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# Radiation Protection And the Safety of Radiation Sources

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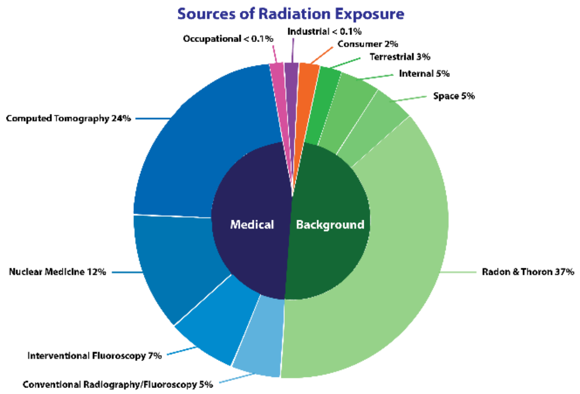
# Abstract

This work was done as part of the INTEREST wave 10 program where it covers various aspects of types of radiation, dose of radiation, radiation protection and radiation detection. Using software programs as ROOTS, SRIM and MATLAB. Number of tasks were assigned where we analyzed ROOTS experimental data files to get the relation between the resolution and applied voltage for scintillation detectors. Plotted the calibration curve using the energy spectrum of known source and identified unknown radiation sources through energy calibration curve. Additionally, we explored the resolution capabilities of different scintillation detectors and assessed alpha particle ranges in air using Plastic detectors. Furthermore, utilized Monte Carlo simulation techniques with SRIM software, we used to evaluate alpha particle ranges and energies comprehensively.

# Introduction

Radiation, like waves or particles, surrounds us daily from sources such as the sun, microwaves, and radios. Most of this radiation is harmless, but some can be risky. It's generally not harmful for small doses, but it can be risky for larger doses. Different types of radiation call for different safety measures. Non-ionizing radiation, which can't remove electrons from atoms, mostly just makes things hotter, like how microwaves heat food. Ionizing radiation, on the other hand, can remove electrons, causing changes in matter and living things. These changes, often involving charged particles, can pose health risks. Balancing the benefits and dangers of radiation requires smart protection strategies to use it safely.




Average Annual Radiation Dose

| Sources | Radon & Thoron | Computed Tomography | Nuclear Medicine | Interventional Fluoroscopy | Space | Conventional Radiography/ Fluoroscopy | Internal | Terrestrial | Consumer | Occupational | Industrial |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Units<br>mrem (United States)<br>mSv (International) | 228 mrem<br>2.28 mSv | 147 mrem<br>1.47 mSv | 77 mrem<br>0.77 mSv | 43 mrem<br>0.43 mSv | 33 mrem<br>0.33 mSv | 33 mrem<br>0.33mSv | 29 mrem<br>0.29 mSv | 21 mrem<br>0.21 mSv | 13 mrem<br>0.13 mSv | 0.5 mrem<br>0.005 mSv | 0.3 mrem<br>0.003 mSv |

(Source: National Council on Radiation Protection & Measurements, Report No. 160)

*Figure 1: sources of radiation*

The danger of ionizing radiation lies in the fact that the radiation is invisible and not directly detectable by human senses. People can neither see nor feel radiation, yet it deposits energy to the molecules of the body. The energy is transferred in small quantities for each interaction between the radiation and a molecule and there are usually many such interactions.

It is therefore very important to know the factors that affect the radiation dose:

- **Activity:** Activity of the source directly influences the radiation dose deposited in the material.
- **Type of radiation**: Each type of radiation **interacts with matter in a different way**.

- **Distance:** The amount of radiation exposure depends on the distance from the source of radiation. Similarly to a heat from a fire, if you are too close, the intensity of heat radiation is high and you can get burned.
- **Time:** The amount of radiation exposure depends directly (linearly) **on the time** people spend near the source of radiation.
- **Shielding:** Finally, the radiation dose also depends on the material between the source and the object. If the source is too intensive and time or distance do not provide sufficient radiation protection, the shielding can be used.

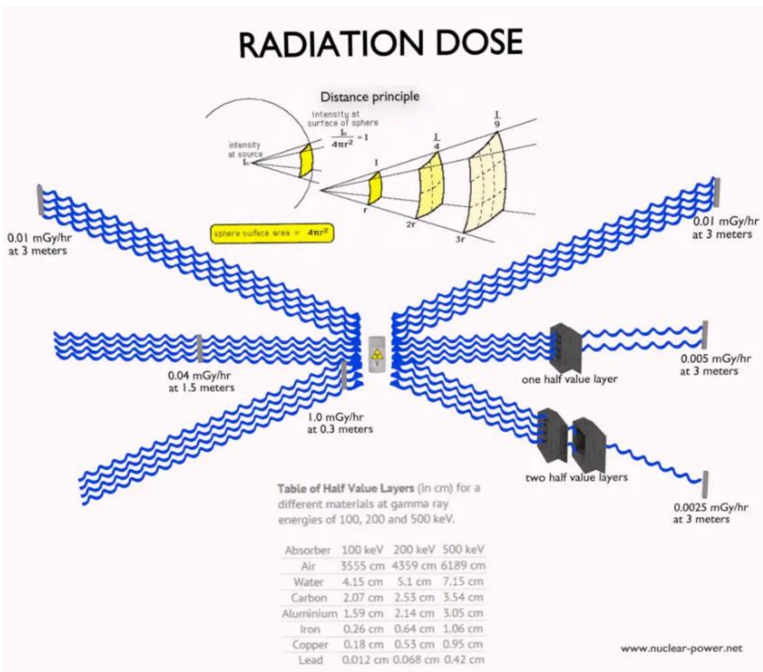



*Figure 2: Radiation dose*

# Radiation detectors

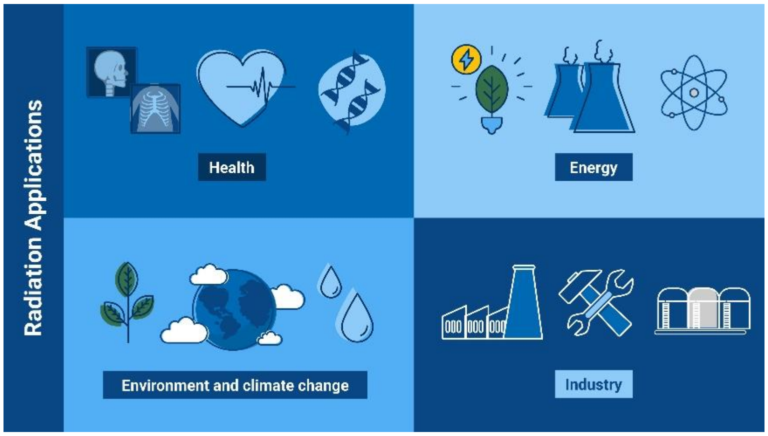



*Figure 3: Radiation applications.*

In fields such as nuclear medicine, industrial applications, and homeland security, radiation detection plays a critical role in ensuring safety and regulatory compliance. Radiation detectors allow for the early identification of possible hazards and the timely implementation of prevention strategies by accurately detecting and measuring radiation levels. Furthermore, accurate radiation detection reduces needless radiation exposure to patients and medical staff while facilitating targeted treatments in medical diagnostics and therapy. Moreover, detectors provide vital information for tracking environmental contamination, estimating radiation levels, and researching the effects of radiation on ecosystems in environmental monitoring and radiation research.

