JOINT INSTITUTE FOR NUCLEAR RESEARCH
INTEREST – **Inte**rnational **Re**mote **S**tudent **T**raining at (**JINR**)

FINAL REPORT ON THE INTEREST PROGRAMME

Radiation Protection and the Safety of the Radiation Sources

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Participation period:
June 13 – July 22, Wave 7

Dubna, 2022

1. Introduction

Radiation and Radioactivity

Many materials in nature are found in unstable forms. The atoms in these unstable materials may undergo spontaneous nuclear transformations resulting in the formation of new stable atoms. This transformation process is often accompanied by the emission of radiation. Radiation may be defined as the emission or transmission of energy in the form of **waves** or particles travelling in space or through material media. Figure 1 below, shows the various types of **electromagnetic radiation** (**wave radiation**) as well as their relative energy distribution. With Ultraviolet, X-ray, and Gamma radiation being on the high end of this energy spectrum. Particle radiation, which is another way energy can be transmitted, includes alpha radiation (α), beta radiation (β), proton radiation (p^+), and neutron radiation (n^0).

All radioactive transformations fall into one of the following categories:

- **Alpha emission ($_2^4He$)**

An alpha particle is a highly energetic Helium nucleus, carrying a positive charge and a mass that is a sum of the masses of two protons and two neutrons. This nucleus is emitted from an unstable nucleus having a low neutron-to-proton ratio.

$$_z^AX \rightarrow {}_{z-2}^{A-4}D + {}_2^4He$$

- Isobaric transitions, particularly **Beta ($_{-1}^0e$** - negatron) emission, and **Positron ($_1^0e$)** emission.

A **Beta** is a negatively charged high energy particle that is released from an unstable nucleus with a high neutron-to-proton ratio. It is formed by the transformation of a neutron into a proton and an electron

$$_z^AX \rightarrow {}_{z+1}^{A}D + {}_{-1}^0e$$

- Isomeric transitions, particularly **Gamma ray** emission.

Gamma rays are monochromatic electromagnetic radiations that are emitted from the nuclei of excited atoms following a radioactive transformation. These provide the excited nuclei a mechanism for giving off the excess energy without affecting either the atomic number or the atomic mass number.

