



***JOINT INSTITUTE FOR NUCLEAR RESEARCH***

***DHELEPOV LABORATORY OF NUCLEAR PROBLEMS***

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# RADIATION PROTECTION AND THE SAFETY OF RADIATION SOURCES

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# ABSTRACT

Radiation protection is defined by the International Atomic Energy Agency as "The protection of people from harmful effects of exposure to ionizing radiation, and the means for achieving this". The radiation protection was implemented due to an exponential increase in activities related to ionizing radiation. Radiation protection is to prevent the occurrence of harmful deterministic effects and to reduce the probability of occurrence of stochastic effects (e.g. cancer and hereditary effects). Radiation protection reduces radiation doses, minimizes the negative effects of ionizing radiation, increases awareness of radiation risks, and avoids unsafe practices. The foundation for radiation protection regulations and protocols has been laid by this initiative.

Important parameters for radiation protection and safe handling of radioactive sources are at the heart of this project's work. The tasks assigned by the professor were successfully completed using various software including ROOT, Origin Analysis, Excel and SRIM simulation, based on test data obtained in the laboratory. The final data was used to compare the technical data of the BGO and NaI detectors. Unknown sources are identified using the equation of the calibration line with known energy. The attenuation coefficients of aluminium and copper, and the range of alpha particles in air are determined. The theoretical part dealt with the different types of radiation sources, and detection of radiation, the limit dose and recommended radiation protection protocol from UNSCEAR, ICRP, IAEA, NEA-OECD, etc., the radioactivity and naturally occurring radioactive materials NORM.

A hands-on experience in dealing with radiation data through identification of unknown source by using energy calibration curve, calculation of Resolution different scintillation detectors, determination of alpha range in air using Pixel and Plastic detectors, determination of Attenuation coefficient for different materials, and the assessment of the ranges and energy of alpha particles using Monto Carlo simulation SIRM software were also undertaken.

# Contents

# 1. Introduction

Radioactivity, property exhibited by certain types of matter of emitting energy and subatomic particles spontaneously. It is, in essence, an attribute of individual atomic nuclei. An unstable nucleus will decompose spontaneously, or decay, into a more stable configuration but will do so only in a few specific ways by emitting certain particles or certain forms of electromagnetic energy. Radioactive decay is a property of several naturally occurring elements as well as of artificially produced isotopes of the elements. The rate at which a radioactive element decays is expressed in terms of its half-life; i.e., the time required for one-half of any given quantity of the isotope to decay. Half-lives range from more than 1024 years for some nuclei to less than 10−23 second (see below Rates of radioactive transitions). The product of a radioactive decay process—called the daughter of the parent isotope—may itself be unstable, in which case it, too, will decay. The process continues until a stable nuclide has been formed. Radioactivity is a phenomenon existing in the universe.

Ionizing radiation can detach electrons from atoms or molecules and alters the atomic level when interacting with matter, including living things. This type of radiation includes alpha particles, beta particles, neutrons, gamma rays, and x-rays, which can damage body cells, organs, and even cause death in high doses. Whereas, non-ionizing radiation is a lower energy radiation, that can make the molecules vibrate resulting to production of heat. This type of radiation includes microwave, UV light, radio waves, and infrared light.

Radiation can be deadly, but it also saves lives. Radioactive sources play a major role in medicine, energy production, industry, agriculture, space exploration, and law enforcement, to name a few. In its correct uses and doses, and necessary safety precautions, ionizing radiation can be utilized beyond measure. Parallel to these applications, the workers, the public, and the environment may be exposed to radiation risks, which should be assessed and controlled, if needed. Therefore, activities that involve the use of ionizing radiation in medicine, the operation of nuclear installations, the production and transport of radioactive material, and the management of radioactive wastes must be subject to safety standards. These concerns prompted the development of radiation protection, which aims to reduce unnecessary radiation exposure and minimize the harmful effects of ionizing radiation.

The main objective of this project is to establish a solid foundation for radiation protection and radiation sources. Additionally, provide the necessary practical skills and basic tools for those interested in working in the field of radiation protection and the safe use of radiation sources through a series of laboratory works.

## 1.1 Joint Institute for Nuclear Research - JINR

The Joint Institute for Nuclear Research (JINR), in Dubna, Moscow Oblast (110 km north of Moscow), Russia, is an international research center for nuclear sciences, with 1200 researchers including 1000 Ph.Ds from eighteen countries, like Armenia, Azerbaijan, Belarus, Kazakhstan and Ukraine, members of the institution. The institute has seven laboratories, each with its own specialisation: theoretical physics, high energy physics (particle physics), heavy ion physics, condensed matter physics, nuclear reactions, neutron physics, and information technology. The institute has a division to study radiation and radiobiological research and other ad hoc experimental physics experiments. Principal research instruments include a nuclotron superconductive particle accelerator (particle energy: 7 GeV), three isochronic cyclotrons (120, 145, 650 MeV), a phasotron (680 MeV) and a synchrophasotron (4 GeV). The site has a neutron fast-pulse reactor (1500 MW pulse) with nineteen associated instruments receiving neutron beams.

*Figure 1 Joint Institute for Nuclear Research*

## 1.2 Radiation

In physics, radiation is the emission or transmission of energy in the form of waves or particles through space or through a material medium. This includes Electromagnetic radiation, such as radio waves, microwaves, infrared, visible

light, ultraviolet, x-rays, and gamma radiation (γ); particle radiation, such as alpha radiation (α), beta radiation (β), proton radiation and neutron radiation (particles of non-zero rest energy); acoustic radiation, such as ultrasound, sound, and seismic waves (dependent on a physical transmission medium); gravitational radiation, that takes the form of gravitational waves, or ripples in the curvature of spacetime.

Radiation is often categorized as either ionizing or non-ionizing depending on the energy of the radiated particles. Ionizing radiation carries more than 10 eV, which is enough to ionize atoms and molecules and break chemical bonds. This is an important distinction due to the large difference in harmfulness to living organisms. A common source of ionizing radiation is radioactive materials that emit α, β, or γ radiation, consisting of helium nuclei, electrons or positrons, and photons, respectively. Other sources include X-rays from medical radiography examinations and muons, mesons, positrons, neutrons and other particles that constitute the secondary cosmic rays that are produced after primary cosmic rays interact with Earth's atmosphere.

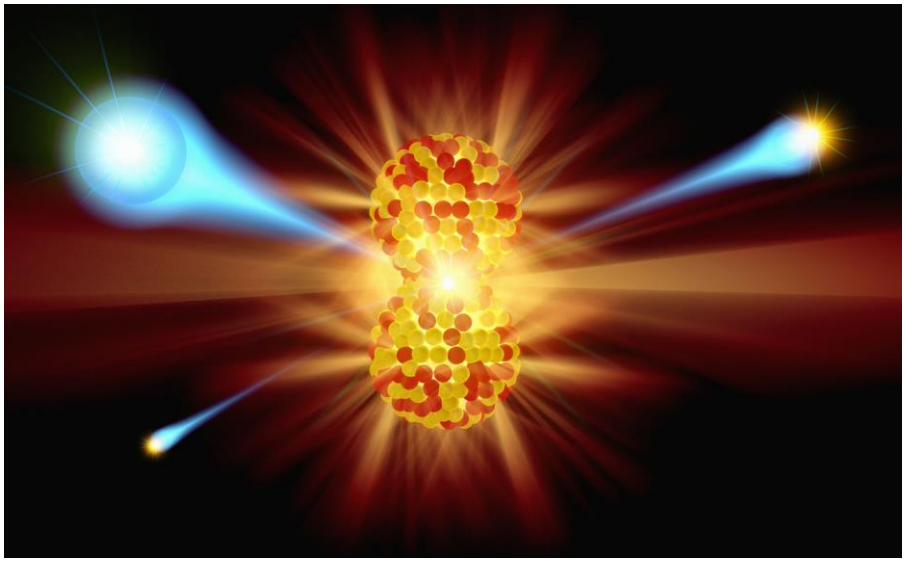
## 1.3 Nuclear Radiation

Nuclear radiation refers to the emission of particles like photons during reactions that particularly include the nucleus of an atom. Nuclear radiation is also recognised as ionising radiation. The particles emitted by nuclear reactions can remove electrons from atoms and molecules and ionise them because they are suitably energetic. The energy released in the form of electromagnetic waves or high-speed charged particles is known as nuclear radiation. Radiation can come from many sources, both manufactured and natural. All living things are continually exposed to low doses of radiation from sunlight, rocks, and cosmic rays.

