JOINT INSTITUTE FOR NUCLEAR RESEARCH
Veksler and Baldin laboratory of High Energy Physics

FINAL REPORT ON THE INTEREST PROGRAMME

Radiation Protection and the Safety of Radiation Sources

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Abstract

This report encapsulates the outcomes of an intensive training program under the INTEREST Programme at the Joint Institute for Nuclear Research, Veksler and Baldin Laboratory of High Energy Physics, aimed at fostering expertise in radiation protection and the safety of radiation sources. The study encompassed a series of laboratory experiments designed to impart practical skills and theoretical knowledge in nuclear physics, radiation detection, dosimetry, and shielding. Key experiments involved the performance evaluation of Bismuth Germanate (BGO), Sodium Iodide (NaI), and Cadmium Telluride (CdTe) detectors, focusing on their energy resolution, calibration, and ability to identify unknown radioactive isotopes through gamma-ray spectroscopy. The impact of applied voltage on BGO and NaI detector resolution was analyzed, revealing improved performance at higher voltages. Gamma-ray attenuation was investigated using aluminum and copper, yielding linear attenuation coefficients of 0.75949 cm^{-1} and 12.15641 cm^{-1}, respectively, highlighting material-specific shielding properties. Additionally, the range of alpha particles in air was determined to be approximately 3.6 cm using a pixel detector, reinforcing the understanding of alpha particle interactions. These experiments were complemented by energy calibration using standard sources (e.g., Co-60, Cs-137, Am-241), enabling precise identification of isotopes such as Sr-87m and Na-24. The acquired skills align with international radiation safety standards (e.g., IAEA, ICRP) and are directly applicable to fields like nuclear medicine, environmental monitoring, and regulatory compliance, equipping participants to ensure safe handling of radiation sources and contribute to global nuclear safety frameworks.

BGO Scintillator Detector

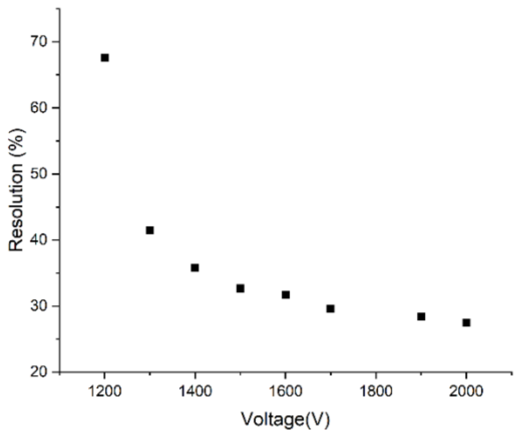
Bismuth Germanate (BGO - $Bi_4Ge_3O_{12}$) is a dense, high-Z scintillator crystal known for its excellent gamma-ray absorption. It is mechanically robust, non-hygroscopic, and maintains stable performance up to ~100 rad, with minimal afterglow and no cleavage planes, allowing flexible shaping. However, BGO emits light mostly above 500 nm, where PMT sensitivity drops, and it is intrinsically radioactive, which may limit its use in some applications. It is also sensitive to radiation damage starting around 1–10 Gy, though recovery is possible over time or through annealing. BGO is widely used in PET imaging, Compton suppression systems, geological logging, and various high-energy, nuclear, space, and medical physics applications.

Resolution

This work investigates the effect of applied voltage on the resolution of a BGO scintillator detector using **Co60** by analyzing the spectra and calculating the resolution for different voltages.

