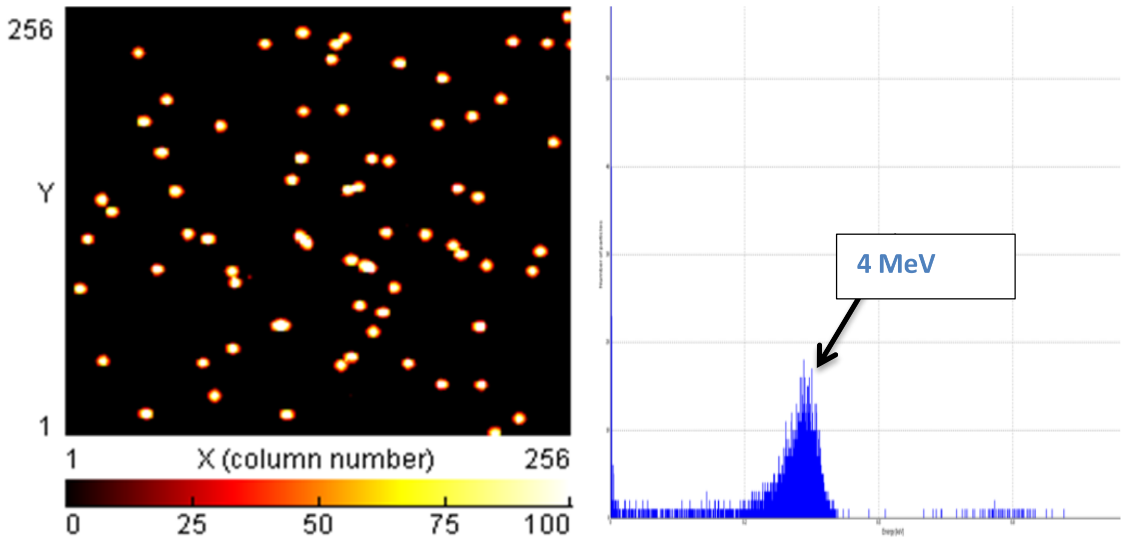

Figure 18. Absorption of alpha particles in the air d=0 cm

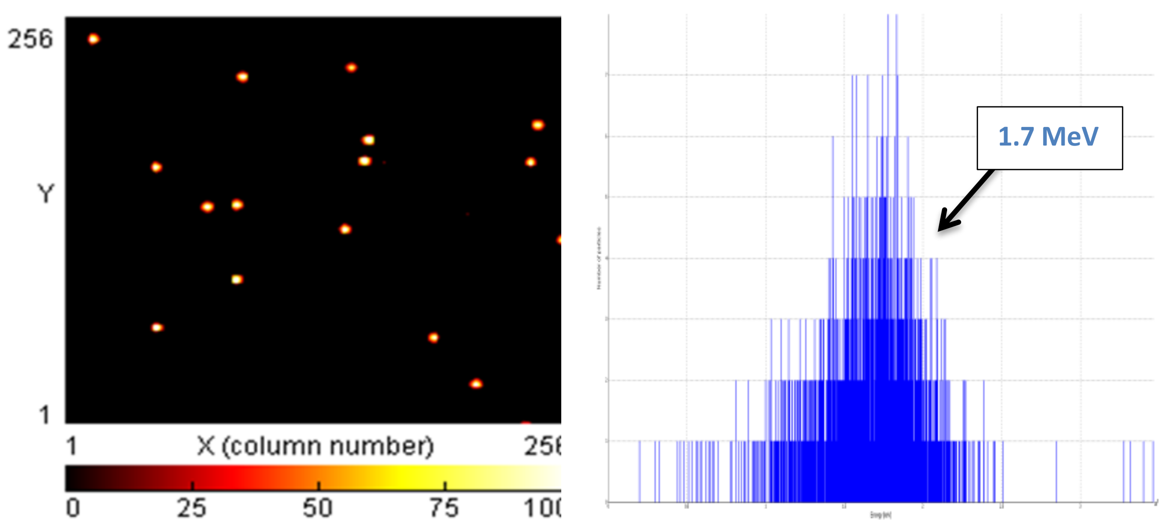

Figure 19. Absorption of alpha particles in the air d=2 cm

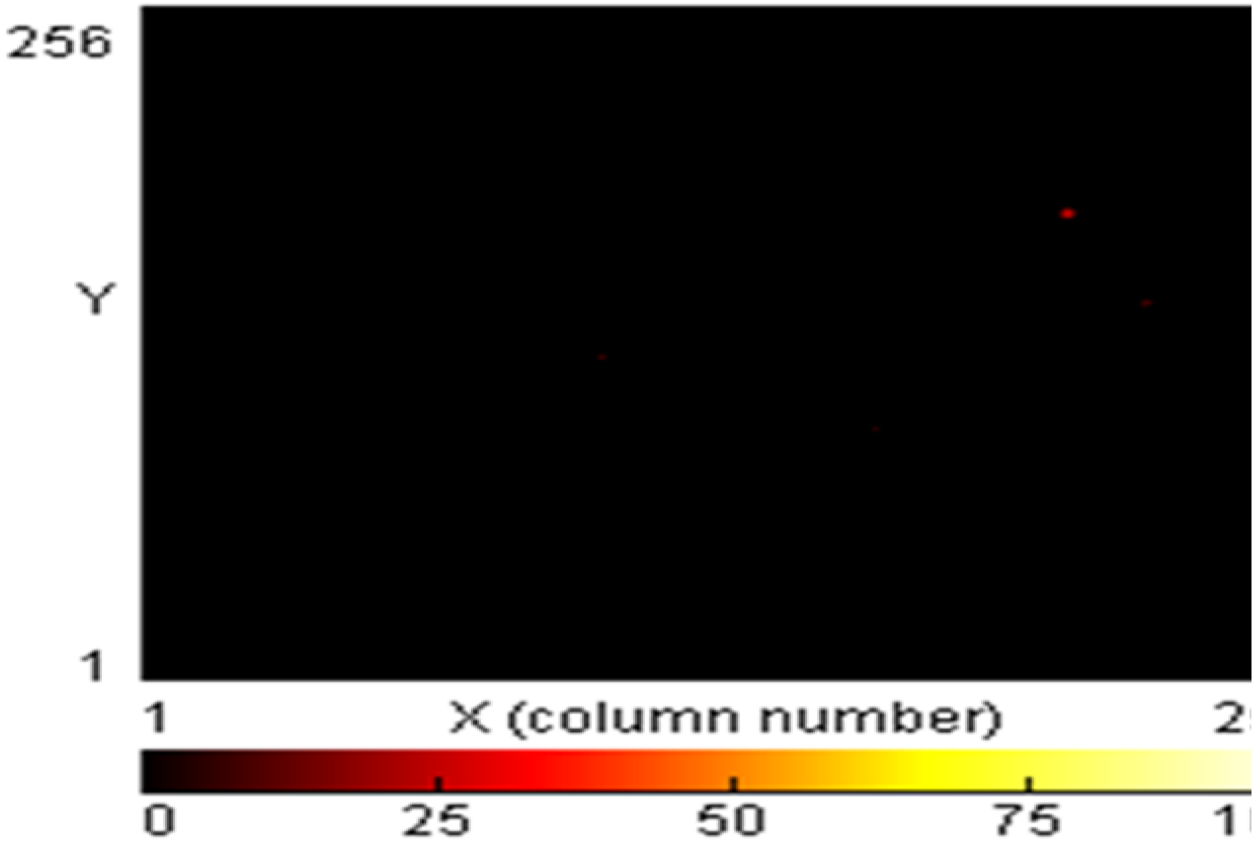

Figure 20. Alpha particle in air d= 3cm.

Figures 18, 19 and 20 show that as you increase the distance between the source and pixel detector, the intensity, energy and number of particles decreases until there are no particles visible.

CONCLUSION

In conclusion, the project was helpful in:

- Acquiring basic knowledge in radiation protection and safety of radiation sources
- Acquiring knowledge on absorbed dose, equivalent dose and effective dose
- Using SRIM to do simulations which were helpful in giving a clear understanding of how radiation particles move through a medium
- Providing the necessary practical skills and basic tools for:
  - Peak fitting and analysis using ROOT
  - Calculating resolution for various scintillation detectors (BGO and NaI detector)
  - Energy calibration of BGO and NaI detector
  - Identification of unknown sources using the energy calibration curve
  - Determination of attenuation coefficients for aluminium and copper
  - Determination of range of alpha in air using SRIM software