Nuclear radiation consists of an electromagnetic spectrum with its energetic portion, the x-rays and the gamma rays.

There are three types of nuclear radiation:

- α-radiation
- B-radiation
- γ-radiation



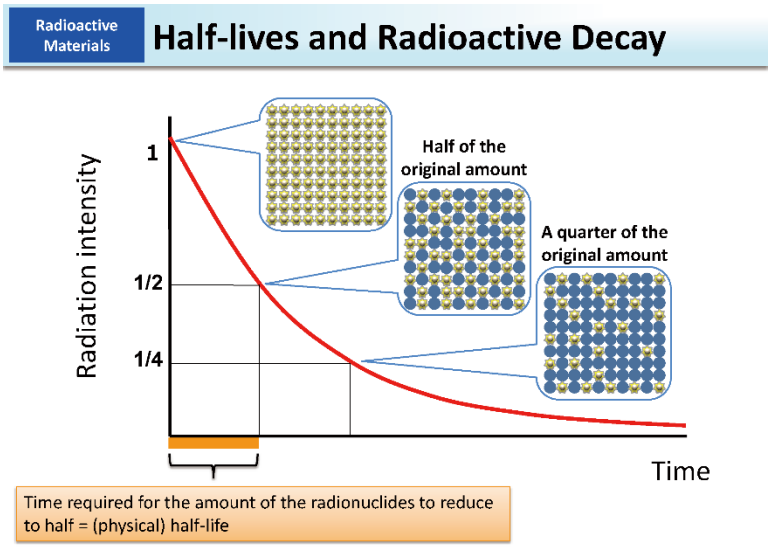
## 1.4 Radioactive Decay

Radioactive decay (also known as nuclear decay, radioactivity, radioactive disintegration, or nuclear disintegration) is the process by which an unstable atomic nucleus loses energy by radiation. A material containing unstable nuclei is considered radioactive. Three of the most common types of decay are alpha decay (α-decay), beta decay (β-decay), and gamma decay (γ-decay), all of which involve emitting one or more particles. The weak force is the mechanism that is responsible for beta decay, while the other two are governed by the electromagnetism and nuclear force. A fourth type of common decay is electron capture, in which an unstable nucleus captures an inner electron from one of the electron shells. The loss of that electron from the shell results in a cascade of electrons dropping down to that lower shell resulting in emission of discrete X-rays from the transitions. A common example is iodine-125 commonly used in medical settings.

## 1.5 Half Life

Half-life (symbol t½) is the time required for a quantity (of substance) to reduce to half of its initial value. The term is commonly used in nuclear physics to describe how quickly unstable atoms undergo radioactive decay or how long stable atoms survive. The term is also used more generally to characterize any type of exponential (or, rarely, non-exponential) decay. For example, the medical sciences refer to the biological half-life of drugs and other chemicals in

the human body. The converse of half-life (in exponential growth) is doubling time. Half-life is the length of time it takes for half of the radioactive atoms of a specific radionuclide to decay. A good rule of thumb is that, after seven half-lives, you will have less than one percent of the original amount of radiation.

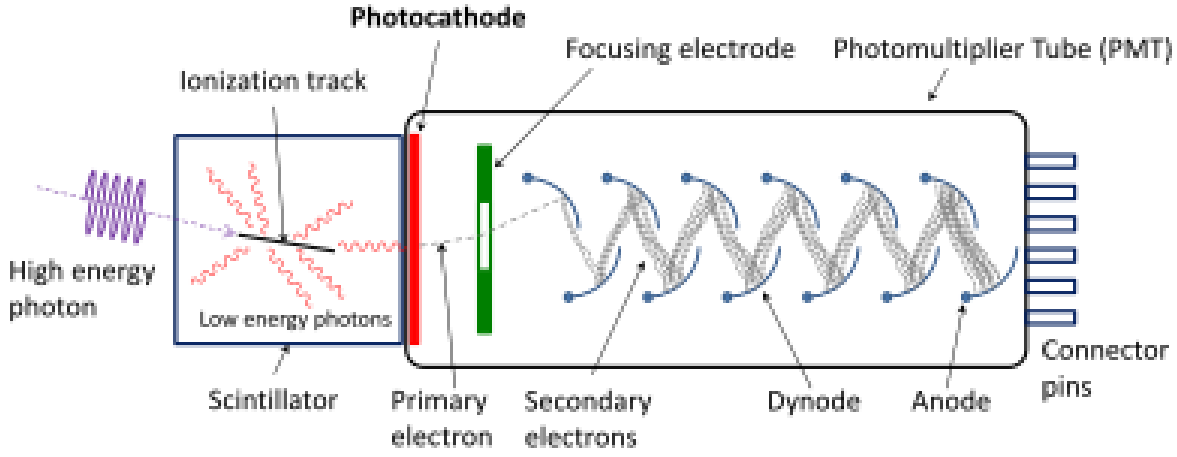



## 1.6 Scintillator Detector

A scintillation counter is an instrument for detecting and measuring ionizing radiation by using the excitation effect of incident radiation on a scintillating material, and detecting the resultant light pulses. It consists of a scintillator which generates photons in response to incident radiation, a sensitive photodetector (usually a photomultiplier tube (PMT), a charge-coupled device (CCD) camera, or a photodiode), which converts the light to an electrical signal and electronics to process this signal. 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.

A scintillation counter is used to detect gamma rays and the presence of a particle. It can also measure the radiation in the scintillating medium, the energy loss, or the energy gain. The medium can either be gaseous, liquid, or solid. The scintillator counter is generally comprised of transparent crystalline material such as glasses, liquids, or plastics. One sector of the scintillators is placed (optical contact) with the pin code.

A charged particle loses energy when passing through the scintillator thus leaving the trail of excited molecules and atoms. A rapid interatomic transfer of electronic excitation energy follows, which leads to the burst of scintillator material luminescence characteristics. The scintillation response, when a particle stops leading to the light output. The energy loss of a particle is measured when a particle passes completely through a scintillator.

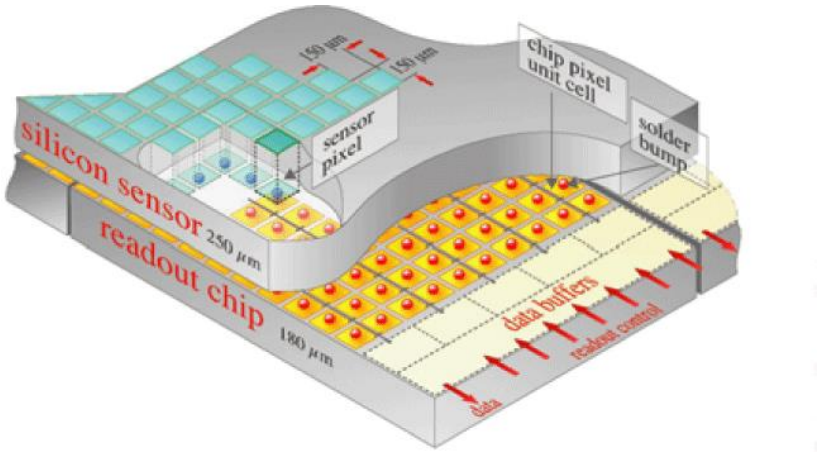



## 1.7 Pixel Detector

The pixel detector, though only about the size of a small suitcase, contains 124 million pixels, allowing it to track the paths of particles emerging from the collision with extreme accuracy. It is also the closest detector to the beam pipe, with cylindrical layers roughly at 3cm, 7cm, 11cm and 16cm and disks at either end, and so will be vital in reconstructing the tracks of very short-lived particles. Each of the four layers is composed of individual silicon modules, splitted into little silicon sensors, like tiny kitchen tiles: the pixels. Each of these silicon pixels is 100µm by 150µm, about two hairs widths. When a charged particle passes through a pixel, it gives enough energy to eject the electrons from silicon atoms. A voltage applied to the sensor allows collecting these charges as a small electric signal, which is amplified by an electronic readout chip (for a total of 16 chips per module).