$$R = \left(\frac{2.355 \times \sigma}{\mu}\right) \times 100$$

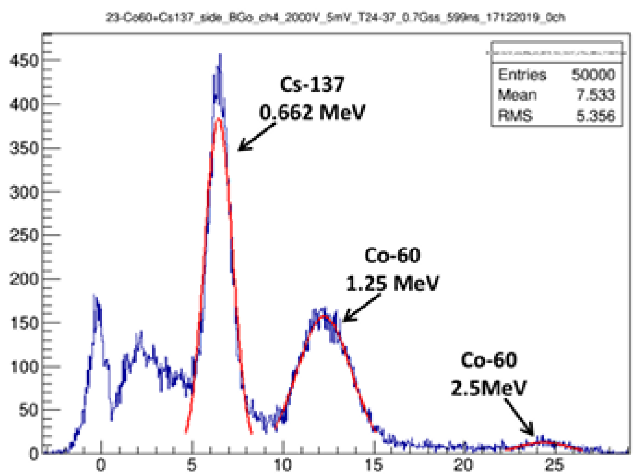
VOLTAGE(V)	MEAN (M)	SIGMA (Σ)	RESOLUTION
1200	1.61007	0.462268	67.6
1300	1.34468	0.236998	4
1400	1.92106	0.291792	35.7
1500	3.00675	0.417324	32.6
1600	4.42445	0.595907	31.7
1700	6.12166	0.770426	29.6
1900	10.626	1.28198	28.4
2000	13.5683	1.5836	27.4



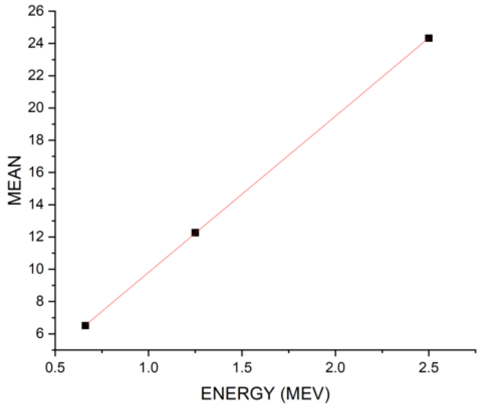
As the voltage increased, the resolution percentage decreased. This means the detector gave clearer and more accurate results at higher voltages. The peaks in the spectra became sharper, which helps in better identifying the energies.

Energy Calibration

PEAK	ENERGY (MEV)	MEAN
1	0.662	6.509
2	1.25	12.268
3	2.5	24.330



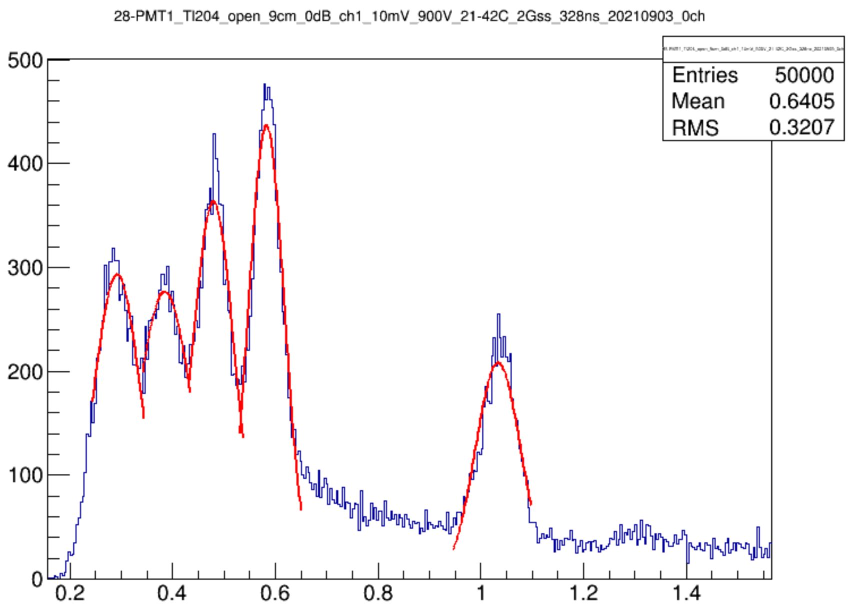
Calibration Equation:



$$\frac{\text{Mean} - 0.0632}{9.706} = \text{Energy (MeV)}$$

Identification of Unknowns:

EXPECTED ELEMENT	MEAN (CHANNEL)	CALCULATED ENERGY (MEV)
SM-151	0.296	0.02397
MG-28	0.389	0.03354
I-129	0.485	0.04346
TE-132	0.590	0.05426
AU-195	1.043	0.10089