## Scintillation detector

Scintillation counters are widely used in radiation protection, an assay of radioactive materials, and physics research because they can be made inexpensively yet with good efficiency and can measure both the intensity and the energy of incident radiation. Gamma cameras, also known as scintillation cameras, are used in hospitals all over the world and are based on the scintillation effect.

The advantages of a scintillation counter are its efficiency and possible high precision and counting rates. These latter attributes result from the extremely short duration of the light flashes, from about 10-9  (organic scintillators) to 10-6 (inorganic scintillators) seconds. The intensity of the flashes and the amplitude of the output voltage pulse are proportional to the energy of the radiation. Therefore, scintillation counters can be used to determine the energy and the number of exciting particles (or gamma photons).

In general, a scintillation detector consists of:

- **Scintillator**. A scintillator generates photons in response to incident radiation.
- **Photodetector**. A sensitive photodetector (usually a photomultiplier tube (PMT), a charge-coupled device (CCD) camera, or a photodiode) converts the light to an electrical signal, and electronics process this signal.

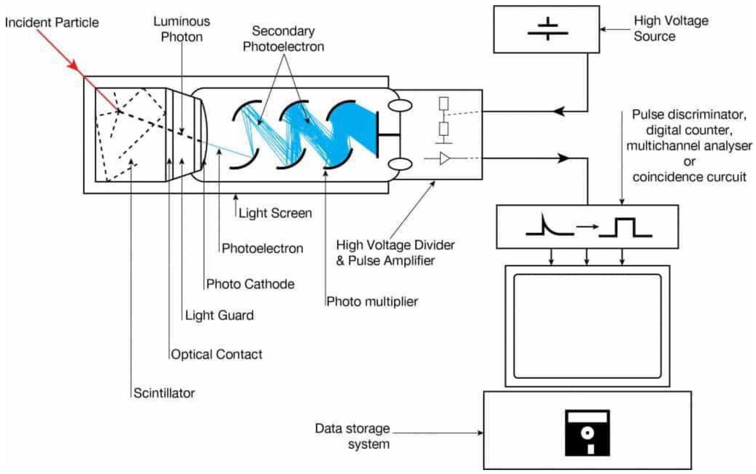



*Figure 4: scintillator detector*

The basic principle of operation involves the radiation reacting with a scintillator, which produces a series of flashes of varying intensity.

In this study we used the experimental data of two types of scintillator detector: BGO and NaI detectors.

## BGO detector:

bismuth germanate (BGO) detectors are used in particle physics, nuclear imaging systems and high energy gamma spectrometry. In addition, in pixelated arrangement, the BGO is one of the suitable detectors to use in positron emission tomography (PET). Its major advantage over many other scintillators is its high density (7.13 g/cm3 ) and the large atomic number. These properties result in the largest probability per unit volume of any commonly available scintillation material for the photoelectric absorption of gamma rays. Its mechanical and chemical properties make it easy to handle and due to these reasons BGO detectors are widely used in the systems that require a high yield of photo fraction.

## NaI detector:

NaI(Tl) (thallium-doped sodium iodide) is the most widely used scintillation material, it is used traditionally in nuclear medicine, geophysics, nuclear physics, and environmental measurements. The iodine provides most of the stopping power in sodium iodide (since it has a high Z = 53).. They exhibit high efficiency for the detection of gamma rays and are capable of handling high count rates. Inorganic crystals can be cut to small sizes and arranged in an array configuration to provide position sensitivity. This feature is widely used in medical imaging to detect X-rays or gamma rays. Inorganic scintillators are better at detecting gamma rays and X-rays. The NaI(Tl) scintillator has a higher energy resolution than a proportional counter, allowing more accurate energy determinations. This is due to their high density and atomic number, which gives a high electron density. A disadvantage of some inorganic crystals, e.g., NaI, is their hygroscopicity, a property that requires them to be housed in an airtight container to protect them from moisture.

## Pixel Detector

It is an **advanced** detector like a digital camera.

It consists of two parts:

1- Sensor (Si) 2- Electronic chip

The size of the sensor is 1.5x1.5 cm.

It has 256 x 256 pixels (65.536 pixel).

The pixel size is 55µm x 55µm.

**It has high resolution.**

It is used for registration different types of radiation:

(x- ray, gamma, electron, neutron and charged particles).

*Figure 5: pixel detector.*

# Tasks

## Task one (Relation between the Resolution and Applied Voltage for BGO detectors)

In the context of radiation detection, resolution typically refers to the ability of a detector to accurately differentiate between two close energy peaks. A lower energy resolution indicates a greater ability to discriminate between adjacent energy peaks, which makes it possible to identify distinct radionuclides or decay processes in the radiation spectrum.

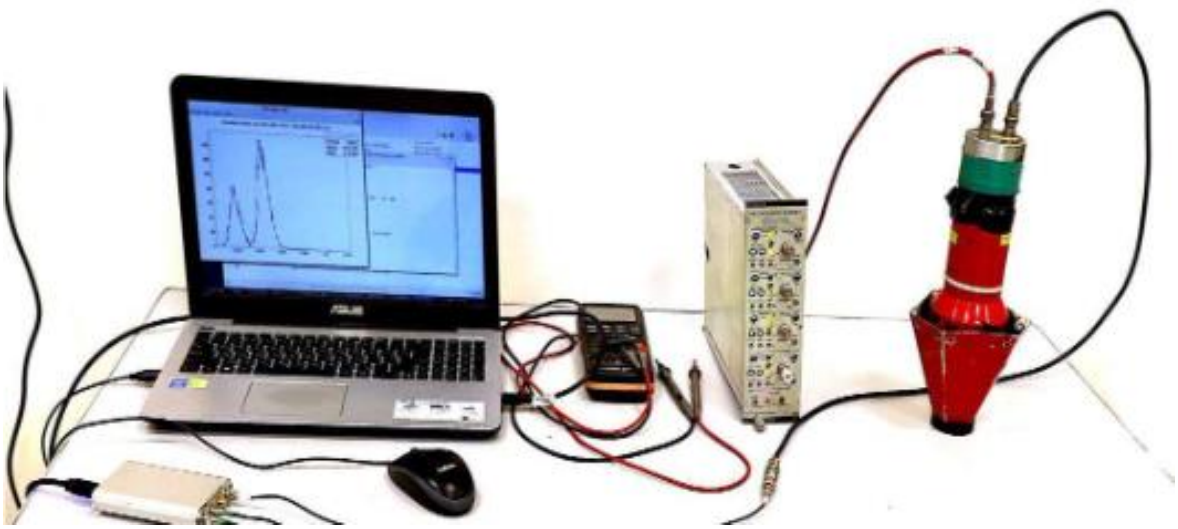


*Figure 6: BGO detector.*

### Procedures

Using the experimental data provided ( 8 roots files)

We were able to get the mean and sigma corresponding to each applied voltage.