Pixel detectors for precise particle tracking in high energy physics have been developed to a level of maturity during the past decade. Three of the LHC detectors will use vertex detectors close to the interaction point based on the hybrid pixel technology which can be considered the ‘state of the art‘ in this field of instrumentation. A development period of almost 10 years has resulted in pixel detector modules which can stand the extreme rate and timing requirements as well as the very harsh radiation environment at the LHC without

severe compromises in performance. From these developments a number of different applications have spun off, most notably for biomedical imaging. Beyond hybrid pixels, a number of monolithic or semi-monolithic developments, which do not require complicated hybridization but come as single sensor/IC entities, have appeared and are currently developed to reader maturity. Most advanced in terms of maturity are so called CMOS active pixels and DEPFET pixels.




## 1.8 Scintillation Crystals

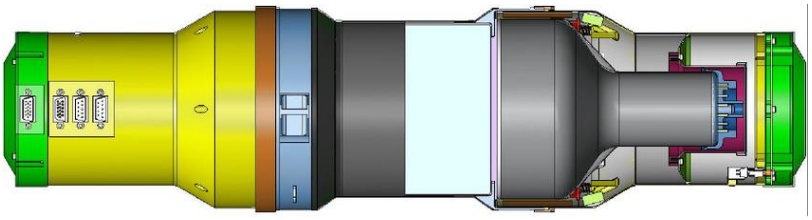
A scintillation crystal absorbs gamma photons by one or more collision processes and converts some of their energy into visible light and ultraviolet (UV) photons. This is done through a process known as scintillation. In a sense, the crystal acts as a wavelength shifter. It generates long wavelength radiation (visible and UV) from short wavelength radiation (gamma photons). Because the light output of a crystal depends on the energy of a gamma photon that interacts with it, a gamma camera can be used for energy-selective counting. The thicker the crystal, the more gamma photons it can stop (and thus detect), and the more efficient a detector based on such a crystal will be. However, there is a trade-off: the thicker the crystal, the coarser the intrinsic resolution of a detector with such a crystal is. Despite these issues, it is desirable for a scintillation crystal to have high atomic number and high density so as to increase the probability of gamma photons interacting within the crystal and to increase the production and output of detectable light photons.

| Scintillator material | Density [g/cm$^3$] | Refractive Index | Wavelength [nm] for max. emission | Decay time constant [μs] | Photons/MeV |
|---|---|---|---|---|---|
| NaI | 3.7 | 1.78 | 303 | 0.06 | $8 \cdot 10^4$ |
| NaI(Tl) | 3.7 | 1.85 | 410 | 0.25 | $4 \cdot 10^4$ |
| CsI(Tl) | 4.5 | 1.80 | 565 | 1.0 | $1.1 \cdot 10^4$ |
| $Bi_4Ge_3O_{12}$ | 7.1 | 2.15 | 480 | 0.30 | $2.8 \cdot 10^3$ |
| CsF | 4.1 | 1.48 | 390 | 0.003 | $2 \cdot 10^3$ |
| LSO | 7.4 | 1.82 | 420 | 0.04 | $1.4 \cdot 10^4$ |
| $PbWO_4$ | 8.3 | 1.82 | 420 | 0.006 | $2 \cdot 10^2$ |
| LHe | 0.1 | 1.02 | 390 | 0.01/1.6 | $2 \cdot 10^2$ |
| LAr | 1.4 | 1.29* | 150 | 0.005/0.86 | $4 \cdot 10^4$ |
| LXe | 3.1 | 1.60* | 150 | 0.003/0.02 | $4 \cdot 10^4$ |

* at 170 nm

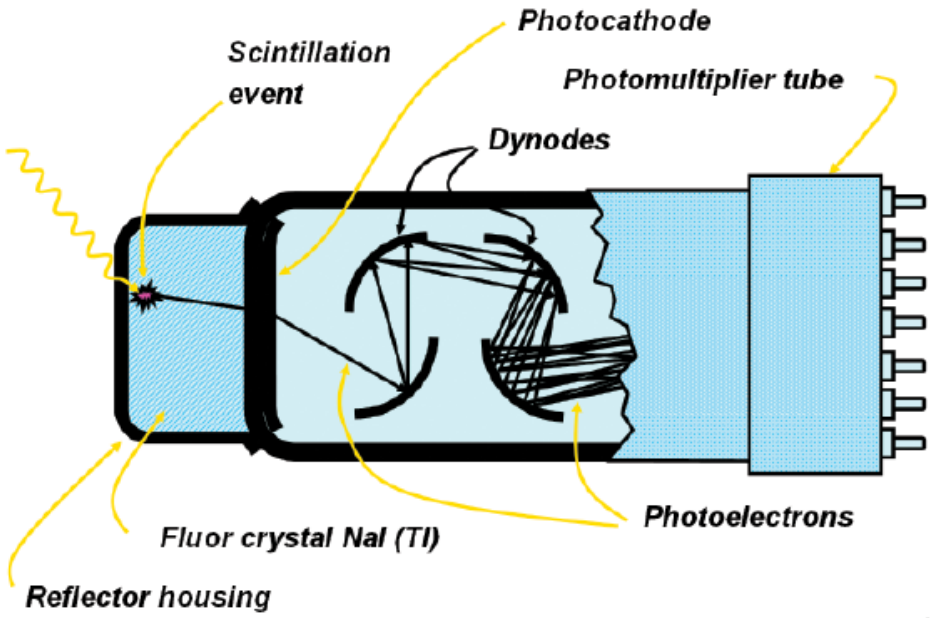
## 1.9 BGO Scintillator

Bismuth germanium oxide or bismuth germanate is an inorganic chemical compound of bismuth, germanium and oxygen. Most commonly the term refers to the compound with chemical formula Bi4Ge3O12 (BGO), with the cubic evlitine crystal structure, used as a scintillator. (The term may also refer to a different compound with formula Bi12GeO20, an electro-optical material with sillenite structure, and Bi2Ge3O9.) BGO stands for bismuth germanate, which is a scintillation material used in detectors for detecting and measuring high-energy gamma rays and X-rays. BGO detectors consist of a crystal of bismuth germanate, which is a dense and high atomic number material that is capable of absorbing high-energy photons and emitting scintillation light. They have several advantages over other scintillation materials, including high density, high atomic number, and high light yield, which makes them well-suited for detecting high-energy photons. They also have a relatively fast response time and good energy resolution, which makes them useful for a wide range of applications, including in nuclear medicine, high-energy physics, and homeland security.