NaI Detector

Sodium Iodide (NaI) scintillation detectors are widely used for gamma-ray spectroscopy due to their high efficiency, relatively low cost, and ease of use. The detector operates by converting incoming gamma radiation into visible light through a scintillation process. This light is then detected by a photomultiplier tube (PMT), which amplifies the signal and converts it into an electrical pulse.
NaI detectors are particularly known for their good detection efficiency but have moderate energy resolution compared to other scintillator materials like $LaBr_3$ or semiconductor detectors like HPGe. Despite this, their performance is suitable for many applications such as radiation monitoring, nuclear spectroscopy, and environmental measurements.
In this work, the NaI detector is used to analyze gamma-ray spectra from different sources. The resolution of the detector is calculated for each measured peak, and a calibration curve is constructed by correlating the channel number (mean) with known gamma-ray energies. This calibration allows for the identification of unknown radioactive sources based on their spectral peaks.

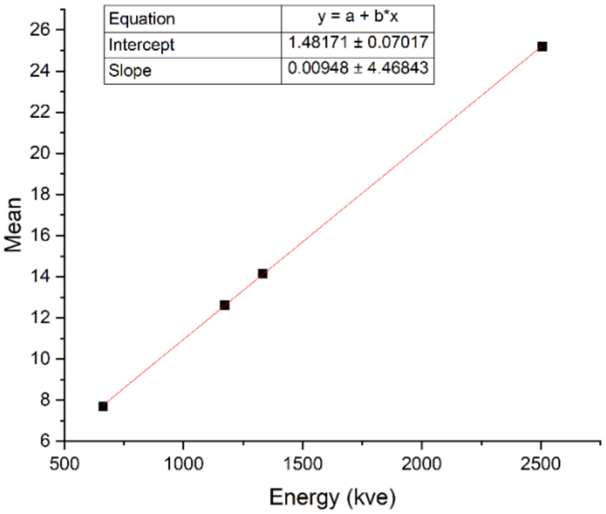
Energy Resolution

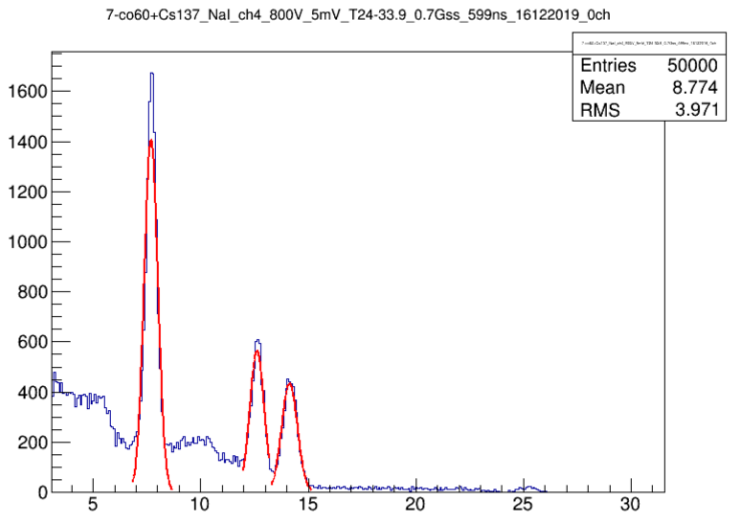
VOLTAGE(V)	MEAN (M)	SIGMA (Σ)	RESOLUTION (%)
900	23.6506	0.644836	6.420931308
900	26.5729	0.596649	5.287749531
1000	40.6422	0.990772	5.74099842
1000	45.4664	0.958879	4.966656795
1100	65.7672	1.53236	5.487093566
1100	73.2687	1.56646	5.034910269
1200	98.7004	2.02198	4.824461603
1200	108.514	1.89465	4.111820364
1300	137.37	2.57797	4.419538
1300	148.807	2.4666	3.903608701

Calibration Using Co-60 and Cs-137

The calibration process begins by identifying the energy values of known elements. Next, the mean value for each peak is determined using a Gaussian fit, as the mean represents the corresponding channel number. Finally, the slope is calculated to establish the relationship between energy and channel number.