To calculate the resolution we used the following relation:

**Resolution= (sigma/mean)*2.35**

## Results

*Table 1: applied voltage and the corresponding Resolution %*

| Applied voltage(v) | mean | sigma | Resolution | Resolution % |
|---|---|---|---|---|
| **1200** | 1.59755 | 0.46363 | 0.682000876 | 68.20008763 |
| **1300** | 1.36433 | 0.247725 | 0.426695704 | 42.66957041 |
| **1400** | 1.92554 | 0.287375 | 0.350723044 | 35.07230439 |
| **1500** | 3.00033 | 0.400443 | 0.313645849 | 31.3645849 |
| **1600** | 4.40599 | 0.573062 | 0.305651102 | 30.56511022 |
| **1700** | 6.11018 | 0.735223 | 0.282769747 | 28.27697466 |
| **1900** | 10.6842 | 1.21507 | 0.267255808 | 26.72558076 |
| **2000** | 13.6175 | 1.5491 | 0.267331375 | 26.73313751 |

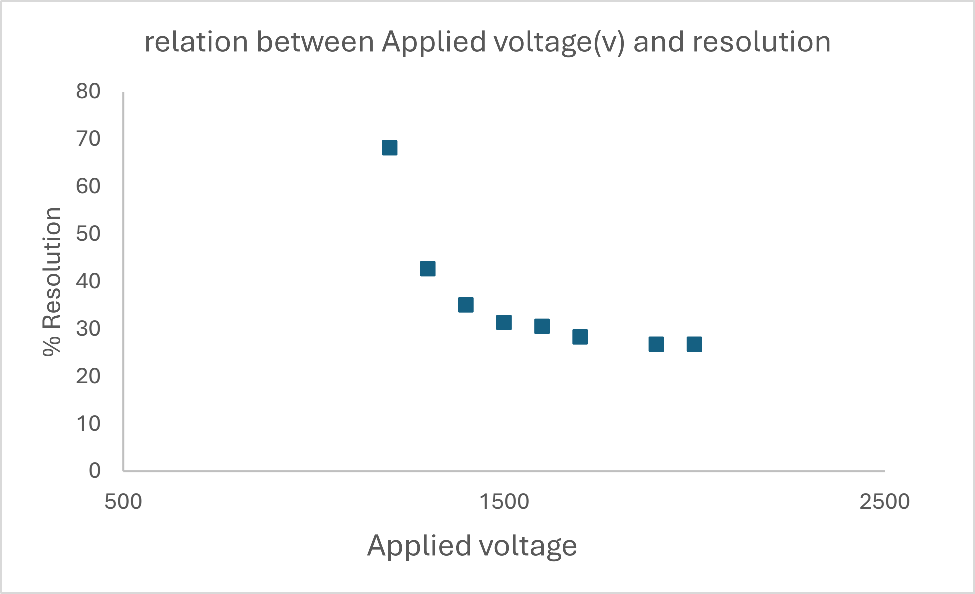



*Figure 7: Relation between applied voltage and resolution %*

## Task Two (Calibrating BGO detector)

### Using a known source Cobalt and Cesium

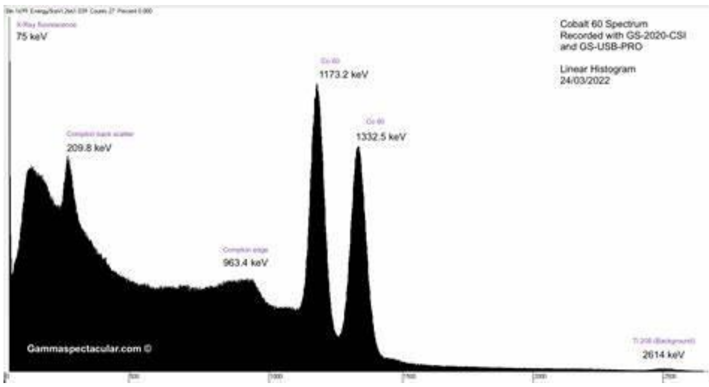



Figure 7: energy spectrum of cobalt 60

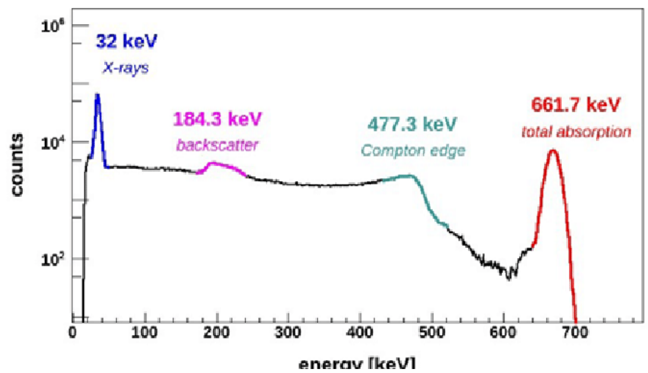



Figure 8: cesium 137 energy spectrum

Knowing the energy spectrum of both sources we were able to identify them in the experimental data provided.

Using roots program we obtained the mean by making gaussian fit.

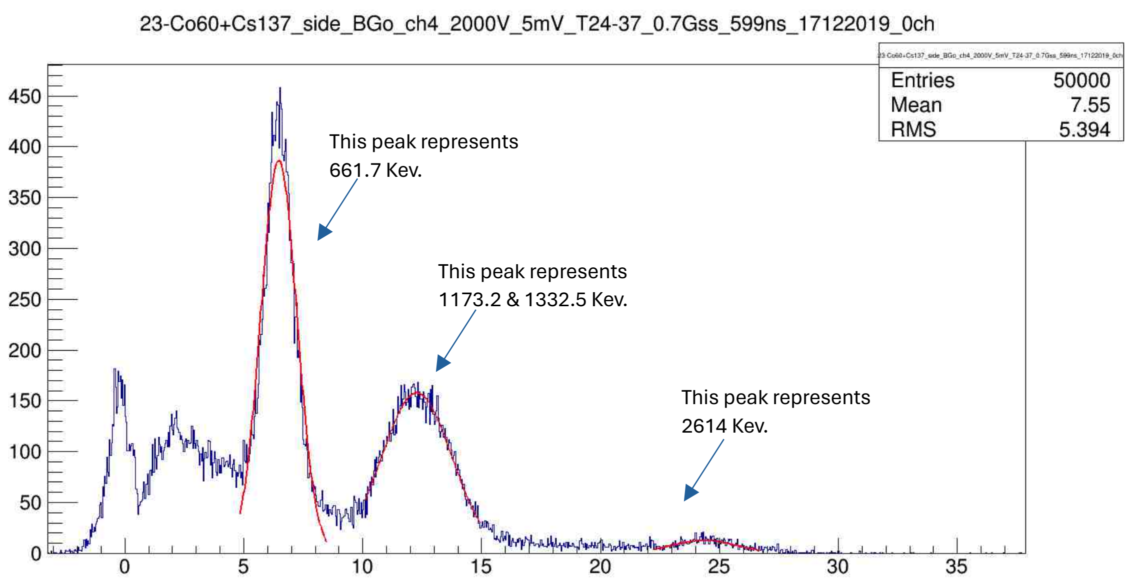



Figure 9: The energy spectrum of cobalt and cesium for BGO at 2000v

Comment: The BGO detector did not differentiate between the two peaks of cobalt (1173.2 & 1332.5 Kev) therefore, we took the average of the two peaks.