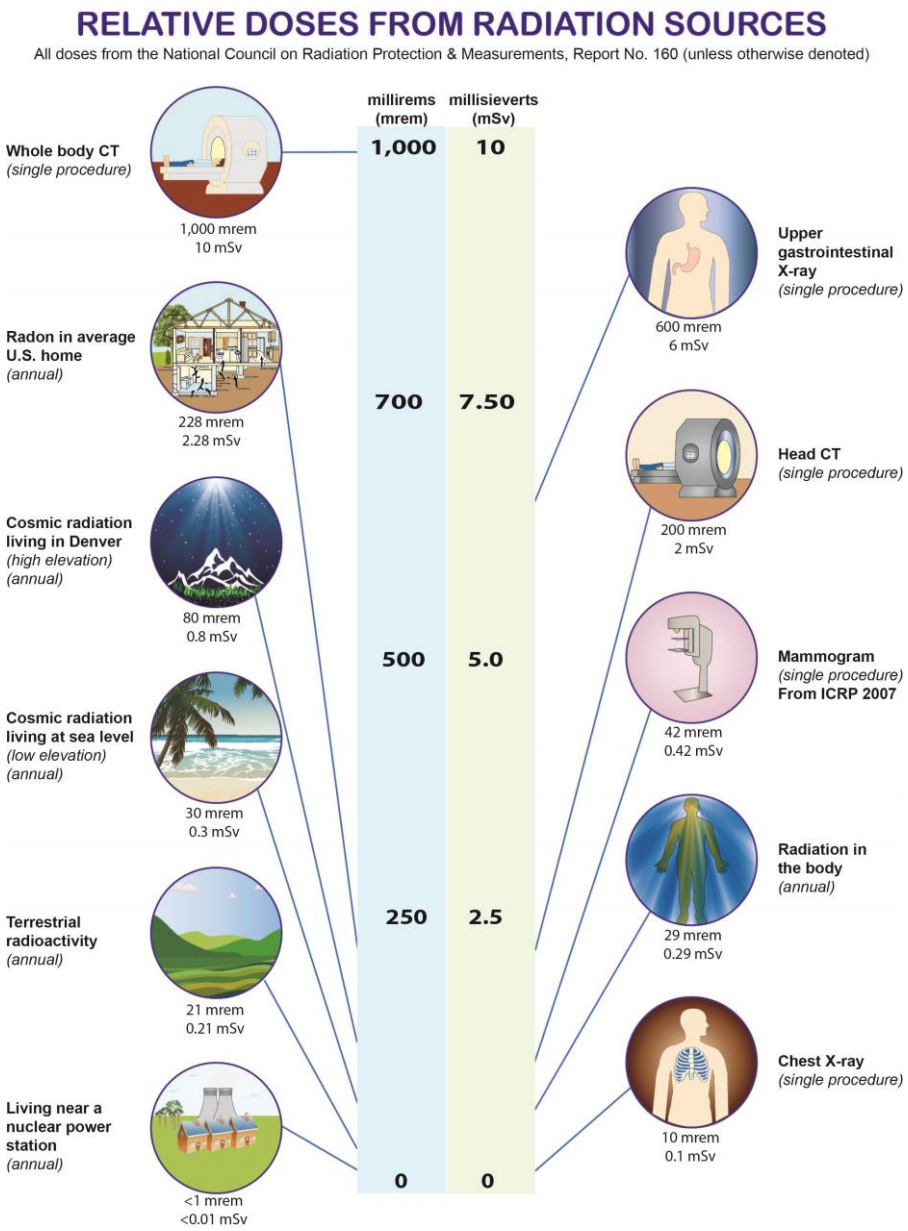


## 1.10 NaI Scintillator

NAI stands for NaI(Tl)-based scintillation detector, which is a type of radiation detector that uses a crystal of sodium iodide doped with thallium (NaI(Tl)) as the scintillator material. The thallium-activated sodium iodide detector, or NaI(Tl) detector, responds to the gamma ray by producing a small flash of light, or a scintillation. The scintillation occurs when scintillator electrons, excited by the energy of the photon, return to their ground state. NAL detectors are commonly used in nuclear medicine, environmental monitoring, and radiation safety applications for detecting and measuring gamma rays and X-rays. They have several advantages over other types of scintillation detectors, including a high light output, good energy resolution, and relatively low cost. However, NAL detectors also have some disadvantages, such as a relatively slow response time and sensitivity to temperature and humidity variations.



## 1.11 Radiation Sources and Exposure




## 1.12 Units for Measurement of Radiation

When ionizing radiation hits the human body or objects in general, energy is deposited. The absorbed energy from exposure is termed as “dose”. The dose quantities of radiation can be defined in several ways, depending on the nature and strength of the radiation source, biological sensitivity of the exposed area, and exposure parameters such as time, distance, and shielding. The most used dose measurements are absorbed dose, equivalent dose, and effective dose.

a. Absorbed dose describes the energy imparted by radiation in a unit mass of material, such as tissue or organ. It is expressed in grays (Gy).

b. Equivalent dose is the absorbed dose multiplied by the radiation factor (WR), which accounts for the differences in effect depending on the type of radiation. It is expressed in sieverts (Sv).

c. Effective dose is the equivalent dose multiplied by organ factors (WT), which accounts for the susceptibility to harm and the differences in sensitivity among organs. It is also expressed in sieverts (Sv).

# 2.0 TASKS

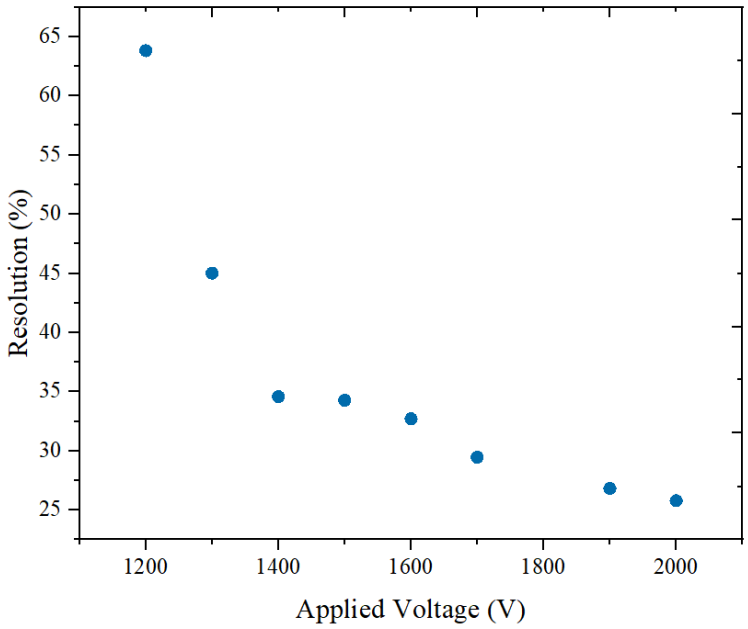
## 2.1 Task 1: Relation between the Resolution and Applied Voltage for BGO detectors

The energy resolution of a detector refers to its ability to separate signals or peaks and accurately determine the energy of the incoming radiation. The better the energy resolution, the finer it can distinguish two adjacent energy peaks, allowing the identification of different decays or radionuclides in the spectrum. The resolution is calculated from the peak at full width half maximum (FWHM) divided by the location of the peak centroid, $H0$:

$Resolution = \sigma Mean *$

2.35 (1)

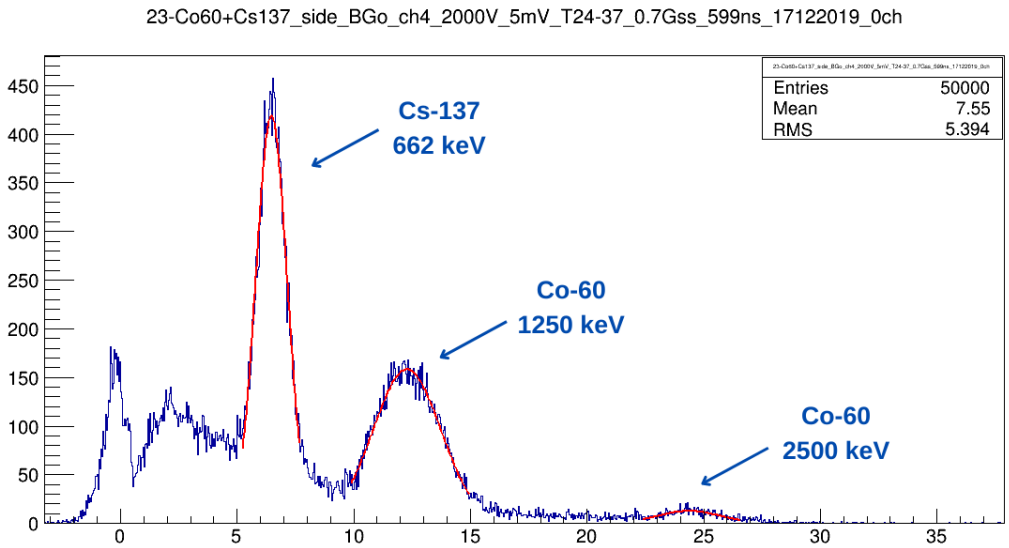
| Applied Voltage (V) | Mean | Sigma | Resolution (%) |
|---|---|---|---|
| 1200 | 1.624 | 0.441 | 63.815 |
| 1300 | 1.378 | 0.264 | 45.022 |
| 1400 | 1.923 | 0.283 | 34.584 |
| 1500 | 2.996 | 0.437 | 34.277 |
| 1600 | 4.410 | 0.614 | 32.719 |
| 1700 | 6.102 | 0.765 | 29.462 |
| 1900 | 10.669 | 1.218 | 26.828 |
| 2000 | 13.662 | 1.500 | 25.801 |