EMENT	ENERGY (KEV)	MEAN
CS137	662	7.7008
CO60	1173	12.6296
CO60	1332	14.1559
CO60 COINC	2505	25.1949





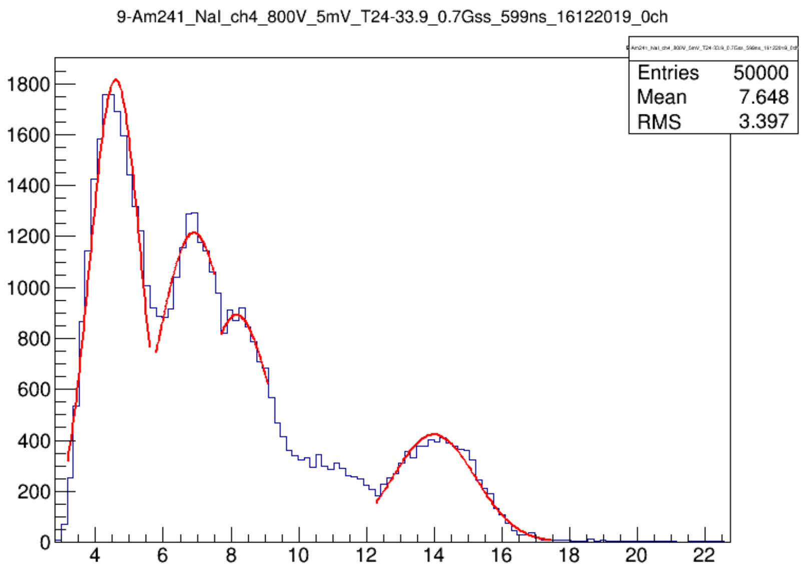
Calibration Equation (to calculate energy from mean channel):

$$\frac{\text{Mean} - 1.48171}{0.00948} = \text{Energy (keV)}$$

Identifying Unknown Elements

From the calibration process using elements with known energies, we derived an equation that allows us to calculate the energy of unknown elements. We then compare the calculated energy with known spectral data to identify the element with the closest possible match.

PEAKS	ENERGY (KEV)	MEAN	UNKNOWN NUCLIDE
PEAK 1	**377.8118949**	**4.62875**	**Sr-87m**
PEAK 2	**618.6965491**	**6.91165**	**Br-82**
PEAK 3	**741.2798151**	**8.07339**	**Mo-99**
PEAK 4	**1368.093783**	**14.0138**	**Na-24**

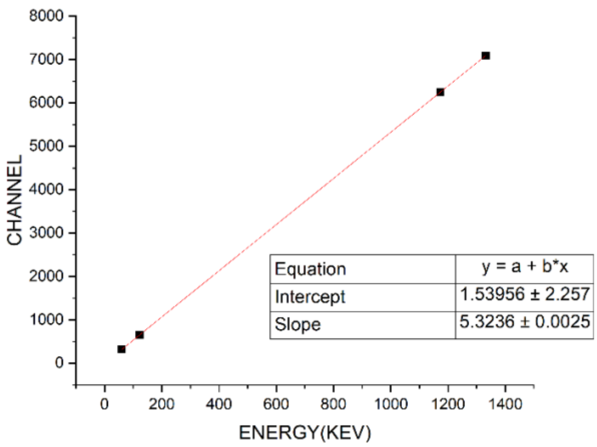


CdTe Detector

Cadmium Telluride (CdTe) detectors are semiconductor radiation detectors that are widely used for the detection of X-rays and gamma rays. Unlike scintillation detectors, CdTe detectors operate based on the direct conversion of incident radiation into an electrical signal, offering high energy resolution and compact size.
CdTe detectors are especially effective at room temperature due to their high atomic number (Z) and wide bandgap, which contribute to efficient photon absorption and low noise performance. These properties make them suitable for applications in nuclear medicine, environmental monitoring, security, and portable gamma-ray spectrometry.
In this experiment, the CdTe detector is used to measure gamma-ray spectra from known sources. The resolution of the detector is evaluated for different peaks, and a calibration curve is created by relating the measured channel means to the known energies of gamma emissions. This calibration enables the identification of unknown energies from observed spectral data.