## Results

*Table 2: channel number(mean) and energy of peaks for BGO detector*

| Channel number | Energy (kev) |
| --- | --- |
| **6.47135** | **661.66** |
| **12.2738** | **1252.85** |
| **24.3523** | **2614** |

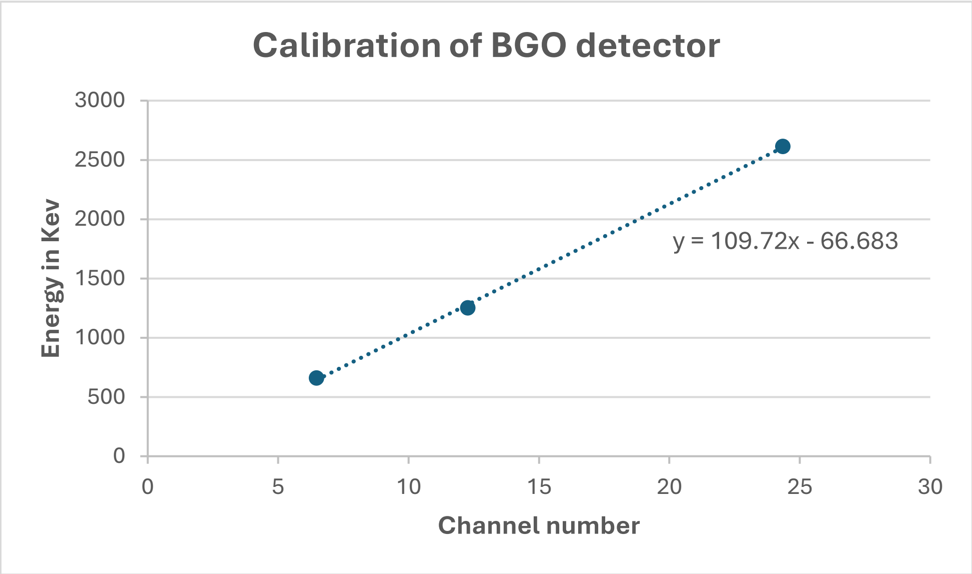



*Figure 10: calibration curve of BGO detector*

**The equation of the energy calibration line for BGO detector is:**

$y = 109.72x - 66.683$

where:

**x** is the mean

**y** is the energy in Kev

## Identifying unknown source using BGO detector

The calibration results in a relation between the mean (channel number) and the energy of the peak in Kev. Using this relation y = 109.72x - 66.683 where y is the energy in Kev and x is the channel number.

Utilizing this equation we were able to identify the peaks of the given experimental data

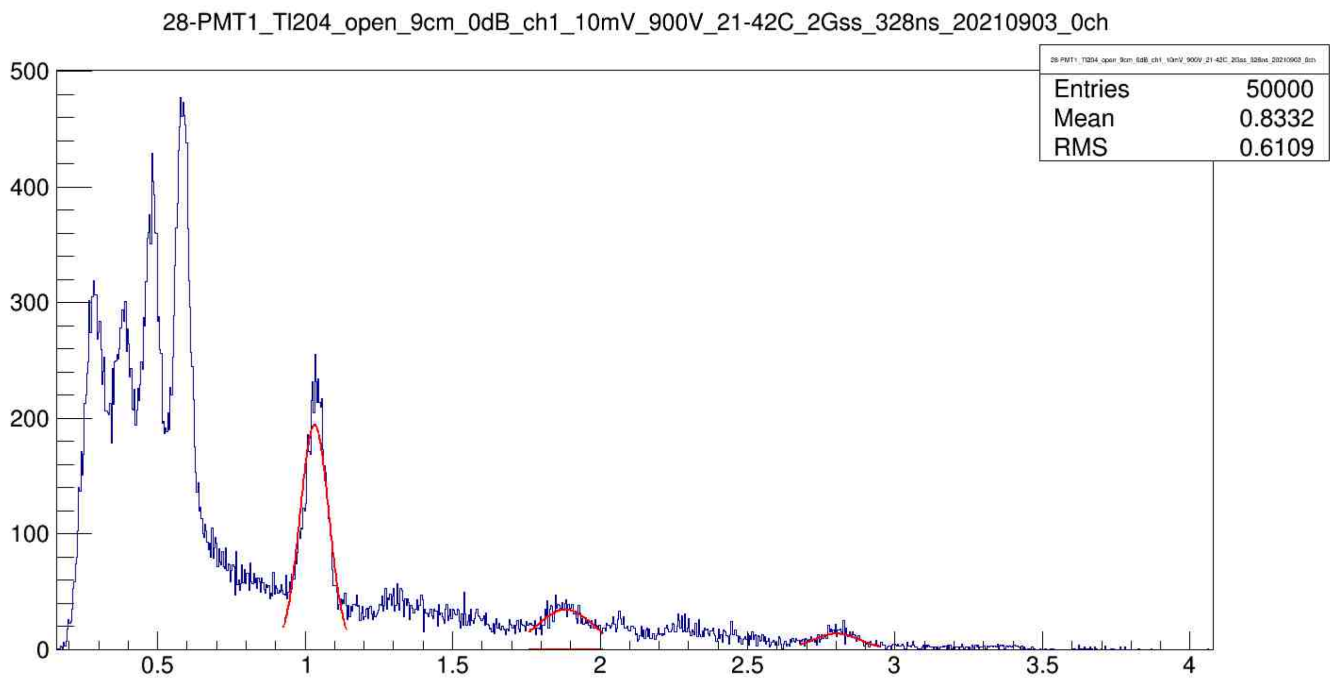



*Figure 11: The energy spectrum of unknown source for BGO detector*

## Results:

*Table 3: The energy corresponding to the channel number of the energy spectrum*

| Channel number | Energy in Kev |
|---|---|
| **1.03448** | **46.8231** |
| **1.8782** | **139.396** |
| **2.79215** | **239.674** |

# Task three

## Relation between the Resolution and Applied Voltage for NaI detector

Using the experimental data provided ( 8 roots files) We were able to get the mean and sigma corresponding to each applied voltage.