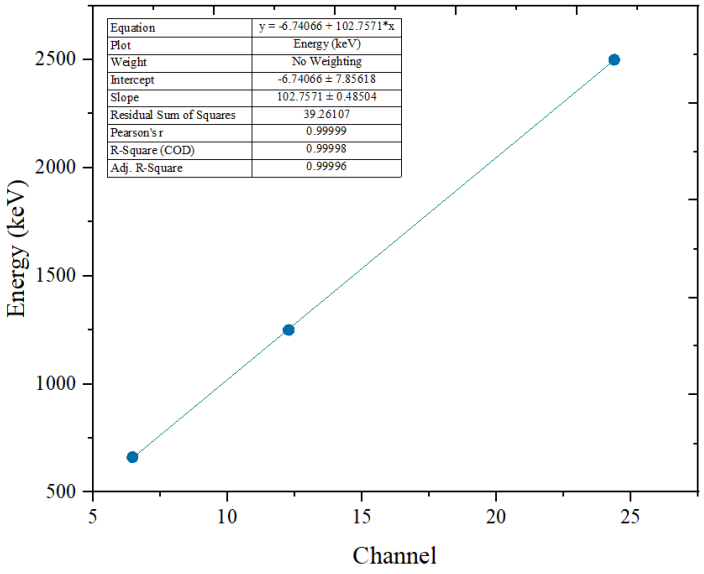

In detectors, energy resolution is expressed as a percent of the FWHM of a specific energy. If the percent value is lower, the better is the energy resolution. The obtained plot indicates that the higher the applied voltage, the better the energy resolution.

## 2.2 Task 2: Energy Calibration of BGO detectors at 2000V

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.



| Isotope | Channel | Energy (keV) |
|---|---|---|
| **Cs-137** | 6.475 | 662 |
| **Co-60** | 12.279 | 1250 |
| | 24.379 | 2500 |




The equation of the energy calibration line for BGO detector is: $\boldsymbol{y=102.7571x-6.74066}$

Where:

x = channel number (mean),

y = energy of the peaks (in keV)

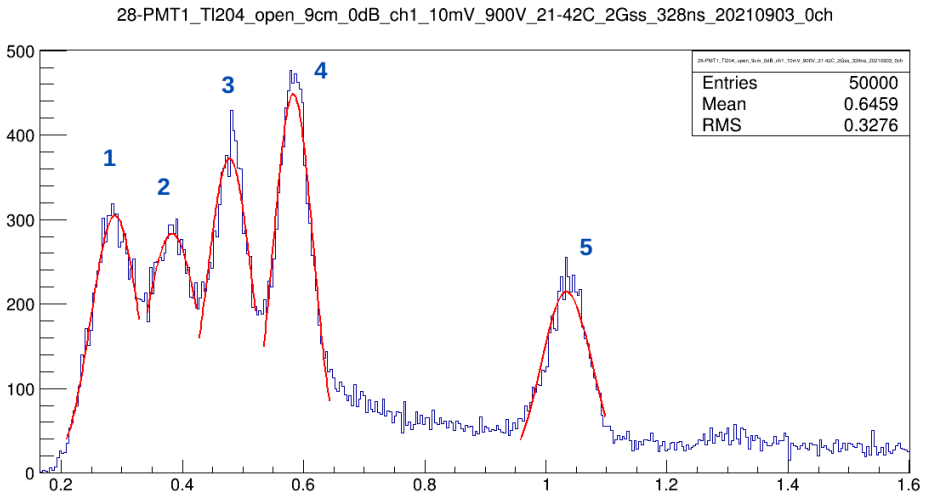
**2.1. Identification of Unknown Sources**

For the identification of the energy spectrum and its unknown sources, the following steps can be applied:

i. Using the ROOT software, a Gauss function is fitted into the spectrum of the unknown energy, and the channel number (mean) is obtained.

ii. From the equation of the calibration line of BGO detector, the channel number can be converted to energy.

iii. The unknown source of the calculated energy can be determined using the Nuclide Datasheet




| Peak | Channel | Energy (keV) | Energy (MeV) | Peak ID |
|---|---|---|---|---|
| 1 | 0.289 | 22.956 | 0.022956 | **Sm-151** |
| 2 | 0.383 | 32.615 | 0.032615 | **Mg-28** |
| 3 | 0.478 | 42.377 | 0.042377 | **Rh-103m or I-129** |
| 4 | 0.583 | 53.167 | 0.053167 | **Rh-104m or Te-132** |
| 5 | 1.034 | 99.510 | 0.099510 | **Gd-153 or Au-145** |

**Sample Calculation (Peak 1):**

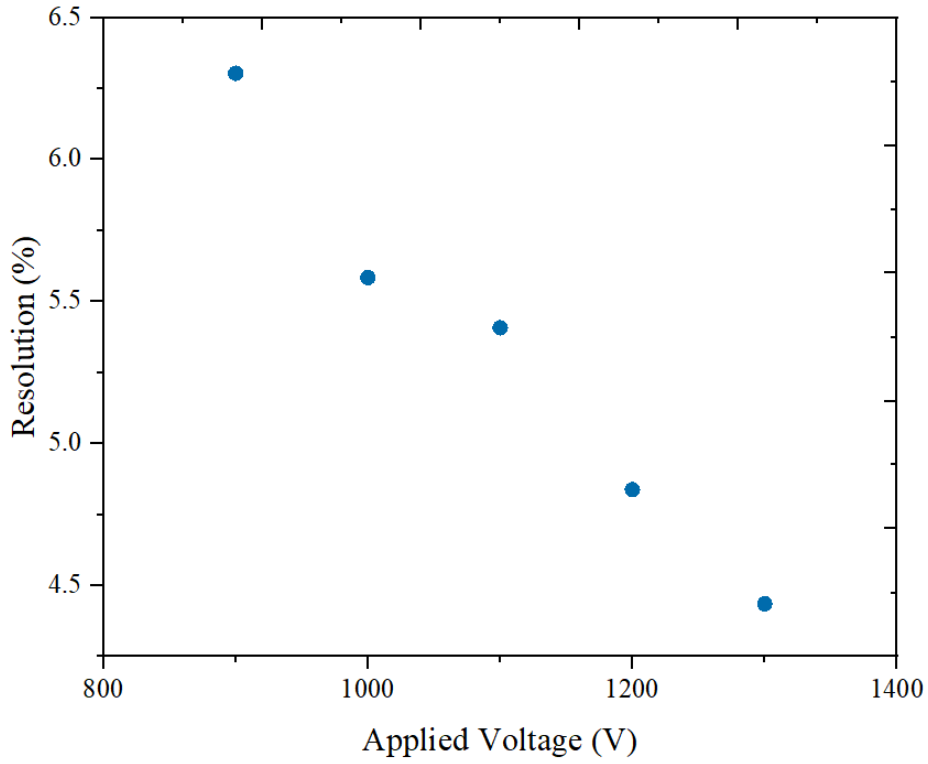
Equation of the calibration line: $\boldsymbol{y}$=$\mathbf{102.7571}\boldsymbol{x}\mathbf{-6.740}$ ; and $\boldsymbol{x}$=$\mathbf{0.289.}$

Substitute the value of x: $y$=102.7571∗0.289−6.74066

$y$=22.956 keV

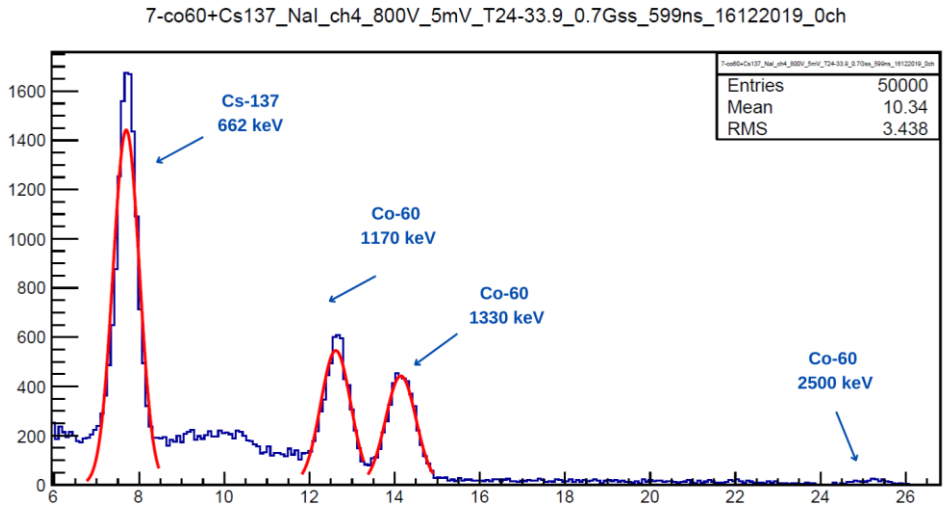
## 2.3 Task 3: Relation between the Resolution and Applied Voltage for NaI detectors

| Applied Voltage (V) | Mean | Sigma | Resolution (%) |
|---|---|---|---|
| 900 | 23.670 | 0.635 | 6.304 |
| 1000 | 40.655 | 0.966 | 5.584 |
| 1100 | 65.792 | 1.514 | 5.408 |
| 1200 | 98.707 | 2.032 | 4.838 |
| 1300 | 137.347 | 2.616 | 4.476 |