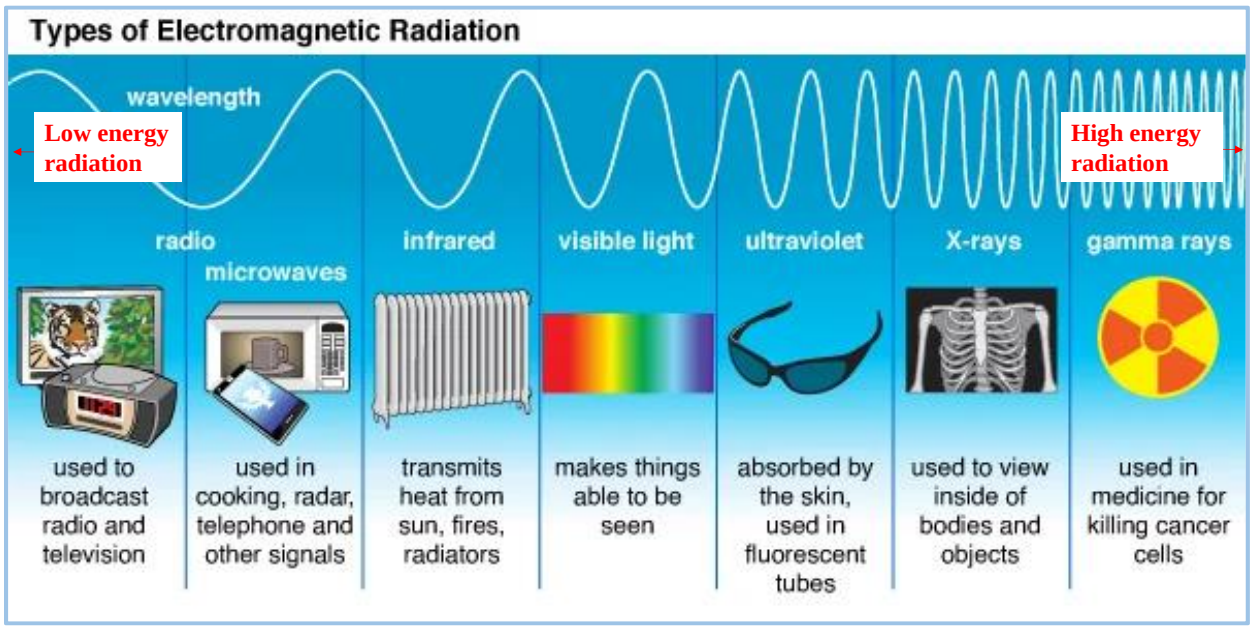

Figure 1: Showing the various types of Electromagnetic radiation.

Radiation detectors

With the knowledge of radioactive materials and the high energy radiation they emit, one might next ask about the detection of this radiation. Radiation detectors/sensors specifically measure the nuclear, electromagnetic, or light radiation emitted by radioactive materials. These devices identify nuclear radiation through the measurement of the degree of ionization due to the emission of ionizing radiation from alpha, beta, or gamma rays.

In this section, we describe the most widely used detectors using the scintillation of various materials. Table 1 below, shows the scintillator detectors and their properties.

Table 1: Showing various types of scintillator detectors and their properties.

Scintillator properties of crystals

Scintillator	Light output	Decay (ns)	Wavelength (nm) max	Density (g/ cm2)	Hygroscopic
Na(Tl)	100	250	415	3.67	yes
CsI	5	16	315	4.51	slightly
BGO	20	300	480	7.13	no
BaF2(f/s)	3/16	0.7/630	220/310	4.88	slightly
CaF2	50	940	435	3.18	no
CdWO4	40	14000	475	7.9	no
LaBr3(Ce)	165	16	380	5.29	yes
LYSO	75	41	420	7.1	no
YAG(Ce)	15	70	550	4.57	no

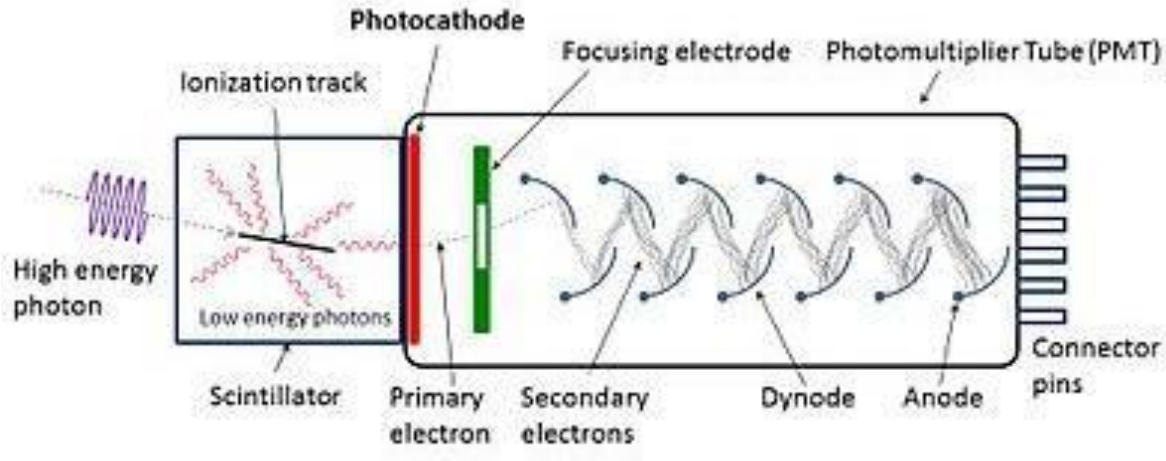

Figure 2:Schematic diagram of a scintillator detector fitted with a photomultiplier tube (PMT).