To calculate the resolution we used the following relation:

**Resolution= (sigma/mean)*2.35**

### Results:

*Table 4: Resolution % corresponding to the applied voltage for NaI detector*

| Applied voltage(v) | mean | sigma | Resolution | Resolution % |
|---|---|---|---|---|
| **900** | 23.663 | 0.625963 | 0.062165112 | 6.21651122 |
| **1000** | 40.5942 | 1.10411 | 0.063916976 | 6.391697582 |
| **1100** | 65.7562 | 1.54989 | 0.055390085 | 5.539008489 |
| **1200** | 98.7199 | 2.05796 | 0.04898917 | 4.898917037 |
| **1300** | 137.349 | 2.67908 | 0.045838251 | 4.583825146 |

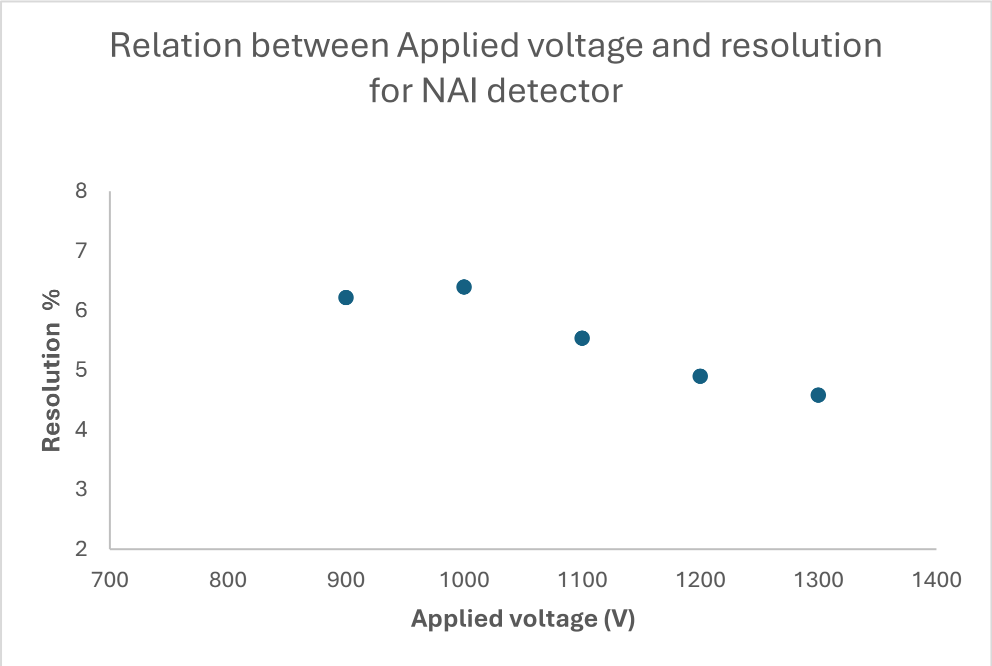



*Figure 12: Relation between applied voltage and resolution for NaI detector*

## Calibration curve of NaI detector

A source of cesium and cobalt will be employed using the NaI detector at 800 volt.

The energy spectrum shows the peak of cesium and three peaks of cobalt correctly unlike the BGO detector.

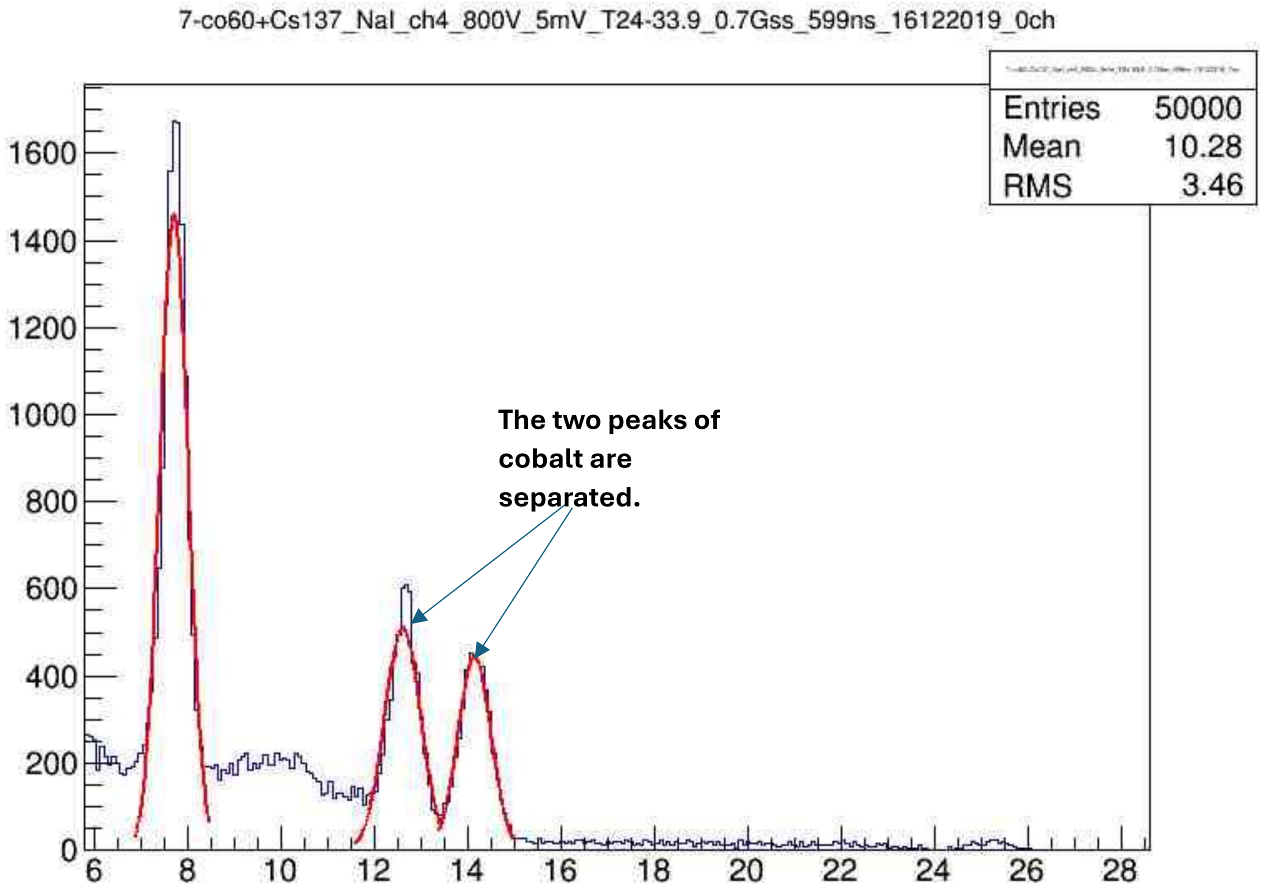



*Figure 13: The energy spectrum of cobalt and cesium for NaI detector*

# Results

*Table 5: Channel number(mean) and energy of Cs-137 and Co-60 peaks from a NaI detector.*

| Channel number | Energy (kev) |
|---|---|
| **7.69594** | **661.66** |
| **12.6025** | **1173.2** |
| **14.1392** | **1332.5** |
| **25.1949** | **2614** |