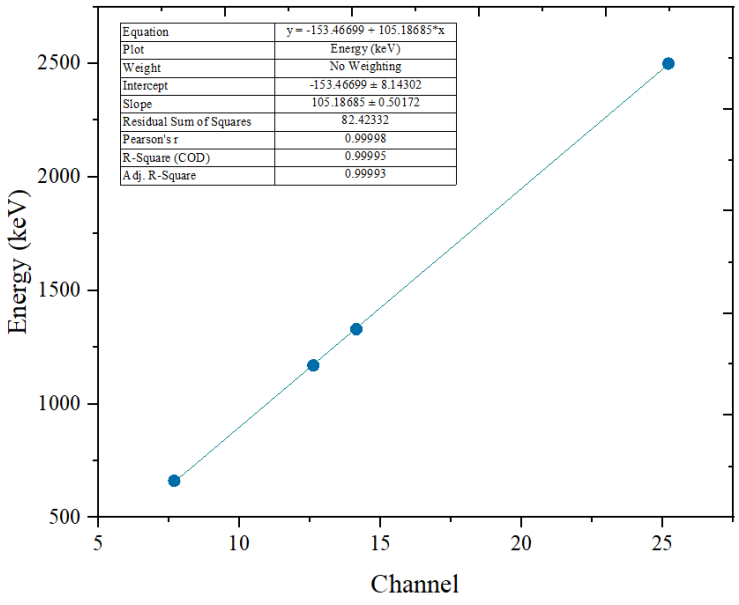

## 2.4 Task 4: Energy Calibration of NaI detectors at 800V

An NaI detector has more light output, so its resolution is twice as good as a BGO detector. It can separate the two peaks of Co-60 with energies of 1170 keV and 1330 keV, respectively. This is the reason that four peaks are visible instead of three, in the energy spectrum below.

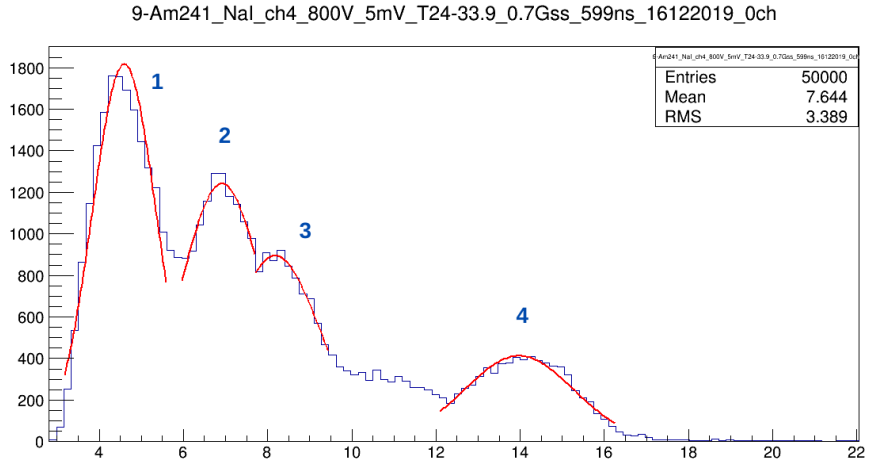



| Isotope | Channel | Energy (keV) |
|---|---|---|
| **Cs-137** | 7.696 | 662 |
| **Co-60** | 12.624 | 1170 |
| | 14.145 | 1330 |
| | 25.199 | 2500 |

Similarly, the channel number (mean) is obtained by making a Gaussian fit using the ROOT software. The channel and the energy of each peak is given on the table above. The energy is plotted against the channel number, and a calibration curve is fitted into it. From this, the equation of the generated calibration line for NaI detector is: $\mathbf{y=105.18685x-153.46699}$



## 4.1. Identification of Unknown Sources




| Peak | Channel | Energy (keV) | Energy (MeV) | Peak ID |
|---|---|---|---|---|
| 1 | 4.593 | 329.656 | 0.32966 | **Ir-194** |
| 2 | 6.915 | 573.900 | 0.57390 | **Bi-207** |
| 3 | 8.178 | 706.751 | 0.70675 | **Tc-129m** |
| 4 | 13.973 | 1316.309 | 1.31631 | **Ca-47** |

**Sample Calculation (Peak 1):**
Equation of the calibration line: $\mathbf{y=105.18685x-153.46699;}$ and $\boldsymbol{x}\mathbf{=4.593.}$
Substitute the value of x: $y$=105.18685∗4.593−153.46699
$y$=329.656 keV

## 2.5 Task 5: Determination of the attenuation coefficient

Every material has its unique attenuation coefficient. Linear attenuation coefficient (μ) is a constant that describes the fraction of attenuated (absorbed or scattered) incident photons in a beam per unit thickness of a material. This covers all possible interactions such as coherent scattering, Compton scattering, and photoelectric effect. Linear attenuation coefficient can be calculated from the following formula: $I=I_0e-\mu x$
Where:
x = absorber thickness,
I = intensity transmitted through an absorber of thickness x,
$I_0$ = intensity at zero absorber thickness,
μ = linear attenuation coefficient.
Linear attenuation coefficient has two main features: increases as the atomic number and physical density of the absorbing material increases, and it

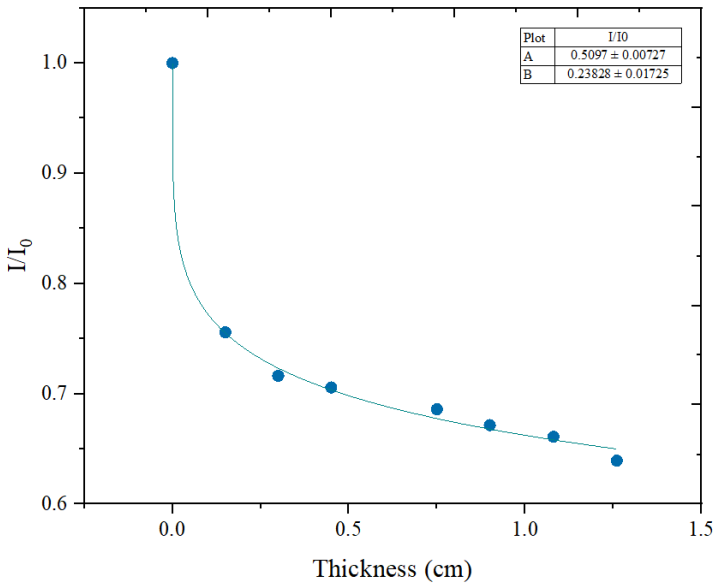
decreases with increasing photon energy (except at K-edges). Its variant is the mass attenuation coefficient, which is defined as a normalization of the linear attenuation coefficient per unit density of a material, resulting in a value that is constant for a given element or compound.

