JOINT INSTITUTE FOR NUCLEAR RESEARCH

FINAL REPORT ON THE INTEREST PROGRAMME

Radiation Protection and the Safety of Radiation Sources

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1. Abstract

Radiation is involved in everyday life that can have both positive and negative effects. Radiation sources can seriously endanger both human health and the environment if not properly managed. As a result, radiation safety and radiation protection have emerged as major global concerns. Radiation Protection aims to reduce the harmful effects of exposure to ionizing radiation. In this research we aimed to learn about the various types of radiation sources, and detection of radiation, the limit doses of radiation and recommended radiation protection protocols. A number of tasks has been done successfully which highlights on dealing with radiation data through identifying unknown source by using energy calibration curve, determination of Attenuation coefficient for different materials, calculation of Resolution different scintillation detectors, determination of alpha range in air using Pixel and Plastic detectors, and the assessment of the ranges and energy of alpha particles using Monte Carlo simulation SRIM software.

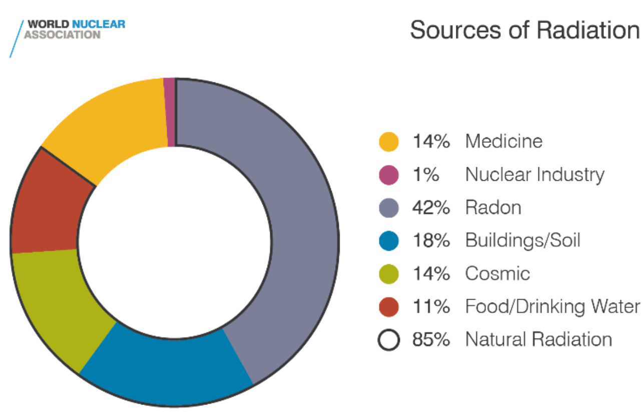
2. Introduction

Natural radiation sources are unique characteristics of the environment, and radioactivity is a phenomenon that exists in the universe. The spontaneous release of energy or particles that occurs when an unstable atom changes into a stable state is known as radioactivity. Radiation is the name given to this type of energy or particle. There are two types of radiation: ionizing and non-ionizing, depending on its ability to penetrate matter.

When ionizing radiation interacts with matter, including living things, it has the ability to separate electrons from atoms or molecules and change the atomic level. Alpha, beta, neutron, gamma, and x-ray particles are among the radiation types that can harm bodily tissues and organs, even result in death at high exposure levels. Non-ionizing radiation, on the other hand, is a type of lower energy radiation that can cause molecules to vibrate and produce heat. Microwave, UV, radio, and infrared light are examples of this type of radiation. Radioactive sources are crucial to the fields of medicine, energy production, industry, agriculture, space exploration, and law enforcement. Ionizing radiation has endless applications when used properly, at the right doses, and with all required safety measures. Radiation risks that could be present in conjunction with these applications for the general public, employees, and the environment should be evaluated and managed. Radiation protection, which attempts to minimize the negative effects of ionizing radiation and reduce needless radiation exposure, was developed in response to these worries. Creating a strong foundation for radiation sources and radiation protection is the main aim of this project. Additionally, through a series of laboratory works, provide the fundamental knowledge and abilities needed for those interested in pursuing careers in radiation protection and the responsible handling of radiation sources.

2.1. Background

2.1.1. Sources and Types of Radiation



Radiation constantly surrounds humans and is classified into two types: natural background radiation and artificial radiation. Natural background radiation comes from three sources: cosmic radiation (in space), terrestrial radiation (in nature), and internal radiation (in the body). On the contrary, artificial radiation is emitted as a result of human activities such as nuclear weapon testing, the use of radiation in medicine and consumer products, and so on.

2.1.2. Radiation Units

Energy is deposited when ionizing radiation strikes the human body or other objects. A "dose" is the amount of energy that is absorbed during exposure. The biological sensitivity of the exposed area, the type and strength of the radiation source, and exposure parameters like time, distance, and shielding can all be taken into consideration when defining the radiation dose quantities. The three most common dose measurements are the effective dose, equivalent dose, and absorbed dose.

The energy that radiation imparts in a unit mass of material, such as tissue or an organ, is referred to as the "absorbed dose." Greys (Gy) are used to express it.

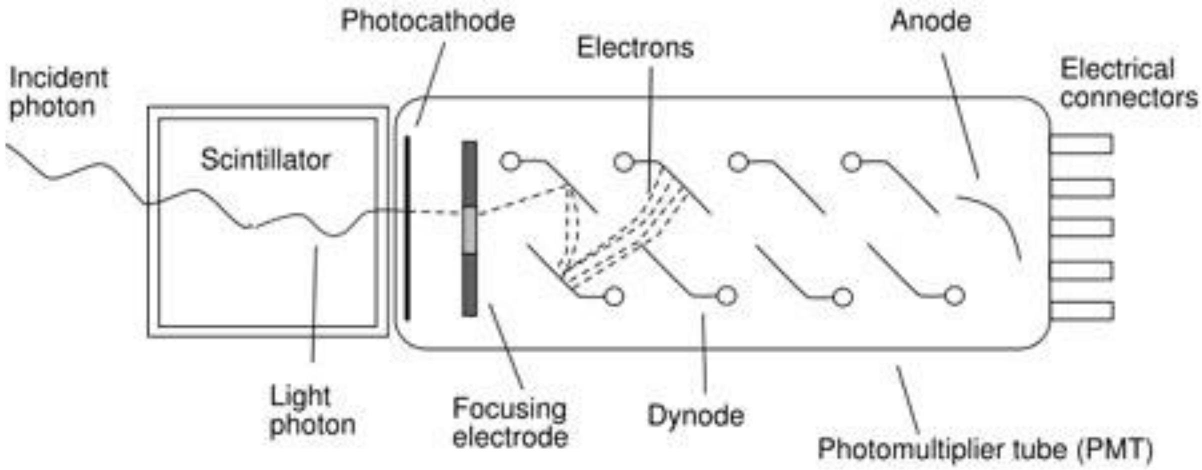
The equivalent dose is calculated by multiplying the absorbed dose by the radiation factor (WR), which takes into consideration the variations in effect caused by different radiation types. Sieverts (Sv) are used to express it.