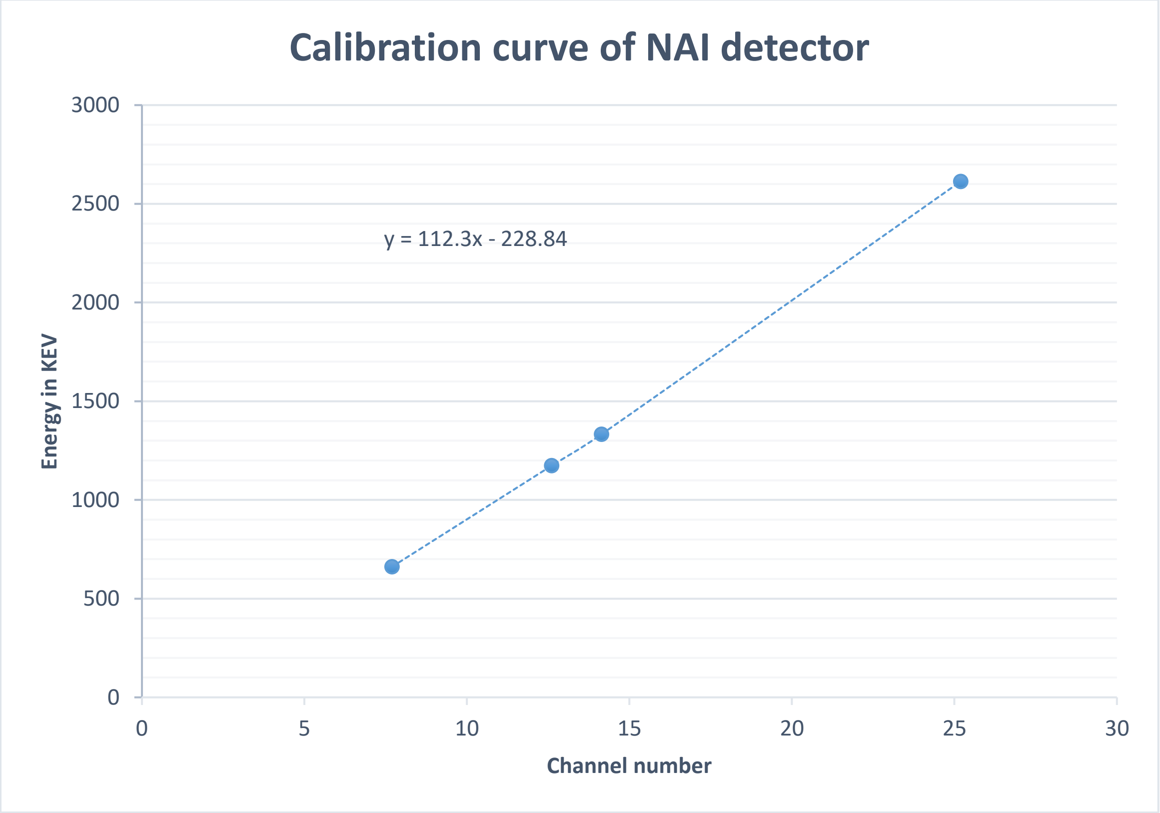



*Figure 14: Calibration curve of NaI detector*

## Identifying unknown source using NAI detector

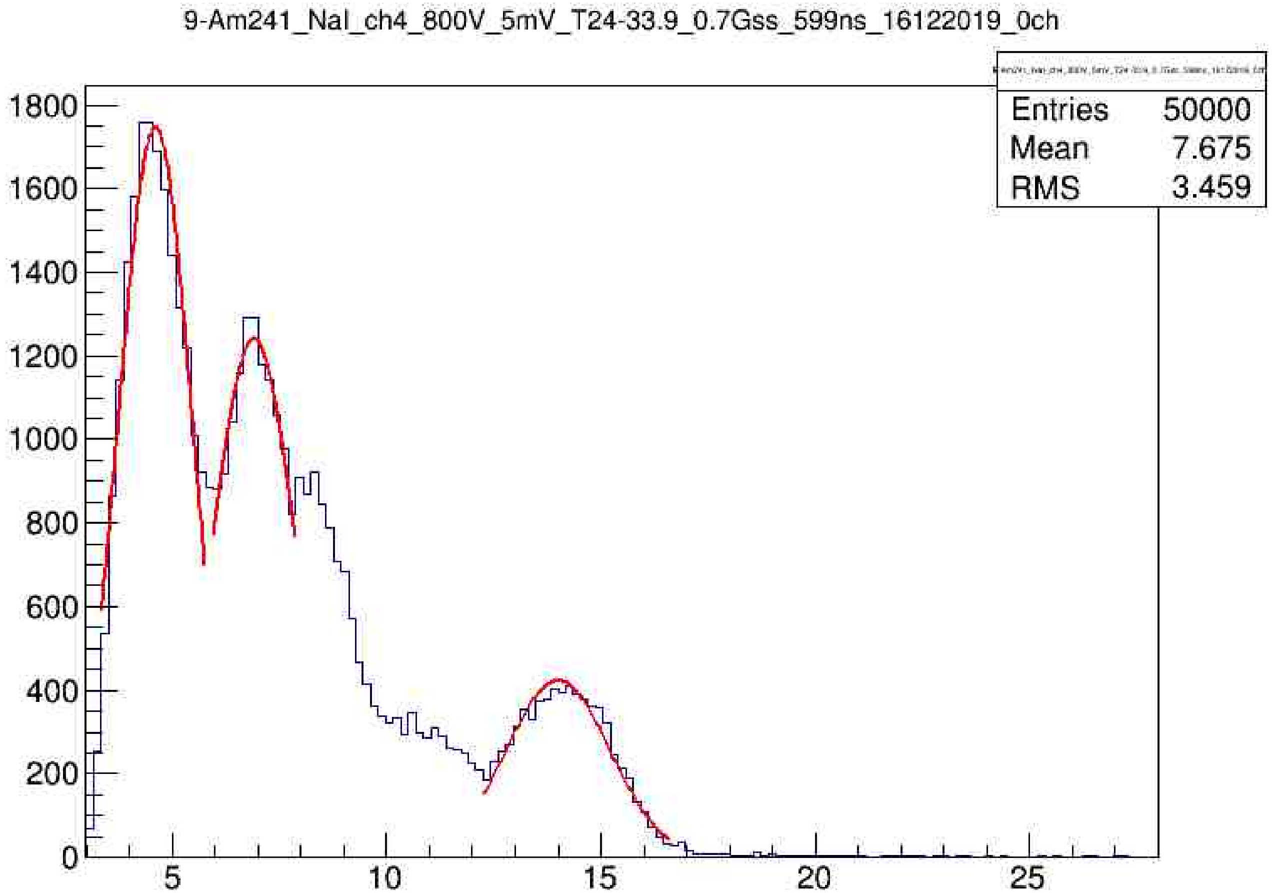



*Figure 15: The energy spectrum of Unknown source for NaI detector measured at 800V*

## Results:

**Using the relation between the channel number and energy from calibration curve y = 112.3x - 228.84 where y is the energy in Kev and x is the channel number.**

| Channel number | Energy in Kev |
|---|---|
| **4.60866** | **288.7125** |
| **6.91166** | **547.3394** |
| **13.9953** | **1342.8321** |

## Task four (Alpha range in air)

Alpha particles are a form of ionizing radiation and can cause considerable damage to living tissue. However, alpha particles produced by radioactive decay have a lower penetration depth than, for example, beta or gamma radiation. Usually, all it takes is a few centimeters of air, a sheet of paper, or a few layers of skin to stop an alpha particle.