A scintillator detector uses a scintillating material such as NaI, BGo, or YAG(Ce), and those listed in table 1. The materials are usually inorganic crystals or doped plastic, which emit light when its atoms are

ionized or excited. As mentioned, radioactive transformations usually emitted high energy radiation capable of deionizing other materials (In this case, scintillator crystals/doped plastics). The hundreds of low energy scintillation photons produced from just a single particle are then collected by the photocathode to produce electrons. The photocathode electrons are further multiplied in the PMT until they are collected by the connector pins. The following figure 3 below, shows the experimental/measurement setup of the detection.

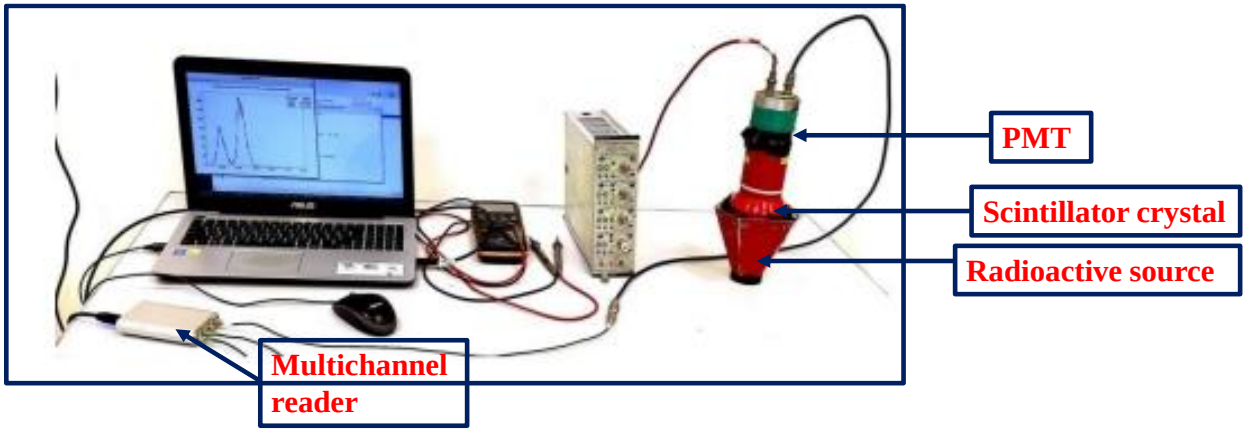

Figure 3: Scintillation detector measurement setup.

Radiation protection and Dosimetry

This section deals with the interaction of ionizing radiation with other matter, including biological materials. Particularly, since the fraction of the energy in a radiation field absorbed by the biological object "body" is energy dependent, it is necessary to distinguish between radiation *exposure* and radiation *absorbed dose.*

Absorbed Dose

With Absorbed Dose, the amount of radiation damage depends on the absorption of energy from the radiation and is proportional to the mean concentration of absorbed energy in irradiated tissue. For this reason, the basic unit of radiation dose is in terms of absorbed energy per unit mass of tissue, that is,

$$\text{Radiation Absorbed dose} = \frac{\Delta E}{\Delta m}$$

The unit for radiation absorbed dose in SI units ***Gray (Gy)*** *where[1 Gy = 1 J.Kg^{-1}].*

Equivalent Dose

With Equivalent Dose, the amount of radiation damage is like absorbed dose. However, with equivalent dose, we consider the quality of radiation, through radiation weighing factor **Wr**. The resulting dose is measure in **Sievert** (**Sv**) units.

$$\text{Radiation Equivalent dose} = Wr * \frac{\Delta E}{\Delta m}$$

Effective Dose

Effective dose, if equivalent dose in Sv units accumulated over a prolonged period of time. This is providing the measure of long-term consequences of exposure to radiation.

2. Experimental, Results, and Discussion section

In this section, we first present the results obtained from the experiment of comparing the efficiencies of two detectors, i.e., BGO and NaI. We present their resolution as a function of applied potential curves, as well as their calibration curves. The calibration curves are then further used to determine the identity of an unknown radiation source. Secondly, we investigated the attenuation of radiation through various materials, i.e., Copper and Aluminum, using Cs-137 source and BGO detector. Finally, we investigated the range of alpha particle in air using plastic detector and STIM simulation.