The effective dose is the equivalent dose times the organ factors (WT), which take into consideration the organs' varying sensitivity and susceptibility to damage. The unit of measurement is also Sieverts (Sv).

2.1.3. Scintillator Detectors

A scintillation counter is a device that uses the excitation effect of incident radiation on a scintillating material to detect and measure ionizing radiation by looking for the resulting light pulses. A charge-coupled device (CCD) camera, a sensitive photodetector (often a photomultiplier tube; PMT), a scintillator that produces photons in response to incident radiation, and a photodiode that transforms light into an electrical signal make up this system.

Scintillation counters are widely used in radiation protection, assay of radioactive materials and physics research because they can be made inexpensively yet with good quantum efficiency, and can measure both the intensity and the energy of incident radiation.

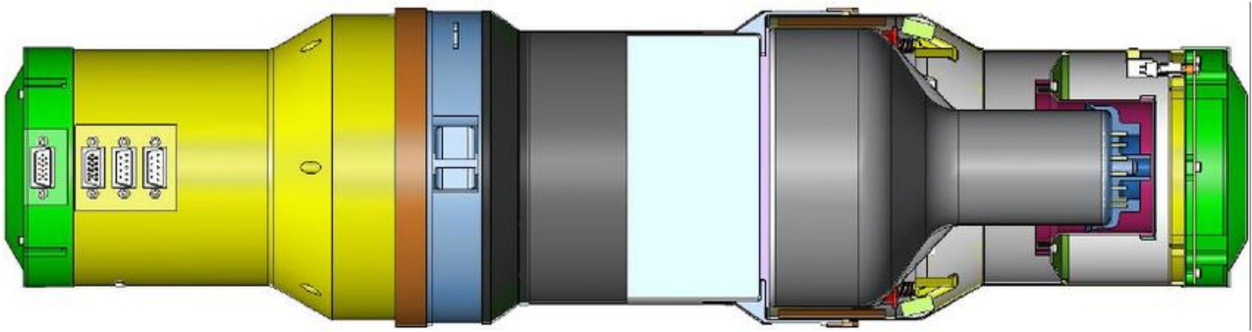


2.1.4. BGO Scintillator

Bismuth germinate, or BGO for short, is a scintillation material that is used in detectors to measure and identify high-energy X-rays and gamma rays.

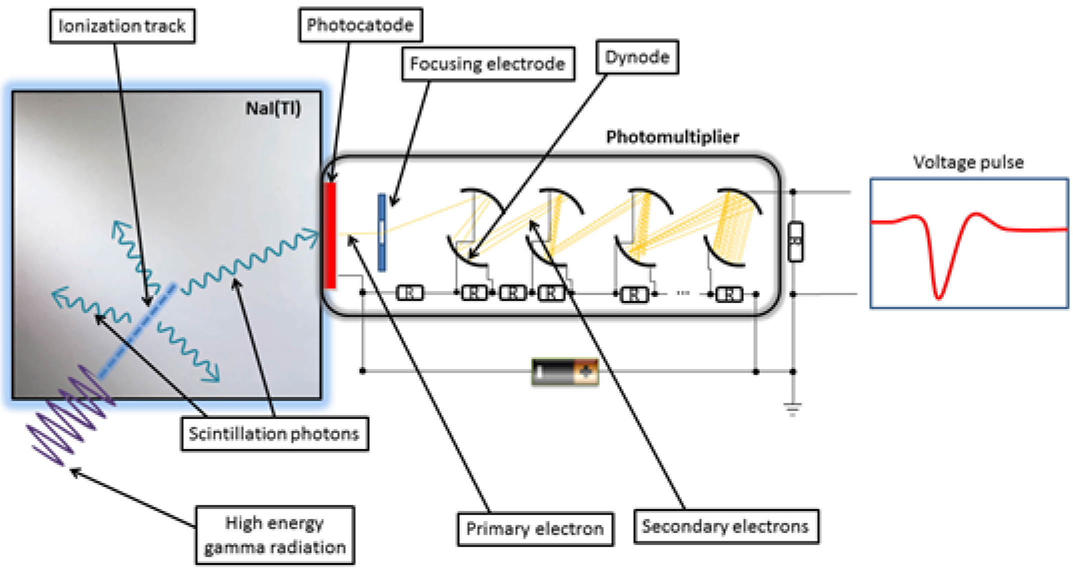
The compound with the chemical formula Bi4Ge3O12 (BGO), which has the cubic evlitine crystal structure and is used as a scintillator, is most frequently referred to by this term.

Bismuth germinate, a dense material with a high atomic number that can both emit and absorb scintillation light in response to high-energy photons, is the component used in BGO detectors. Their high density, high atomic number, and high light yield set them apart from other scintillation materials and make them ideal for high-energy photon detection. In addition, their good energy resolution and relatively quick response time make them valuable in a variety of fields, such as homeland security, high-energy physics, and nuclear medicine.



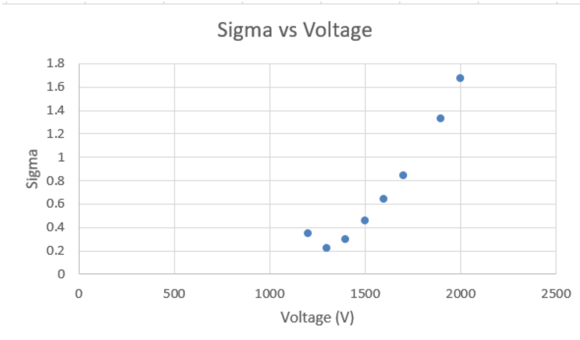
2.1.5. NaI Scintillator

NaI Scintillator is a kind of radiation detector where the scintillator material is a crystal of sodium iodide doped with thallium (NaI(Tl)). The thallium-activated sodium iodide detector, also known as the NaI(Tl) detector, produces a scintillation, which is a brief flash of light, in response to the gamma ray. When scintillator electrons return to their ground state after being excited by photon energy, scintillation happens. Gamma and X-ray detection and measurement are common uses for NAL detectors in nuclear medicine, environmental monitoring, and radiation safety applications.