Energy Calibration

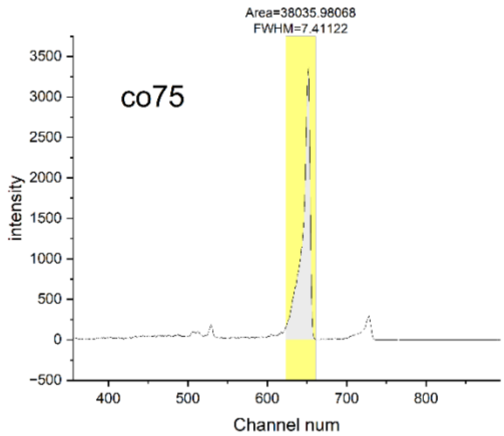
ISOTOPE	ENERGY(KEV)	CHANNEL
AM241	59.5	317
CO57	122	652
CO60	1173	6249
CO60	1332	7090

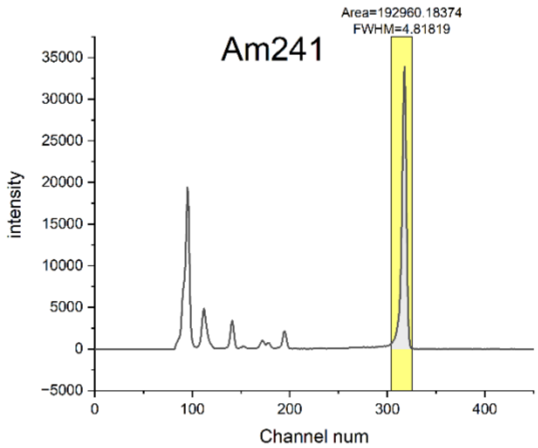


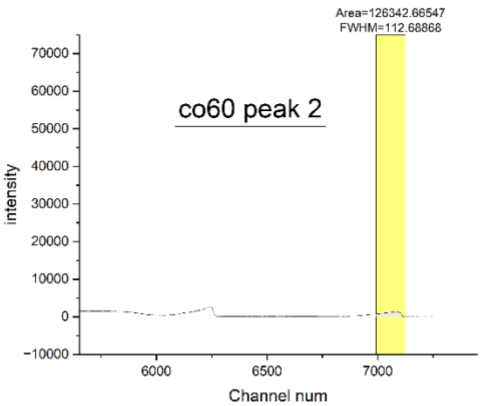
Gamma-Ray Spectroscopy Results: FWHM and Energy Resolution

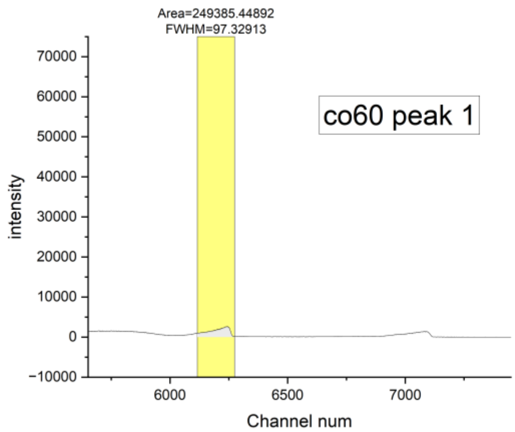
The gamma-ray spectra of Am-241, Co-57, and Co-60 were analyzed using a CdTe detector. The Full Width at Half Maximum (FWHM) and energy resolution were calculated for the characteristic peaks of each isotope.

ISOTOPE	PEAK CHANNEL	ENERGY (KEV)	FWHM (CHANNELS)	FWHM (KEV)	RESOLUTION (%)
AM-241	317	59.5	4.81	0.78	1.31
CO-57	652	122	7.4	1.45	1.19
CO-60 (1)	6249	1173	97.32	19.13	1.6
CO-60 (2)	7090	1332	112.05	22.55	1.7









Attenuation Factor (μ)

Objective:
To measure the attenuation curves of gamma radiation at various photon energies using different absorber materials.