1. BGO Detector

Table 2: Showing resolution calculations of Co-60 radiation energy detected with BGO crystal detector.

Trial	Std	Mean	Applied potential	Resolution
1	**0,402673**	**1,63749**	1200	**0,577885392**
2	**0,260662**	**1,37206**	1300	**0,446449645**
3	**0,29346**	**1,92349**	1400	**0,358531108**
4	**0,417773**	**2,98932**	1500	**0,328424709**
5	**0,54695**	**4,42721**	1600	**0,290325623**
6	**0,745093**	**6,11578**	1700	**0,286303391**
7	**1,27448**	**10,6497**	1900	**0,281231208**
8	**1,54982**	**13,6317**	2000	**0,267177021**

$$\text{Resolution} = \frac{\text{Std}}{\text{Mean}} * (2,35)$$

From figure 4 below, it can be observed that the resolution in the detection efficiency of the BGO detector is improved with increased applied voltage V. In fact, the resolution is highest at 2000V applied voltage

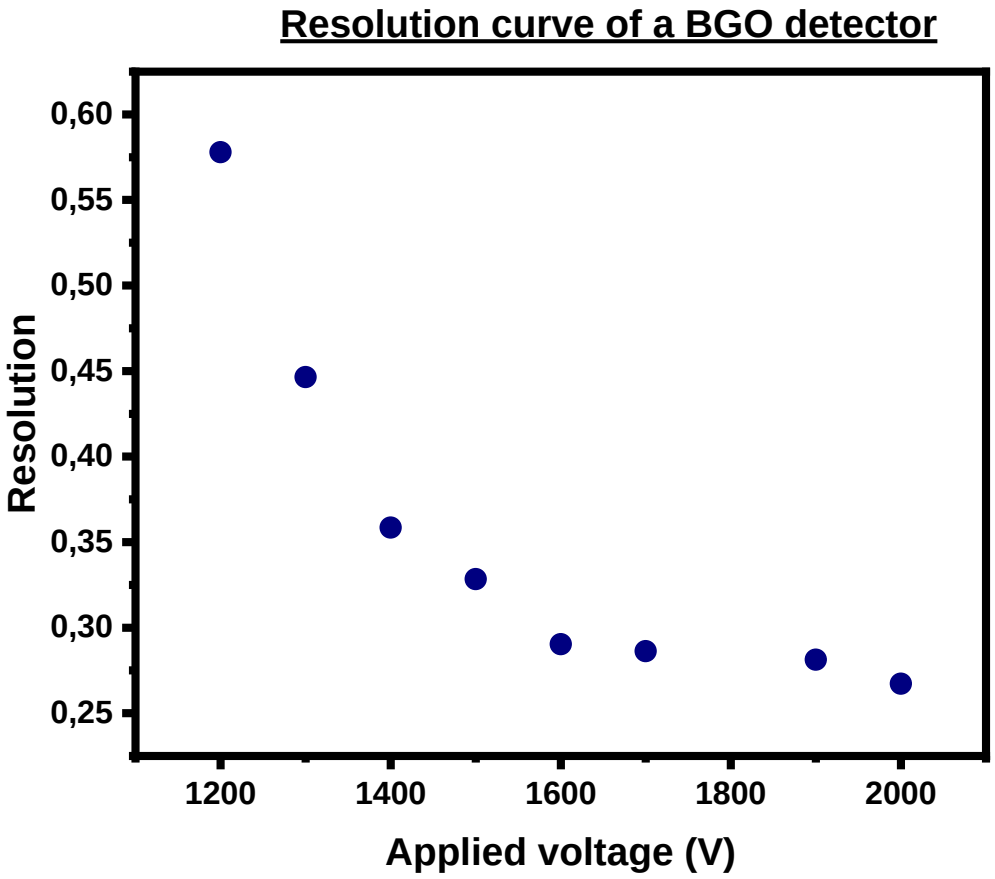

Figure 4:Showing the resolution curve of a BGO detector given as a function of Applied Voltage V.

To properly use a detector with a BGO crystal, one must first determine its efficiency through calibration. Below in table 3, we have calculated the calibration data for BGO detector. This data consists of channel numbers and their corresponding radiation energies of the radiation sources.