**Experimental Equipment:**

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

### 5.1. Attenuation coefficient of Aluminum (Al)

| Thickness (cm) | 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 |

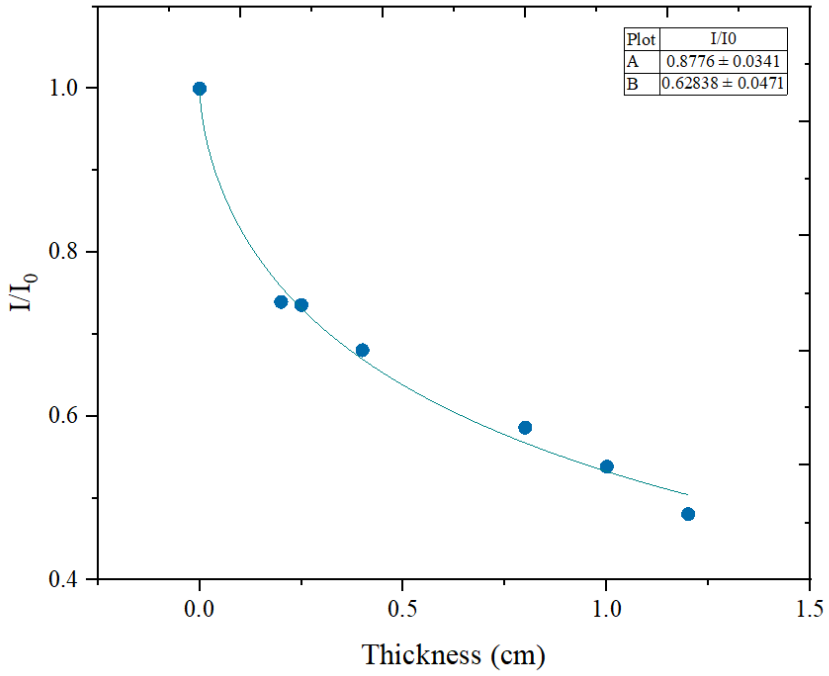


From the non-linear fitting curve in Origin Analysis, the obtained linear attenuation coefficient of aluminum (Al) is: ***0.23828 ± 0.01725 cm-1***.

### 5.2. Attenuation coefficient of Copper (Cu)

| Thickness (cm) | 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***.




## 2.6 Task 6: Range of Alpha Particles in Air

Range is characterized as the path length that a particle travel from its source through matter, before it is stopped. It is influenced by the type of particle, its original kinetic energy, and the medium through which it travels. Range is especially important for charged particles, like electrons and alpha particles. Alpha particles particularly travel in almost straight lines because they are

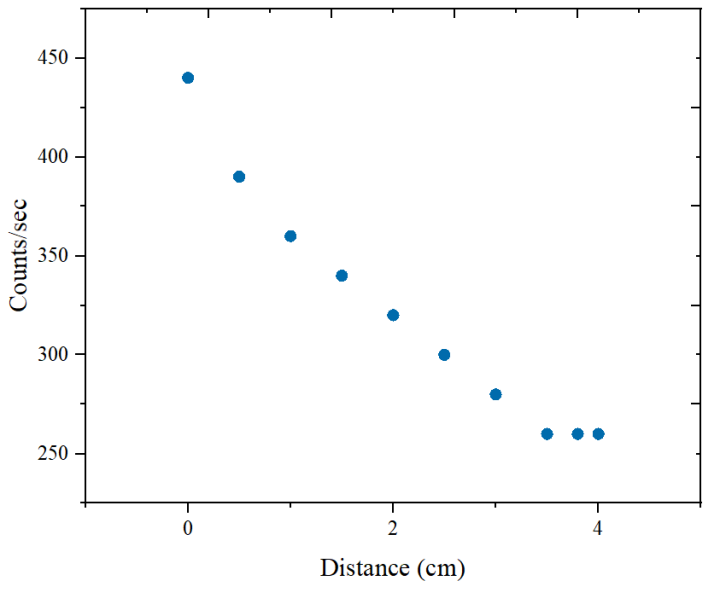
thousands of times heavier than atomic electrons, to which they lose energy slowly. Their range is usually measured in a straight line from the source to the point where ionization stops.

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

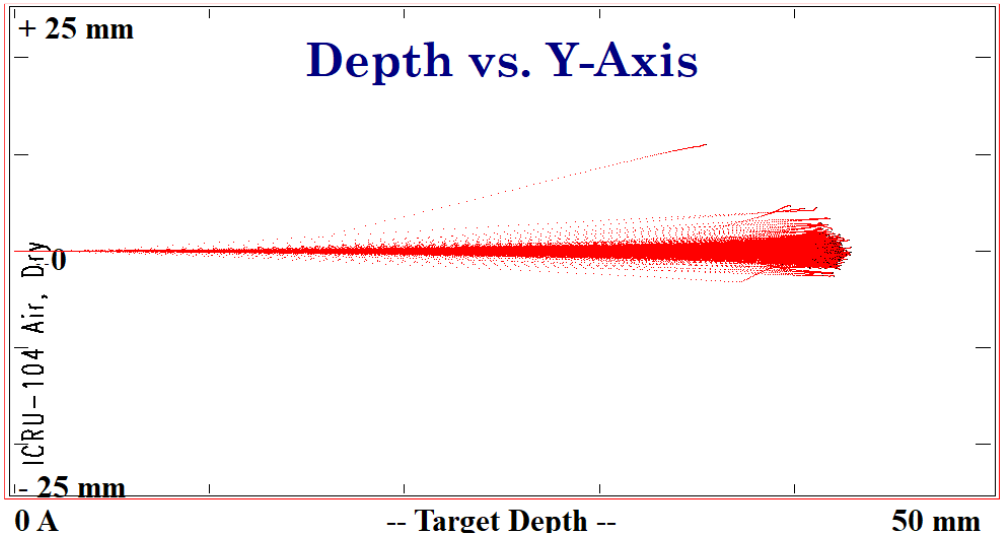
| Distance (cm) | Counts/sec |
|---|---|
| 0 | 440 |
| 0.5 | 390 |
| 1 | 360 |
| 1.5 | 340 |
| 2 | 320 |
| 2.5 | 300 |
| 3 | 280 |
| 3.5 | 260 |
| 3.8 | 260 |
| 4 | 260 |

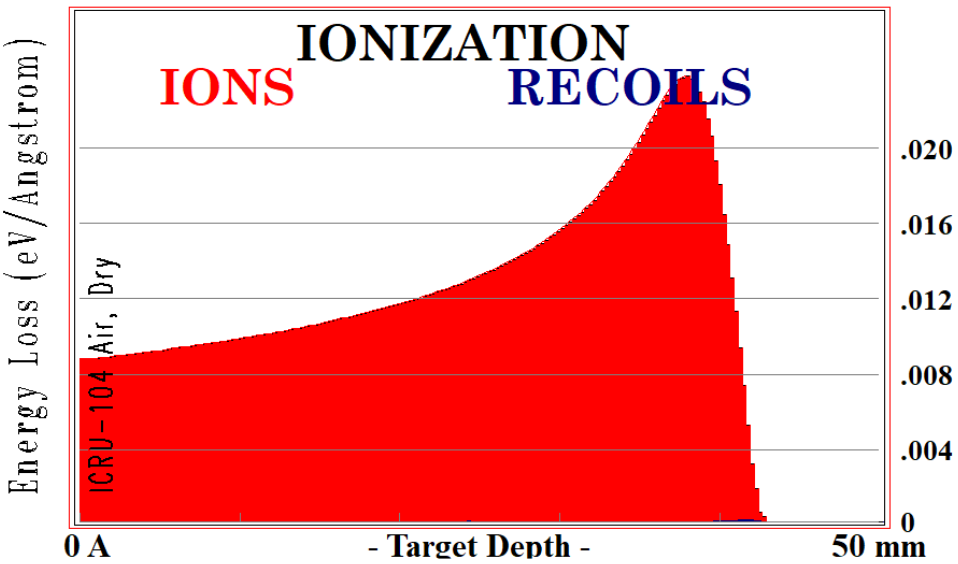


From the table and the plot, it can be observed that the counts per second decreases as the distance increases, until reaching a point where the number of counts is constant. It means that there is no more signal detected. Therefore, the range of alpha particles in air is about ***3.5 cm***.

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

Using the SRIM software, it is possible to observe the simulation of the total path length travelled by alpha particles in air. Two plots are obtained: the depth vs. y-axis and the ionization (Bragg peak/curve) of the alpha particles. The Bragg curve represents the energy loss rate as a function of the distance through a stopping medium. The Bragg peak is the maximum, and beyond that, the energy deposition drops sharply.