Background:
The fundamental property of gamma-ray absorption is the exponential reduction in radiation intensity as a homogeneous beam of gamma rays passes through matter. When a beam with intensity I passes through a thin slab of material with thickness dx, the decrease in intensity is directly proportional to both the thickness and the initial intensity:

$$\mu I \, dx - = dI$$

Here, μ is the **attenuation coefficient**, which depends on the type of absorbing material and the energy of the incoming gamma photons.
By integrating the above differential equation, we obtain the exponential attenuation law:

$$\exp(-\mu x) \cdot {}_0 I = I$$

- $\boldsymbol{I}$: incident on a slab of thickness
- $\boldsymbol{I}_0$: is an intensity at no matter
- $\boldsymbol{x}$: thickness of matter
- μ : Attenuation coefficient

Results

Two different materials, *Copper* and *Aluminum*, were used with varying thicknesses to measure gamma ray attenuation. The resulting attenuation graphs are shown below:

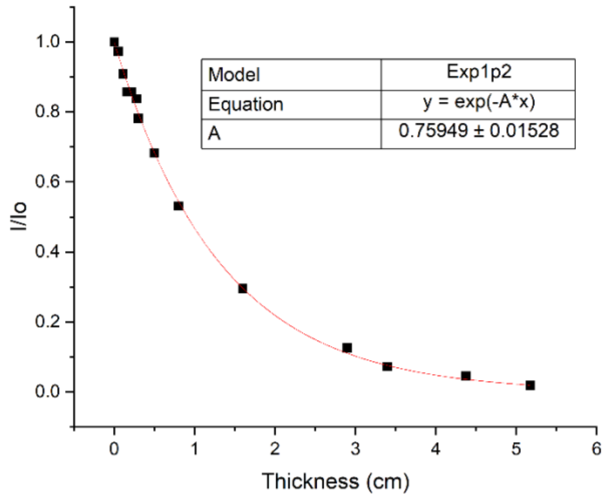
Figure 1: Attenuation curve for Aluminum
Figure 2: Attenuation curve for Copper

These graphs show how the intensity of gamma radiation decreases with increasing material thickness.

Aluminum:

From the non-linear fitting curve, the obtained linear attenuation coefficient of aluminum (Al) is: **0.75949** ± 0.01538 $cm{-1}$.

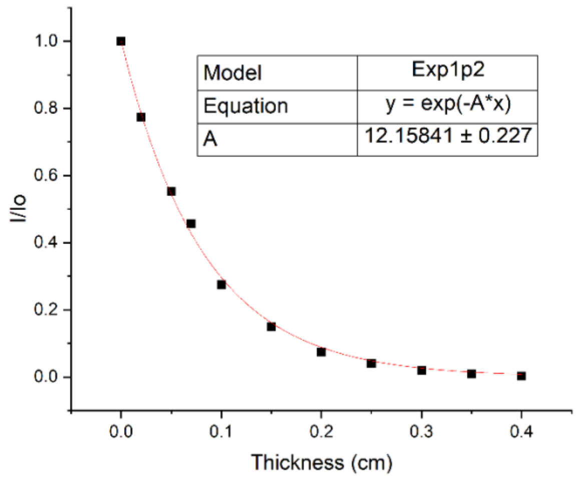
THICKNESS (CM)	I/IO
0	1
0.052	0.972895
0.11	0.908757
0.16	0.857507
0.22	0.857168
0.281	0.837652
0.3	0.781989
0.5	0.682713
0.8	0.531848
1.6	0.295792
2.897	0.126259
3.397	0.072463
4.374	0.04565
5.174	0.018837



Copper:

From the non-linear fitting curve, the obtained linear attenuation coefficient of copper (Cu) is:**12.15641**± 0.227 $cm{-1}$

THICKNESS (CM)	I/IO
0	1
0.02	0.773799
0.05	0.552531
0.07	0.456788
0.1	0.275352
0.15	0.149826
0.2	0.073269
0.25	0.040928
0.3	0.019185
0.35	0.00877
0.4	0.002558

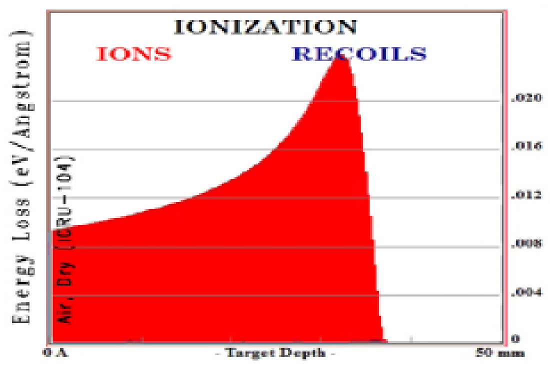


Pixel Detector (PD)