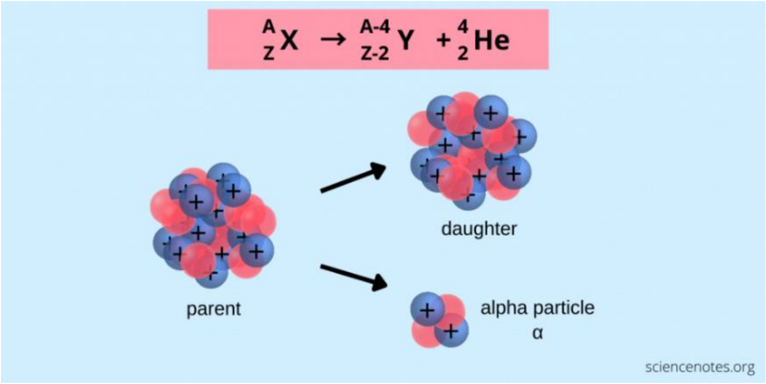



*Figure 8: Alpha particle*

### Experimental work:

Using a plutonium source Pu239 with Energy 5.5 MeV and plastic detector With Applied volt 2000V

| distance | Counts/sec |
|---|---|
| 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 |

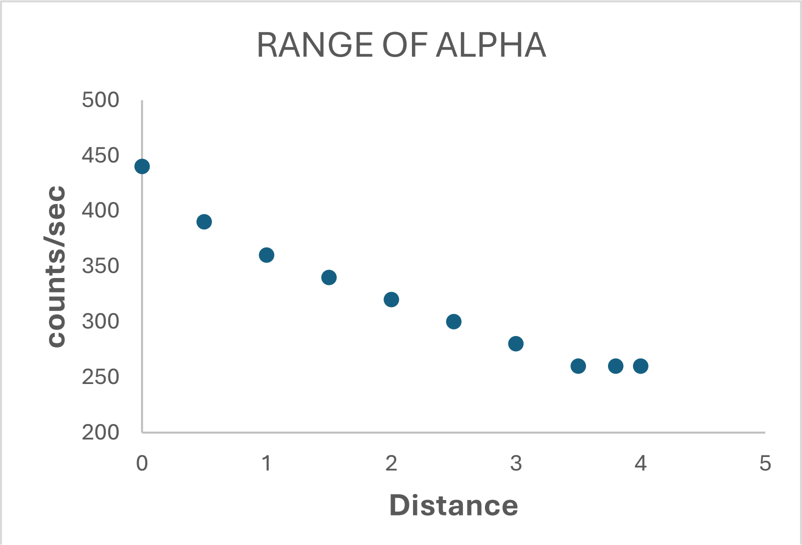



*Figure 16: Alpha radiation counts using a plastic detector.*

## Range of alpha in air using SRIM (Monte Carlo simulation)

SRIM is a software that enables users to simulate and analyze various phenomena such as ion penetration, energy deposition, and particle range within solid materials.

### Input data to SRIM:

**Target:**

Air with Thickness 5cm

**Ion:**

Helium with energy 5500Kev

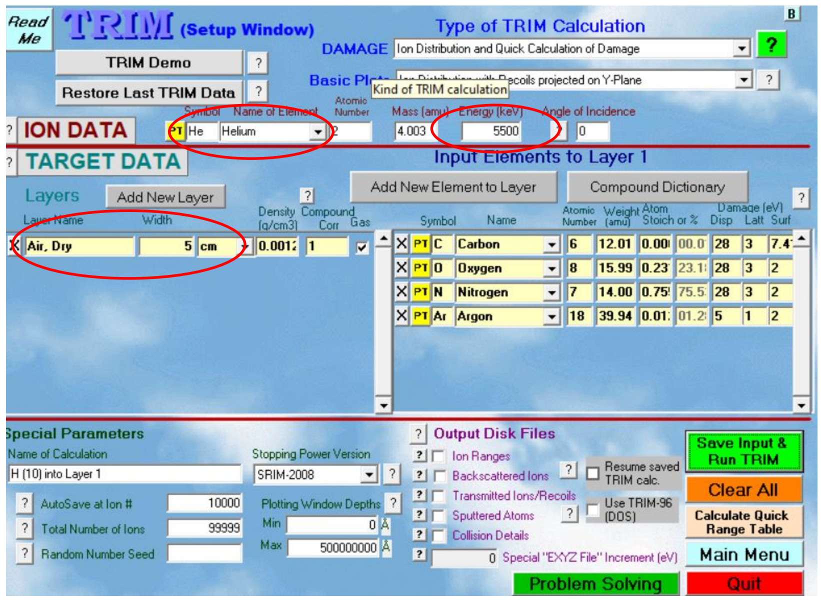
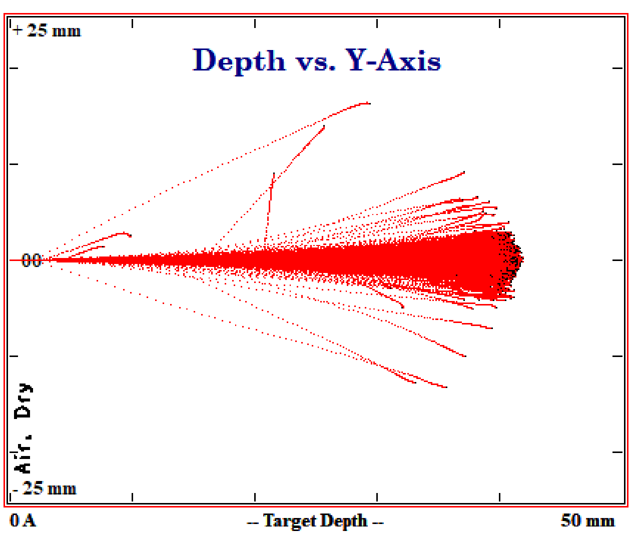