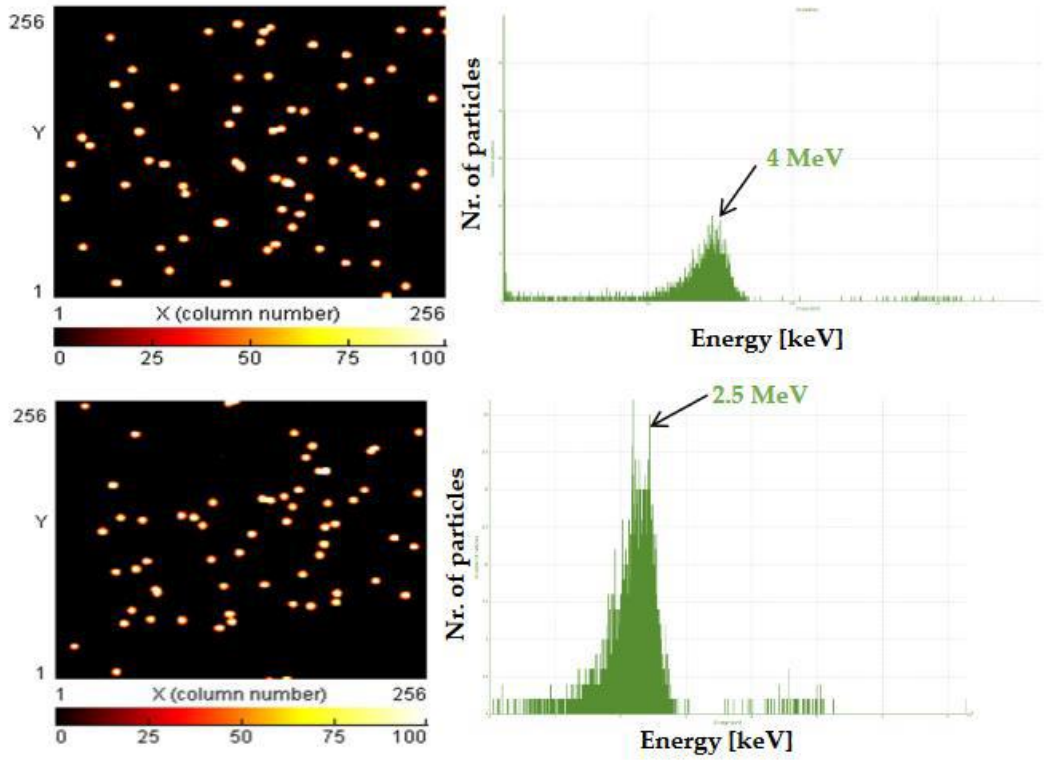



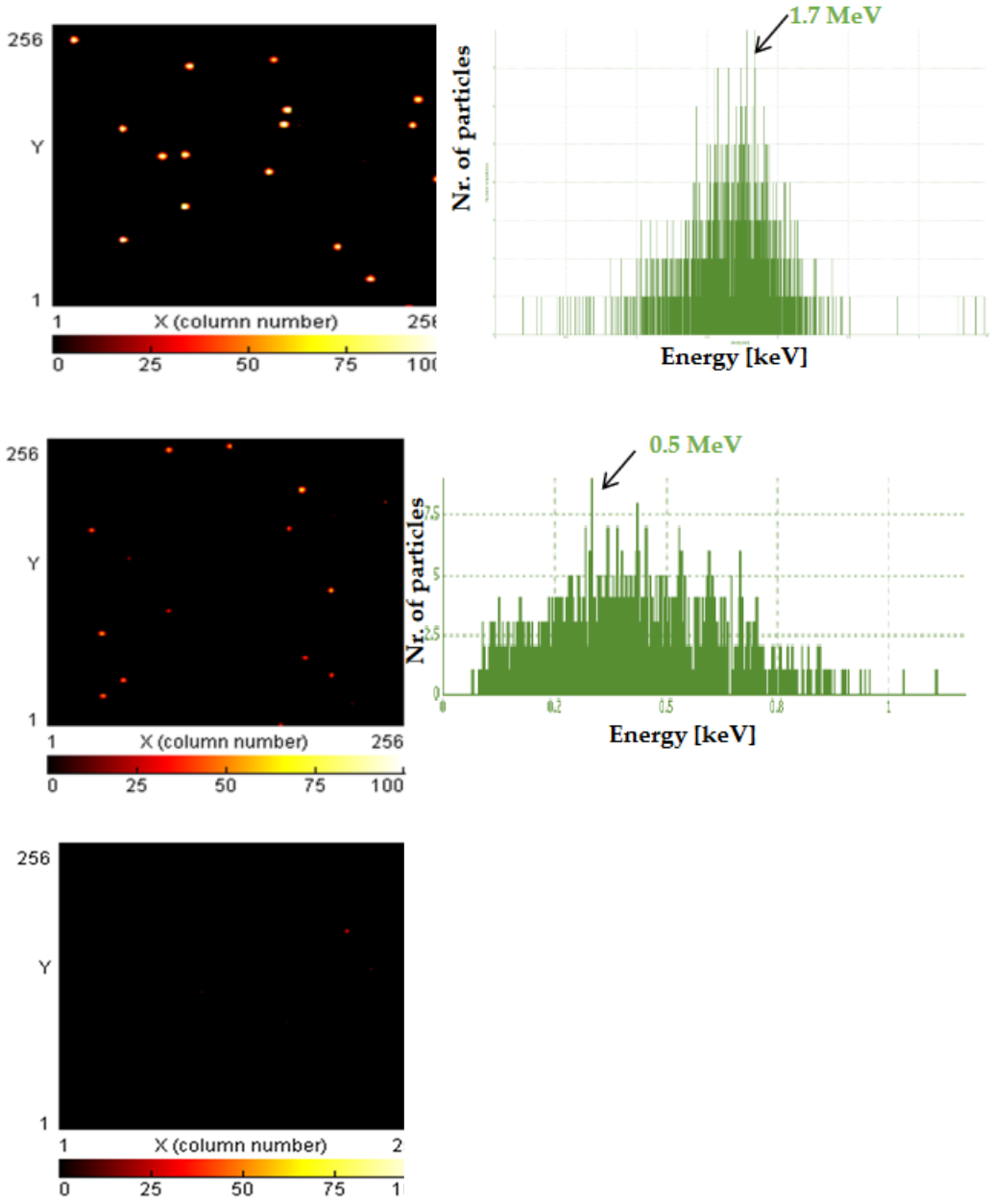
From the two plots, it can be denoted that the intensity of alpha particles decreases when the distance increases. Since, alpha particles lose their energy when they interact with the particles present in the air. Here, the range of the alpha particles in air is around 3.5 to 4 cm. The Bragg peak is about 4.3 cm and beyond that, the energy decreases sharply until no more signal is detected.

**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
-






At a 3 cm distance from the source, there are no alpha particles detected. Therefore, the maximum range of alpha particles in air as measured by a pixel detector is about **3 cm**.

# 3.0 Conclusions

In this project, the fundamental components of radiation protection and radiation sources are investigated. This includes the various radiation sources and types, its units and quantification, radiation protection principles, the various scintillation detectors and scintillating crystals, the components of a scintillation detector, peak integration, energy calculation and source identification, attenuation coefficient determination, and range of alpha particles in air. Software such as ROOT, Origin Analysis, Excel, and SRIM simulation are among the programs used the technical specifications of the two scintillation detectors are compared through the experimental methods and outcomes. In contrast to a BGO detector, a NaI detector clearly has a better and more advantageous resolution. But each one has a unique set of characteristics and applications.

The energy of the unknown source is determined from the equation of the calibration line using a known energy. To pinpoint the source, the calculated energy is contrasted with data from the literature. It should be noted that it is only a rough estimate and may not be the source of radiation in its entirety. Due to the possibility of errors during the Gaussian fitting in ROOT, values may vary. The attenuation coefficients of aluminium and copper are determined using the BGO detector at 2000 V and Cs-137 as the radioactive source. The reduction of an x-ray beam as it passes through matter is known as attenuation, and each material has its own attenuation coefficient. This is a critical factor in medical imaging. When the two materials are compared, copper has a higher attenuation coefficient than aluminium. Copper has a higher atomic number and density than aluminium, making it more efficient for shielding. The range of alpha particles in air is determined using the plastic detector, SRIM simulation, and the pixel detector. It ranges from 3 to 4 cm, depending on the detector, the radioactive source, and the intensity of the energy applied. In a nutshell, the project's primary goals have been accomplished.

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