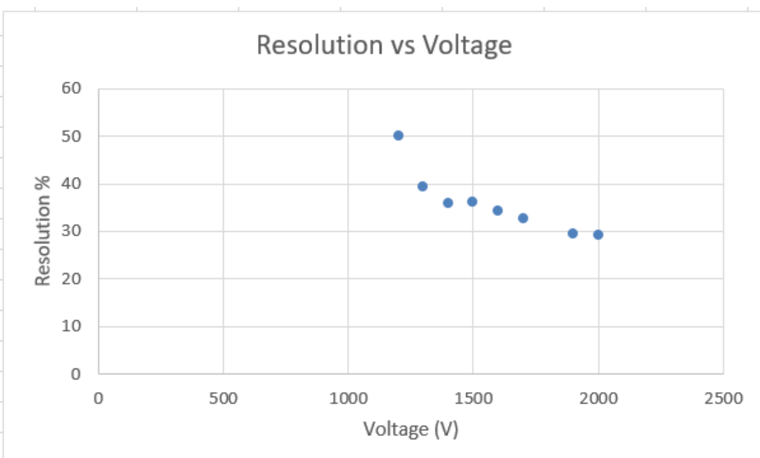


3. Tasks

3.1. Task 1 (Relation between the Resolution and Applied Voltage for BGO detectors).



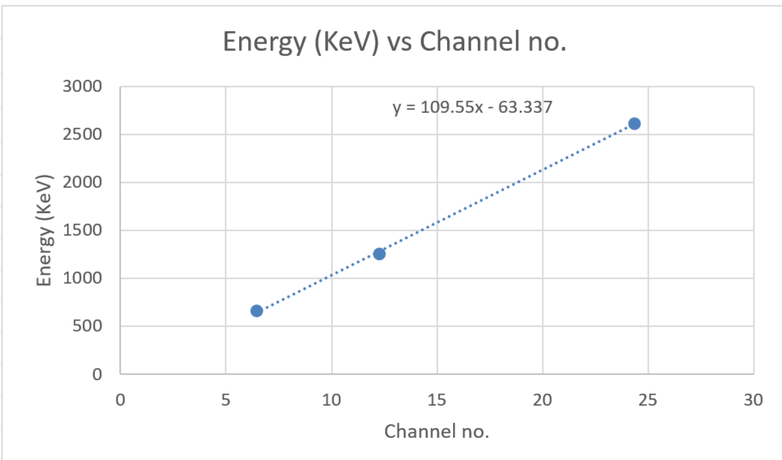
	Voltage	Mean	Sigma	Resolution
1	Voltage	Mean	Sigma	Resolution
2	1200.00	1.65	0.35	50.18
3	1300.00	1.34	0.22	39.42
4	1400.00	1.92	0.29	35.90
5	1500.00	2.99	0.46	36.24
6	1600.00	4.41	0.64	34.38
7	1700.00	6.09	0.84	32.58
8	1900.00	10.62	1.33	29.33
9	2000.00	13.55	1.68	29.07



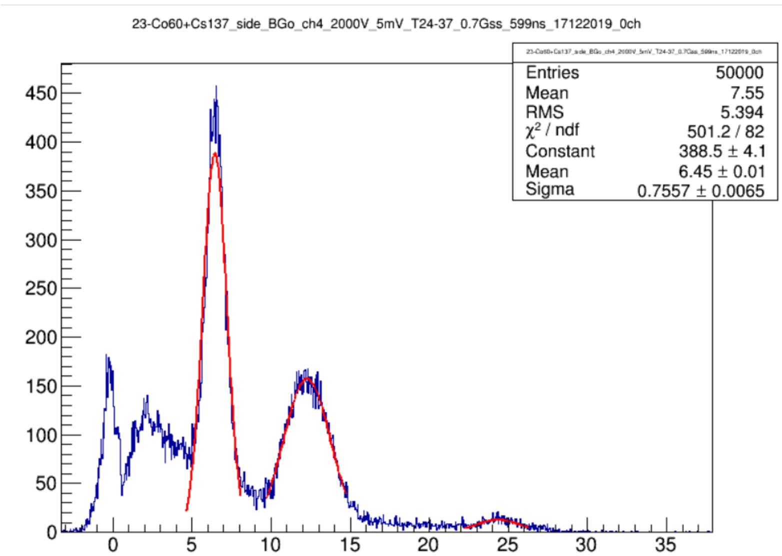
A detector's ability to distinguish between signals or peaks and precisely measure the energy of incoming radiation is referred to as its energy resolution. A higher energy resolution makes it possible to distinguish between two adjacent energy peaks with greater fineness, which in turn makes it possible to identify distinct decays or radionuclides in the spectrum. The resolution can be found by dividing the peak at full width half maximum

(FWHM) by the peak centroid's location : $Resoluion=\sigma Mean*$ 2.35

3.2. Task 2 (Energy Calibration of BGO detectors at 2000V)



	Channel no.	Energy (KeV)
1	Channel no.	Energy (KeV)
2	6.44971	662
3	12.2687	1252.85
4	24.3573	2614



The channel number (mean) is obtained by making a Gaussian fit using the ROOT software. From the plot of energy vs.

channel number (mean), a calibration curve is made, and the equation of the line is generated.

The equation of the energy calibration line for BGO detector is: $\boldsymbol{y}$**=109.55**$\boldsymbol{x}$**-63.337** Where:
x = channel number (mean), y = energy of the peaks (in keV).