A Pixel Detector (PD) is a device used in particle physics, medical imaging, and space research to detect radiation like gamma rays or high-energy particles. It consists of a grid of tiny silicon pixels that capture the position and energy of particles with high precision. When radiation hits the silicon, it creates electrical signals that are processed to track particle paths or create images. These detectors are crucial in experiments like CERN’s LHC for tracking particles, in medical scans like X-rays or PET, and for studying cosmic rays in space. They’re known for their high resolution, with millions of pixels, fast data processing, and ability to handle intense radiation, but they’re expensive and need cooling to function properly.

Alpha Particle (α) Range in Air

Objective
The range of an alpha particle is the distance it travels through a medium before losing its energy and being absorbed. Due to their positive charge, alpha particles have strong ionizing power, but their large mass limits their penetration. Based on their energy, alpha particles can travel a few centimeters in air, with minimal penetration through other materials.

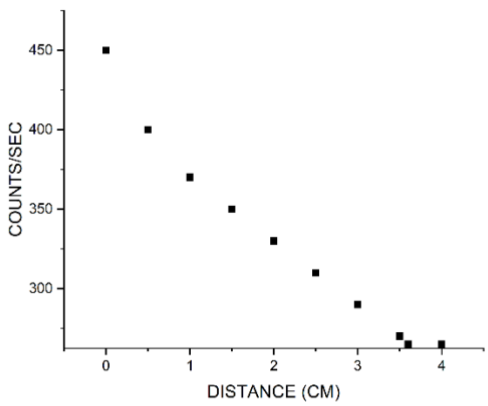


Results
From the experiment's data analysis, the table and plot show a decline in counts per second as the distance increases, eventually leveling off at a constant value, indicating no further signal detection. This suggests that the range of alpha particles in air is approximately 3.6 cm.

Table: Number of Counts per Second of Source at Different Distances from the Detector

- **Source**: Pu-239, Energy: 5.5 MeV
- **Detector**: Plastic
- **Applied Voltage**: 2000 V

DISTANCE (CM)	COUNTS/SEC
0	450
0.5	400
1	370
1.5	350
2	330
2.5	310
3	290
3.5	270
3.6	265
4	265



Conclusion: The range *R=3.6*

Conclusion

The INTEREST Programme successfully achieved its objectives of building a robust foundation in radiation protection and safety through hands-on laboratory work and theoretical training. The comprehensive analysis of BGO, NaI, and CdTe detectors demonstrated their unique strengths, with BGO achieving a resolution of 27.49% at 2000 V, NaI reaching 3.90% at 1300 V, and CdTe exhibiting superior resolution (1.19–1.70%) for low-energy gamma rays. These results underscore the importance of optimizing detector parameters for specific applications, such as nuclear spectroscopy and isotope identification. The calibration processes, utilizing standard sources like Co-60 and Cs-137, enabled accurate identification of unknown isotopes (e.g., Br-82, Mo-99), enhancing the practical utility of gamma-ray spectroscopy in regulatory and environmental contexts. The attenuation studies confirmed the exponential decay of gamma-ray intensity, with aluminum and copper demonstrating distinct shielding capabilities, critical for designing effective radiation barriers. The alpha particle range measurement (3.6 cm in air) validated theoretical models and highlighted the limited penetration of alpha radiation, essential for dosimetry and safety protocols. These findings align with the programme's goals of equipping participants with skills in radiation detection, shielding calculations, and dosimetry, directly supporting safe practices in nuclear facilities and regulatory bodies like the Egyptian Nuclear and Radiological Regulatory Authority (ENRRA). Moving forward, it is recommended to explore advanced detectors (e.g., HPGe) for higher resolution, integrate Monte Carlo simulations (e.g., MCNP) for predictive modeling, and expand training on portable radiation monitors to enhance field applications. These advancements will further empower professionals to address emerging challenges in radiation safety and contribute to global nuclear security.