Table 3: Showing the calibration results of the BGO detector.

Trial	Energy (MeV)	Channel No. (a.u)
1	0,66166	6,4568
2	1,2265	12,2458
3	2,453	24,3843
UNKNC	0,038609325	0,291986
UNKNC	0,047694137	0,382743
UNKNC	0,057166338	0,47737
UNKNC	0,067783287	0,583433
UNKNC	0,113192532	1,03707
	64,88912379	Avg
	29,10125528	Std

$$y = 9.98997x - 0.09372$$

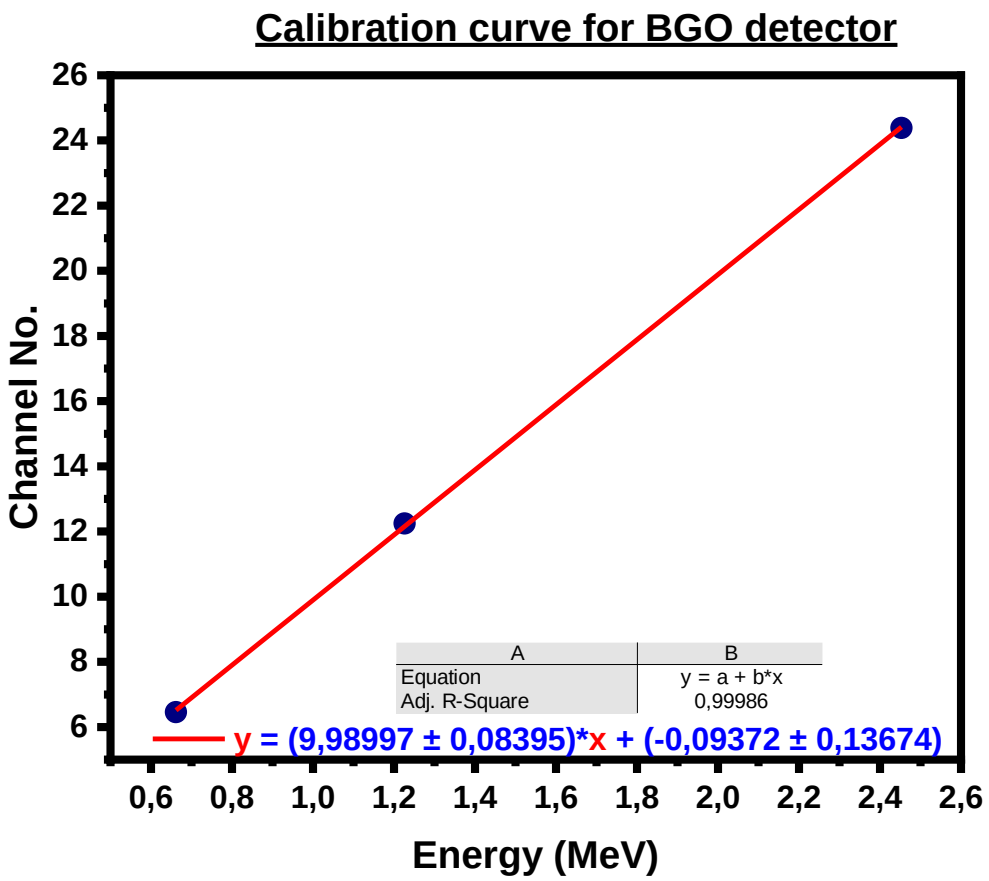

Figure 5: Calibration of BGO detector.

As can be seen in figure 5, the calibration curve is linear, which is as expected since radiation energy has a direct proportionality relationship with channel number. From this relationship, one can determine the corresponding energy of an unknown source when the channel numbers of its radiation energies are known. In this case our unknown source is identified as **Na-22 or Tb-163, Tl-1887m**.

2. Nal Detector

Table 4:Table 2: Showing resolution calculations of Co-60 radiation energy detected with NaI crystal detector.