3.3. Task 3

3.3.1. Identification of Unknown Source

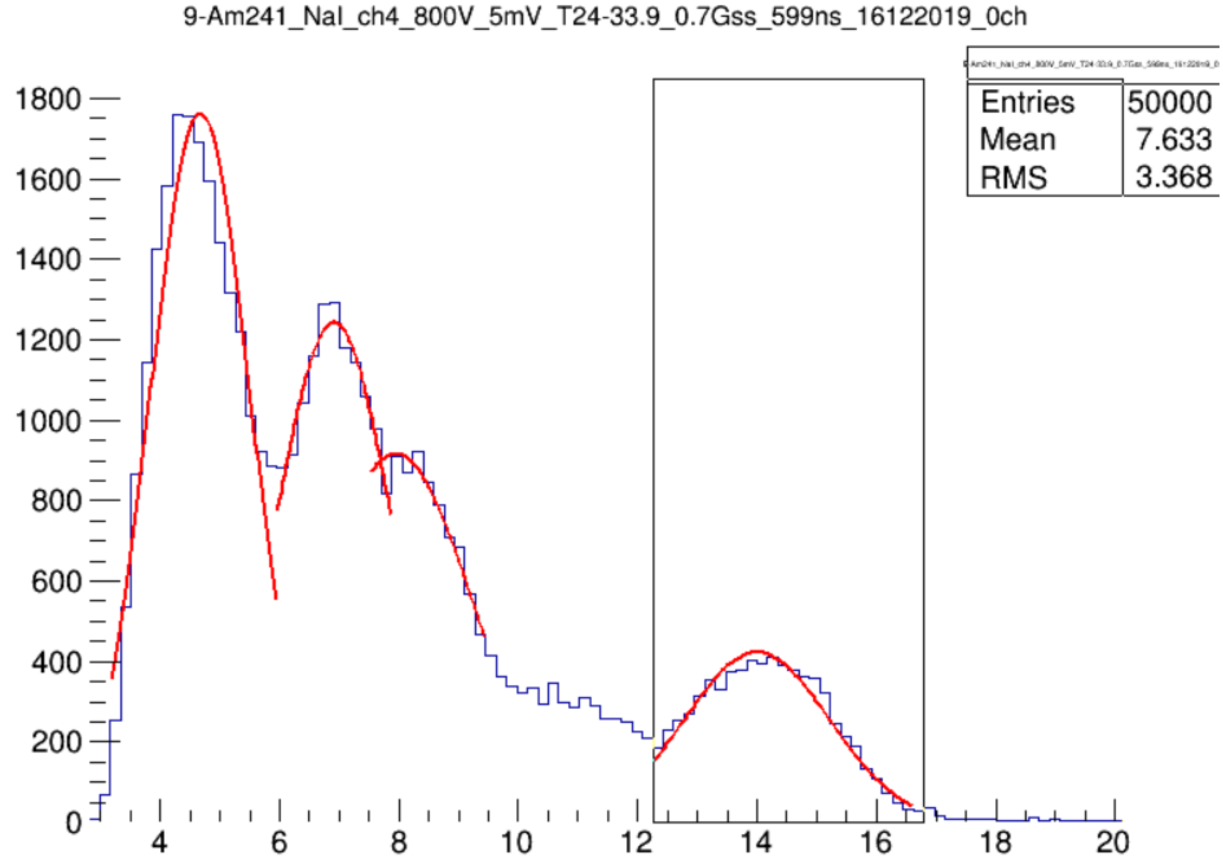
The following procedures can be used to identify the energy spectrum and its unidentified sources:

i. The channel number (mean) is obtained by fitting a Gauss function into the spectrum of the unknown energy using the ROOT software.

ii. The channel number can be translated into energy using the BGO detector's calibration line equation.

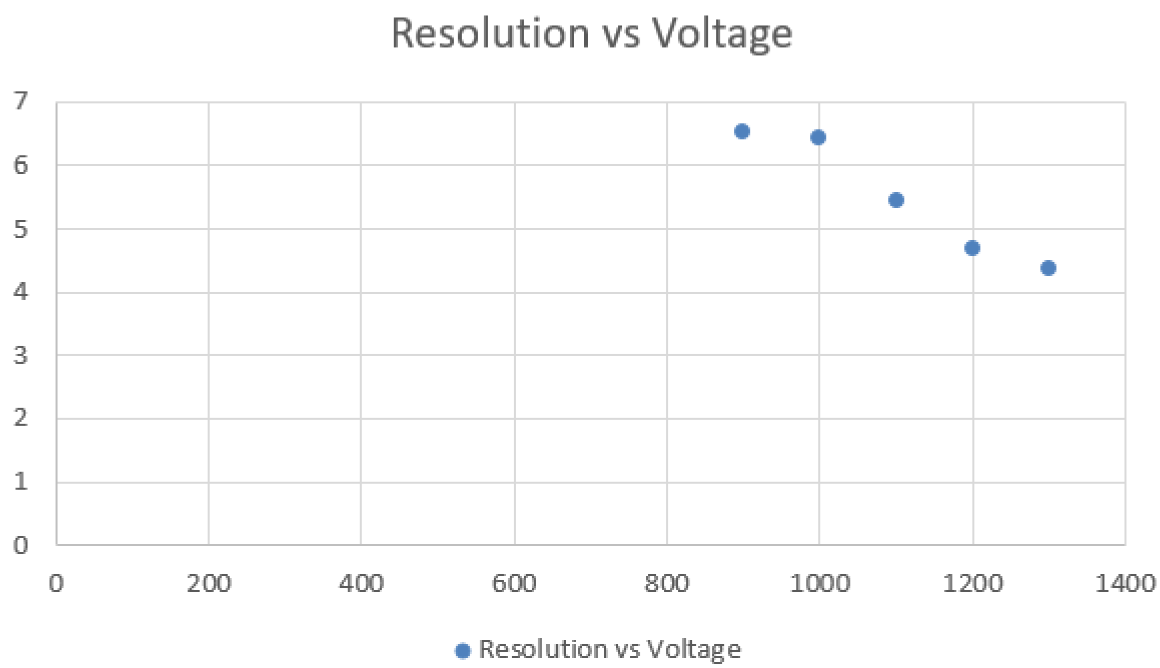
iii. The Nuclide Datasheet can be used to identify the source of the computed energy, which is unknown.