*Figure 17: SRIM Interface*

### Two plots were obtained:



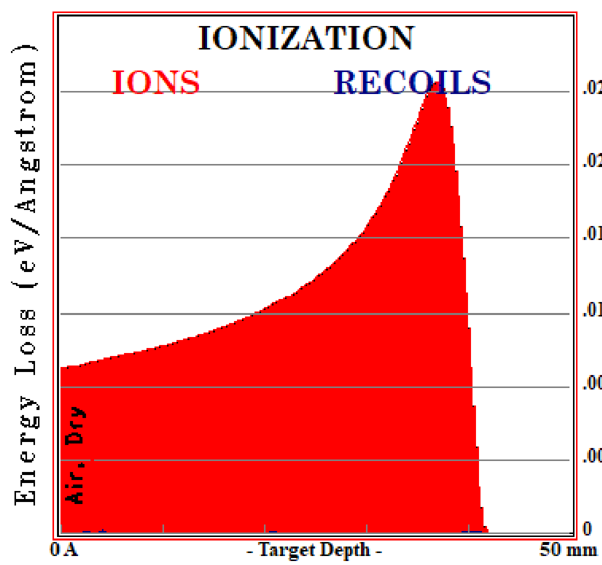




*Figure 18: Depth and Bragg curves of alpha particles in 5 cm air*

## Task five (determination of attenuation coefficient for Al and Cu)

Attenuation coefficient represents the fraction of incident gamma photons that are absorbed or scattered per unit thickness of the material they traverse. This coefficient is influenced by several factors, including the energy of the gamma radiation, the atomic number and density of the material, and the thickness of the material itself.

Materials with higher atomic numbers and densities tend to have higher linear attenuation coefficients, as they are more effective at absorbing and scattering gamma radiation.

The following equation can then describe the attenuation of gamma radiation.

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

**Where:**

I is intensity after attenuation

$I_o$ is incident intensity

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

X is the physical thickness of the absorber (cm).

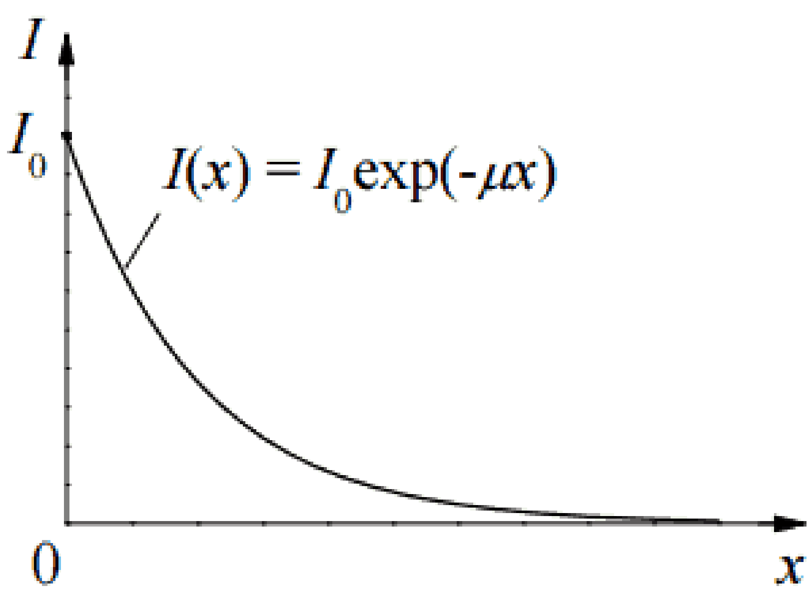



*Figure 19: Dependence of gamma radiation intensity on absorber thickness*

## Al Attenuation Coefficient

*Table 6: Experimental data of attenuation coefficient for Al using BGO detector*

| Thickness | I/Io |
|---|---|
| **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 |

μ for Aluminum = 0.238 cm2 /gm

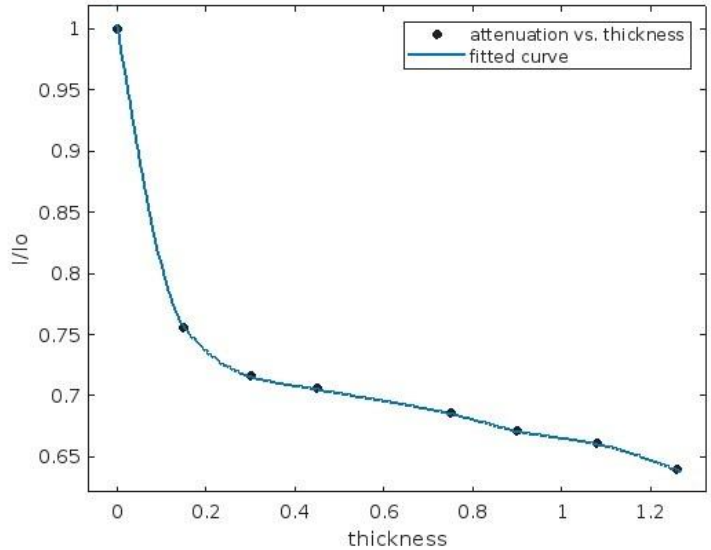



*Figure 20*

## Cu Attenuation Coefficient

*Table 7: Experimental data of attenuation coefficient for Cu using BGO detector*

| Thickness | I/Io |
|---|---|
| **0** | 1 |
| 0.1 | 0.73931 |
| 0.25 | 0.7357 |
| 0.4 | 0.68065 |
| 0.8 | 0.58611 |
| 1 | 0.53827 |
| 1.2 | 0.48042 |

μ for copper = 0.628 cm2 /gm

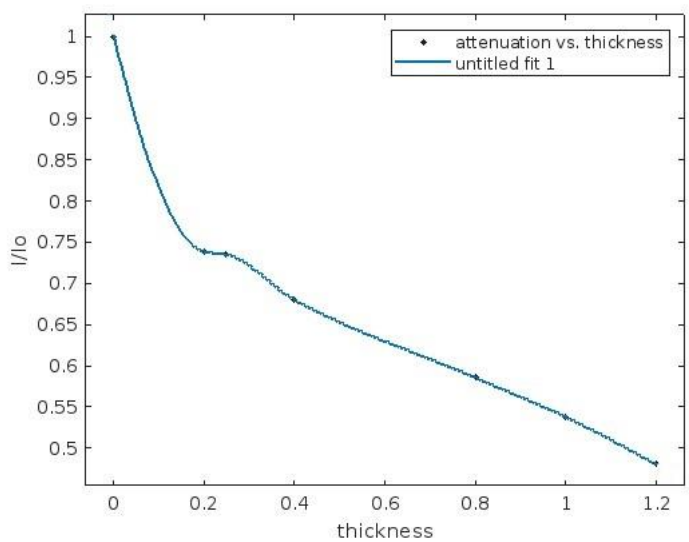



*Figure 21*

# Conclusion:

In conclusion, this report has provided a comprehensive overview of radiation protection principles and highlighted the importance of employing effective measures to mitigate the risks associated with ionizing radiation exposure. The discussion underscored how NaI detectors offer exceptional energy resolution and efficiency more than BGO detectors. Provided information about the importance of understanding the behavior of alpha particles, which have a limited range in air due to their high ionization potential. The range of alpha particles in air typically ranges from a few centimeters to a few tens of centimeters, depending on their energy. Additionally, the incorporation of advanced simulation tools such as SRIM (Stopping and Range of Ions in Matter) software significantly enhances our understanding of ionizing radiation interactions with matter.

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