The calibration line equation is as follows: $\mathbf{y = 105.82x\text{-}159.73}$; and $\boldsymbol{x}$=$\mathbf{4.67}$.
Replace x with the following value: $\boldsymbol{y}$**=334.3 KeV.**



Peak	Channel	Energy (KeV)	Element
1	4.67	334.30	Ir-194
2	6.91	571.66	Bi-207
3	7.95	681.66	Tc-129m
4	14.00	1321.25	Ca-47

3.3.2. (Relation between the Resolution and Applied Voltage for NaI detectors)

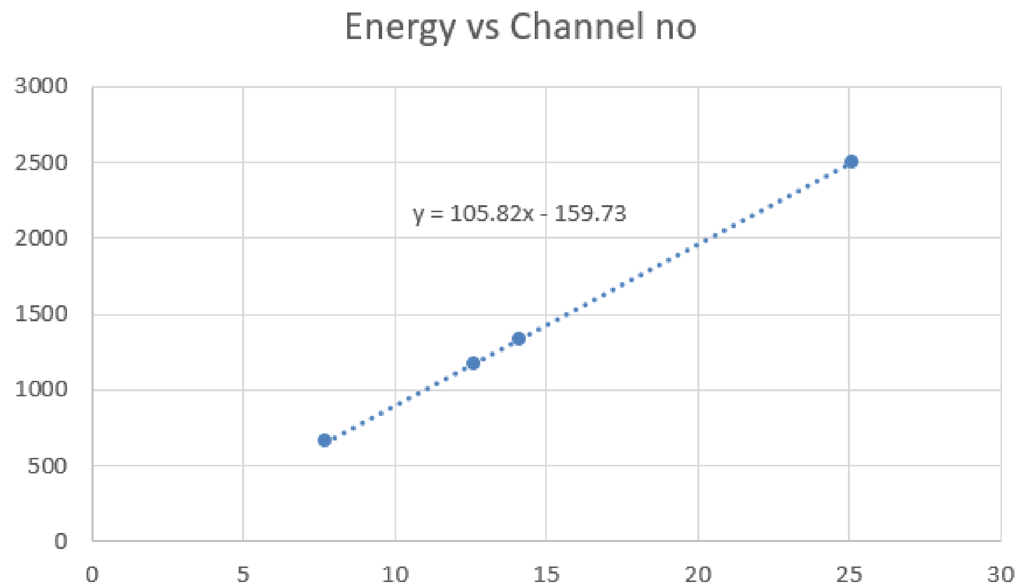


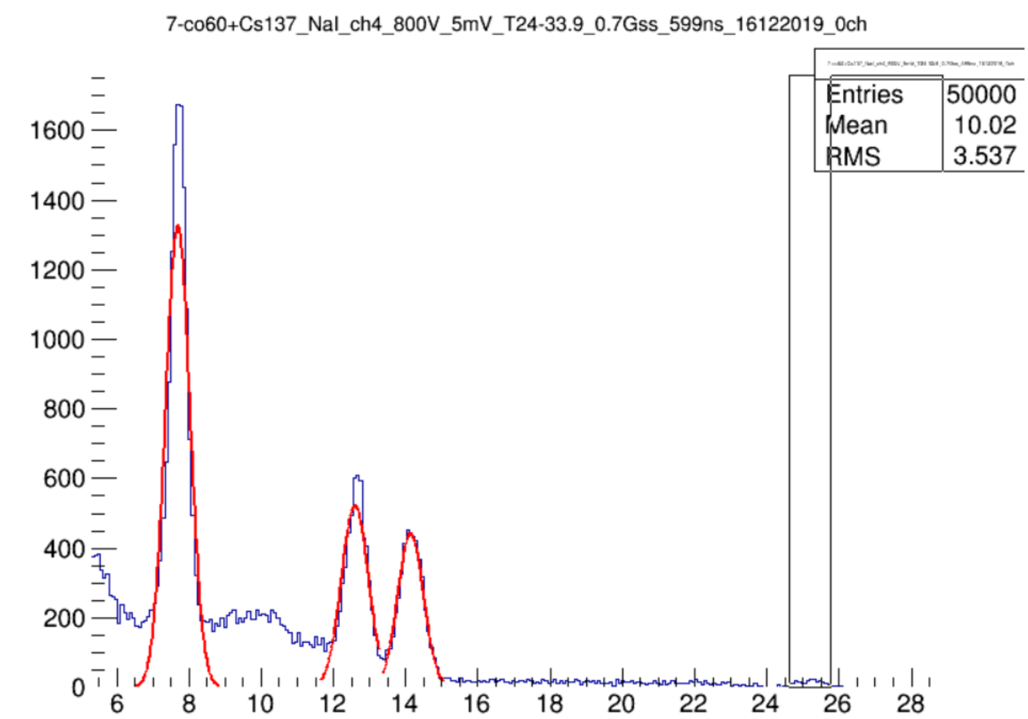
Voltage	Sigma	Mean	Resolution
900	0.655	23.6	6.522245763
1000	1.107	40.57	6.412250431
1100	1.52806	65.7827	5.458792357
1200	1.96799	98.7501	4.683313232
1300	2.56228	137.363	4.383537051

3.3.3. Energy Calibration of NaI detectors at 800V.

A NaI detector's resolution is twice that of a BGO detector because of its higher light output. The two peaks of Co-60 with energies of 1170 keV and 1330 keV, respectively, can be separated by it. For this reason, the energy spectrum below shows four peaks rather than three.

Isotope	Channel	Energy
Cs-137	7.6959	662
Co-60	12.6058	1170
	14.1445	1330
	25.1	2500





Similarly, using the ROOT software to create a Gaussian fit yields the channel number, or mean. The table above provides the channel and energy of each peak. An energy plotted against the channel number is fitted with a calibration curve. This leads to the following equation for the calibration line that the NaI detector generates: **y = 105.82x-159.73.**

3.4. Task 4 (Determination of the attenuation coefficient)

Every material has a different attenuation coefficient. The fraction of attenuated (absorbed or scattered) incident photons in a beam per unit thickness of a material is expressed by the linear attenuation coefficient (μ), a constant. This includes all potential interactions, including the photoelectric effect, coherent scattering, and Compton scattering. The formula for calculating the linear attenuation coefficient is $I = I0e{-}\mu x$.

Where μ is the linear attenuation coefficient, x is the absorber thickness, I is the intensity transmitted through an absorber of thickness x, and I0 is the intensity at zero absorber thickness.

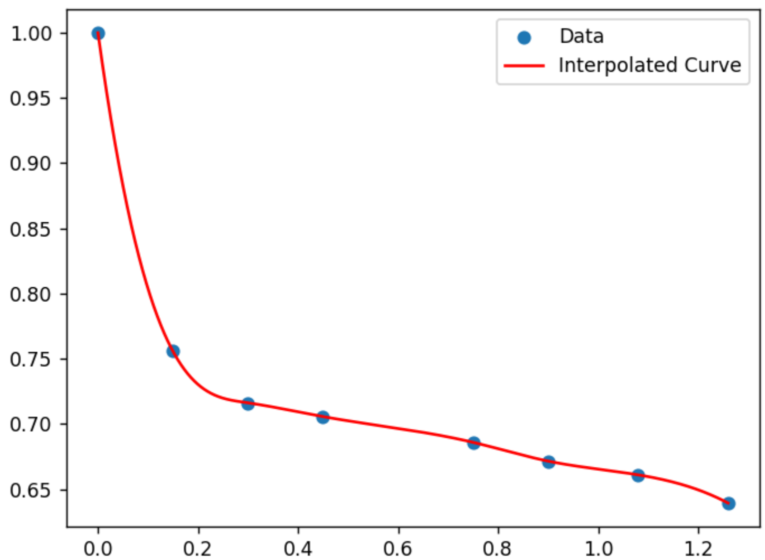
Two main characteristics of the linear attenuation coefficient are as follows: it decreases with increasing photon energy (except at K-edges) and increases with the atomic number and physical density of the absorbing material.

The mass attenuation coefficient is a variant of this that is defined as the linear attenuation coefficient per unit density of a material normalized to produce a constant value for a given element or compound.

Experimental Equipment:

- • Detector: BGO detector
- • Voltage: 2000V
- • Radioactive source: Cs-137, ECs=662 keV
- • Attenuation material: Aluminum and Copper

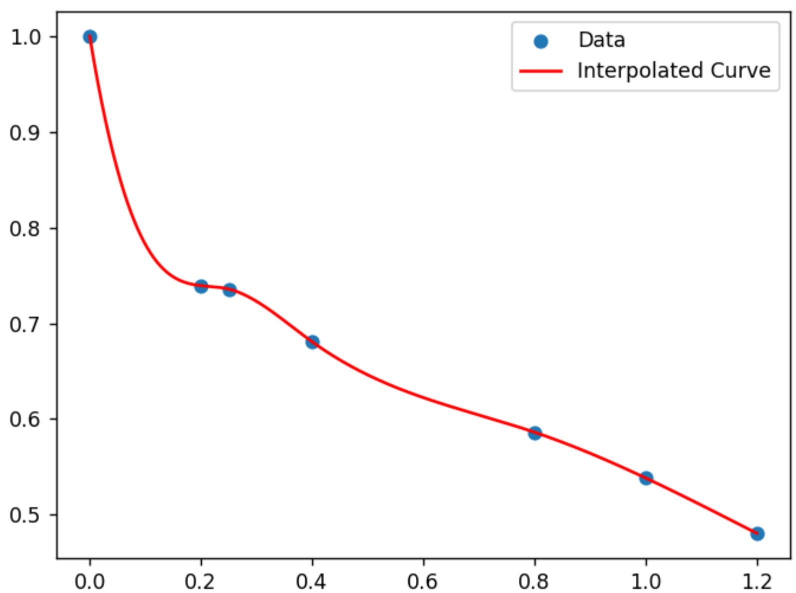
3.4.1. Al Attenuation Coefficient



Thickness	I/I0
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 the non-linear fitting curve in Origin Analysis, the obtained linear attenuation coefficient of aluminum (Al) is: ***0.23828* ± *0.01725 cm-1***

3.4.2. Cu Attenuation Coefficient



Thickness	I/I0
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 the non-linear fitting curve in Origin Analysis, the obtained linear attenuation coefficient of copper (Cu) is: ***0.62838* ± *0.0471 cm-1***.

3.5. Task 5

3.5.1. Range of Alpha Particles in Air

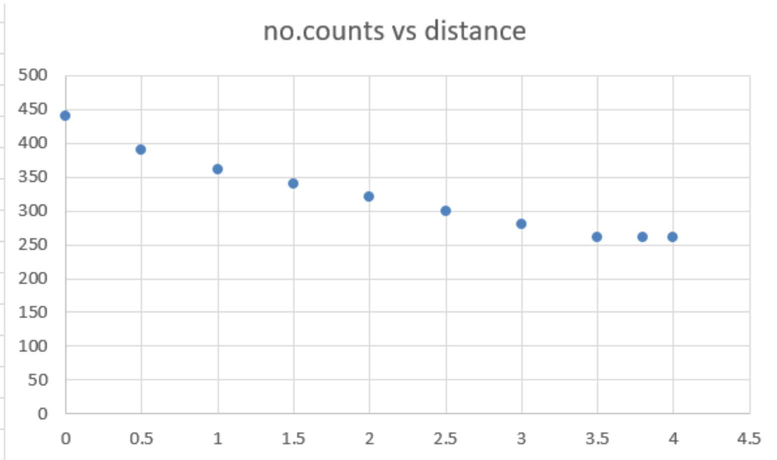
Range is defined as the distance a particle travels through matter from its source before coming to an end. The kind of particle, its initial kinetic energy, and the medium it travels through all have an impact. For charged particles like electrons and alpha particles, range is particularly crucial.
Because alpha particles are 23–23 thousand times heavier than atomic electrons, which lose energy slowly, they in particular move in nearly straight lines. Typically, their range is expressed as a straight line that extends from the source to the ionisation threshold.

In this experiment, plastic detector is used instead of a BGO detector. This is because BGO detector has a thin aluminum foil layer and shielding can occur, leading to energy loss and inaccurate measurements.

Experimental Equipment:

- • Radioactive Source: Pu-239
- • Energy of He: 5.5 MeV
- • Detector: Plastic Detector
- • Voltage: 2000V

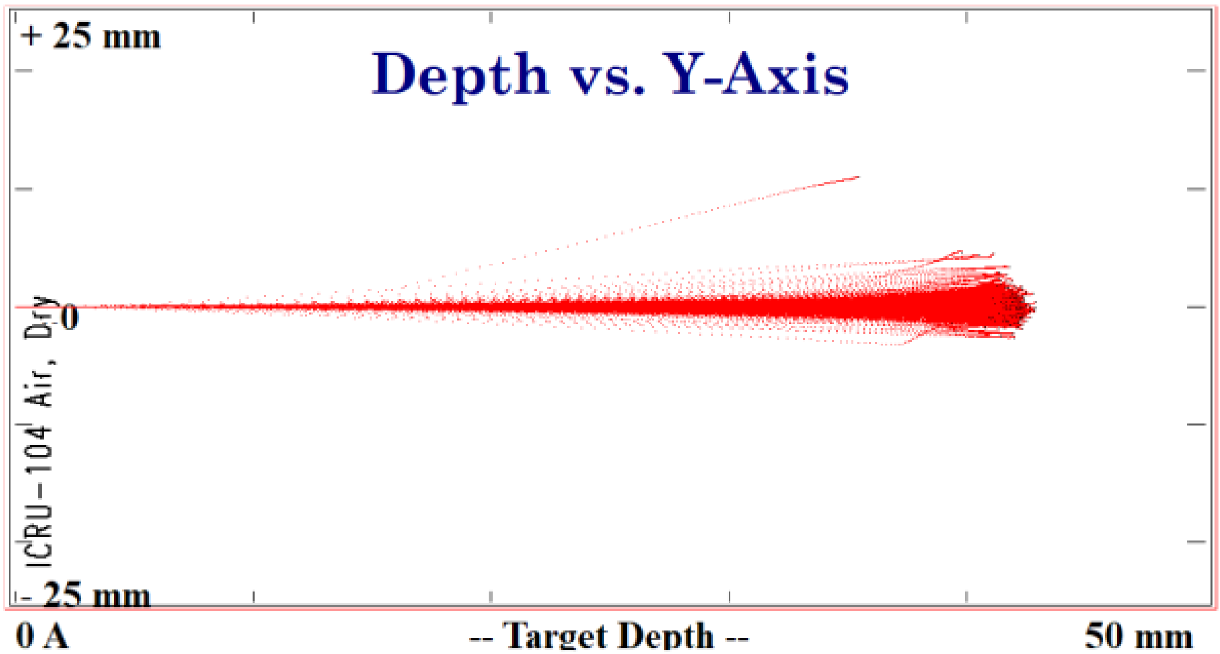
Distance (cm)	no. counts
0	440
0.5	390
1	360
1.5	340
2	320
2.5	300
3	280
3.5	260
3.8	260
4	260

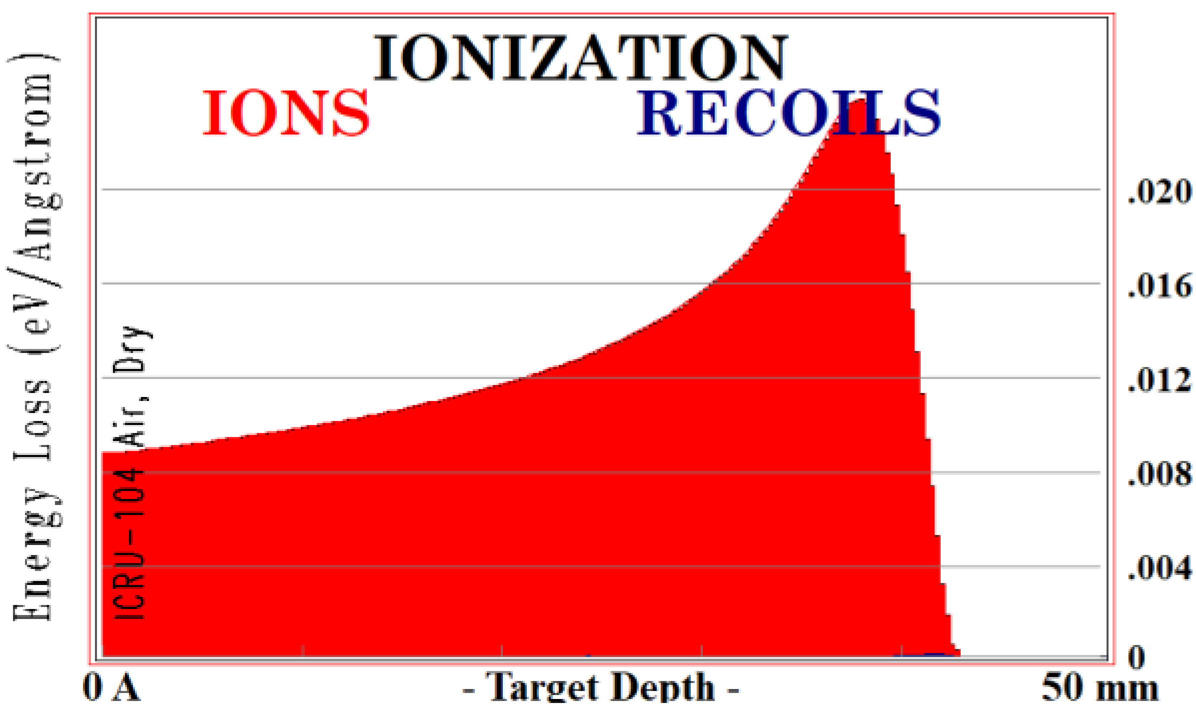


From the table and the plot, it can be observed that the counts per second decreases as the distance increases, until reaching a point where the number of counts is constant. It means that there is no more signal detected. Therefore, the range of alpha particles in air is about ***3.5 cm***

3.5.2. Range of Alpha Particles in Air by SRIM Simulation (Monte Carlo)

The simulation of the entire path length taken by alpha particles in air can be seen using the SRIM software. The depth versus y-axis and the ionization (Bragg peak/curve) of the alpha particles are plotted. The energy loss rate as a function of distance through a stopping medium is represented by the Bragg curve. The maximum is the Bragg peak, after which the energy deposition rapidly decreases.





It is clear from the two plots that as distance increases, alpha particle intensity decreases. Since alpha particles interact with airborne particles, they lose energy in the process. Here, the alpha particle range in the air is between 3.5 and 4 cm. After about 4.3 cm, there is a sharp drop in energy until no more signal is detected, which is the Bragg peak.

3.6. Task 6 (Determination of Alpha Range Particles in Air by Pixel Detectors)

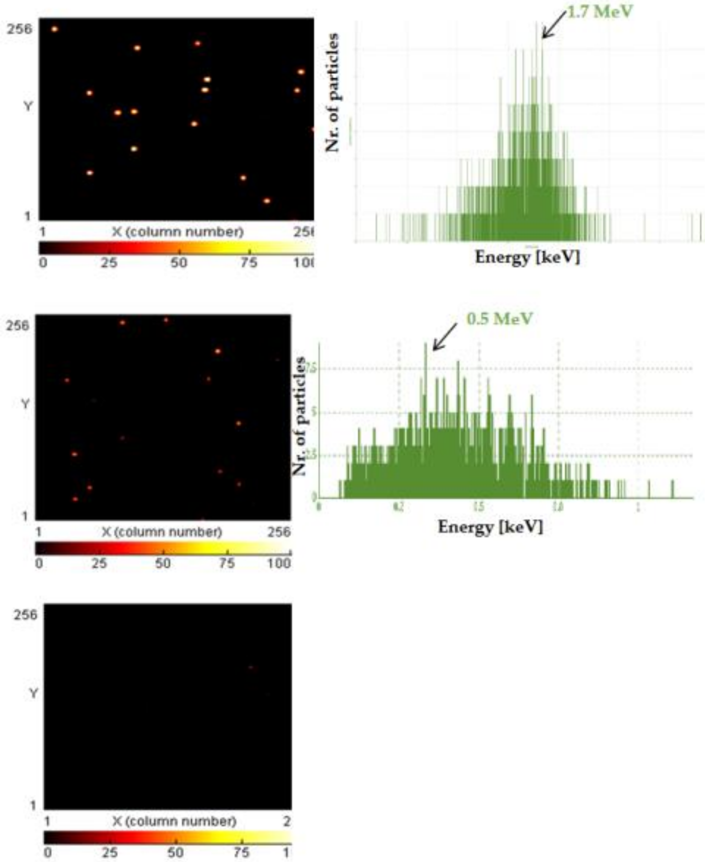
The range of alpha particles with (Am-241) energy about 4 MeV in air using pixel detector.

General dimensions of a pixel detector:

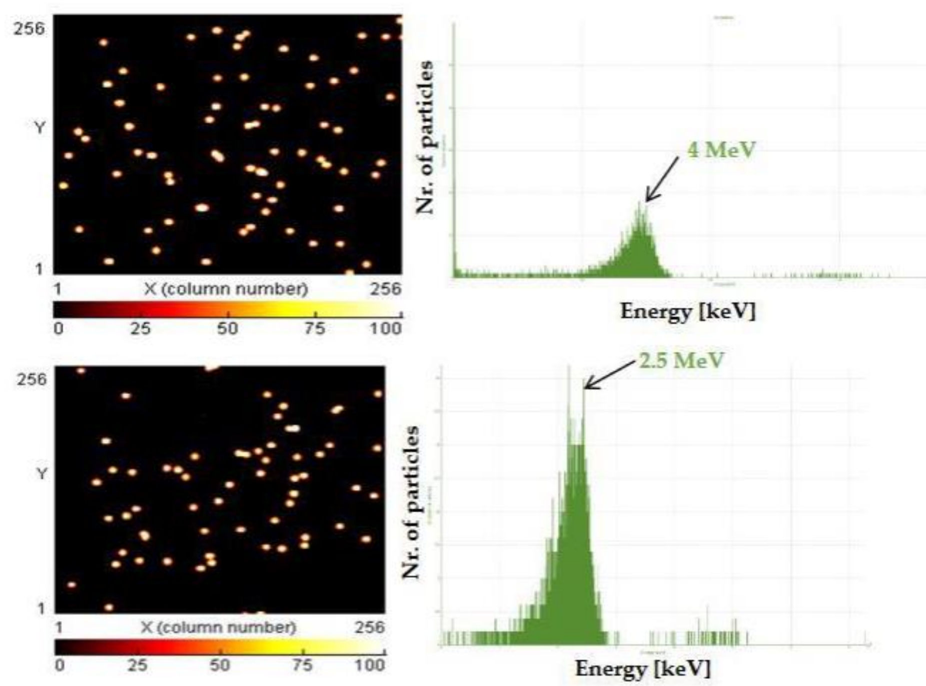
• • Sensor size: 1.5 x 1.5 cm

• • Number of pixels: 256 x 256 pixels (65,536 pixel)

• • Pixel size: 55 µm x 55 µm



256
Y
1
X (column number)
0
25
50
75
1.7 MeV
Nr. of particles
Energy [keV]
0.5 MeV
256



256
Y
1
X (column number)
256
0
25
50
75
100
Nr. of particles
4 MeV
Energy [keV]
2.5 MeV

The alpha particles are not detectable at 3 cm from the source. As a result, a pixel detector's maximum alpha particle range in air is roughly 3 cm.

4. Conclusion

The basic elements of radiation protection and radiation sources are examined in this project. The range of alpha particles in air, energy calculation and source identification, peak integration, different scintillation detectors and scintillating crystals, radiation protection principles, units and quantification of radiation, and attenuation coefficient determination are all included in this. The experimental methods and results are used to compare the technical specifications of the two scintillation detectors using software such as ROOT, Origin Analysis, Excel, and SRIM simulation. It is evident that a NaI detector offers a better and more advantageous resolution than a BGO detector. However, everyone has a distinct set of qualities and uses.

Using a known energy, the calibration line's equation is used to calculate the energy of the unknown source. The computed energy is compared with information found in the literature in order to identify the source. Note that this is only an approximate estimate, and it might not be the complete source of radiation. Values could differ because of the chance of errors during the

Gaussian fitting in ROOT.

Copper and aluminum attenuation coefficients are calculated with Cs-137 acting as the radioactive source and the BGO detector set to 2000 V. Attenuation is the term used to describe how much an x-ray beam is reduced as it travels through matter; the attenuation coefficient varies depending on the material. This is an essential component of medical imaging. Upon comparison of the two materials, copper exhibits a greater attenuation coefficient than aluminum. Copper is more effective at shielding than aluminum because it has a higher atomic number and density. SRIM simulation, the pixel detector, and the plastic detector are used to measure the range of alpha particles in air. Depending on the detector, the radioactive source, and the intensity of the applied energy, it can range from 3 to 4 cm. To put it briefly, the main objectives of the project have been fulfilled.

5. References

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