Trial	Std	Mean	Applied potential	Resolution
1	**0,644836**	**23,6506**	900	**0,577885392**
2	**0,990772**	**40,6422**	1000	**0,446449645**
3	**1,56456**	**65,7475**	1100	**0,358531108**
4	**1,98112**	**98,7405**	1200	**0,328424709**
5	**2,56462**	**137,363**	1300	**0,290325623**

$$\text{Resolution} = \frac{\text{Std}}{\text{Mean}} * (2,35)$$

From figure 6 below, it can be observed that the resolution in the detection efficiency of the NaI detector is improved with increased applied voltage V. In fact, the resolution is highest at 1300V applied voltage

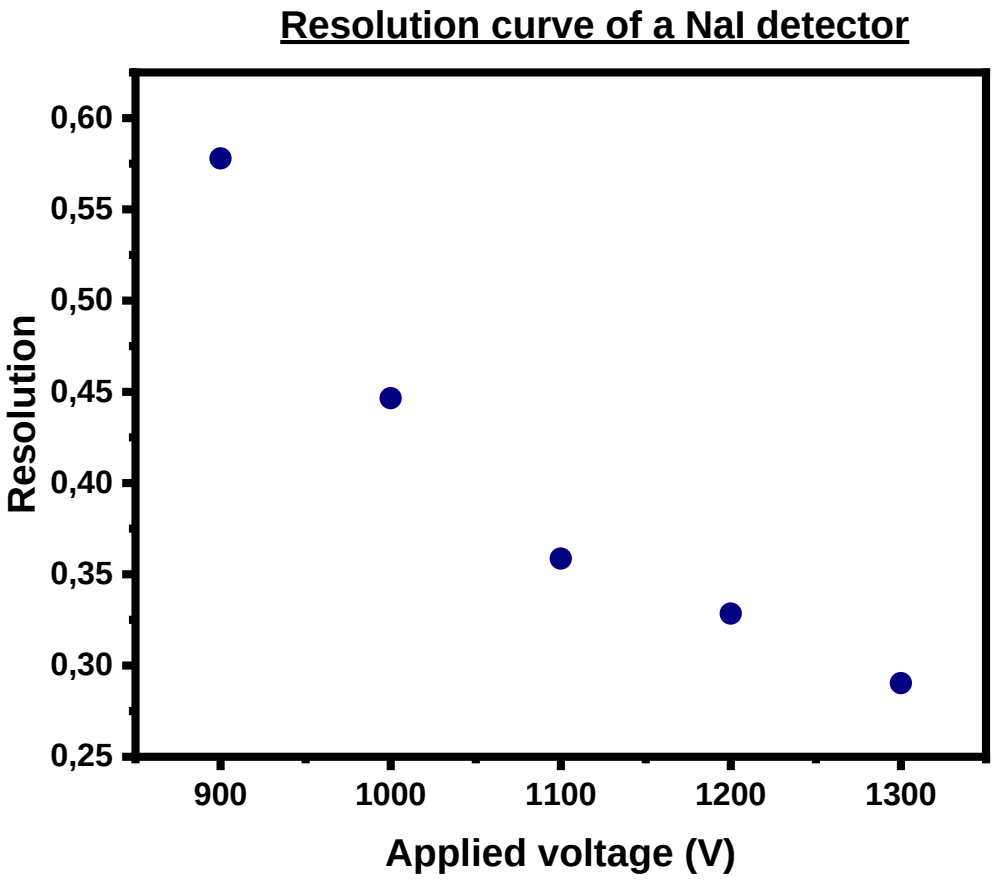

Figure 6: Showing the resolution curve of a NaI detector given as a function of Applied Voltage V.

Table 5:Showing the calibration results of the NaI detector.

Tria	Energy (MeV)	Channel No. (a.u
1	0,66166	7,69369
2	1,121	12,6075
3	1,332	14,1565
4	2,453	25,189
UNKN	0,319977367	4,5109
UNKN	0,567061193	6,9083
UNKN	0,69791132	8,17791
UNKN	1,297820831	13,9987
	0,720692678	Avg
	0,415440043	Std

$$y = 9.70278x + 0.21016$$

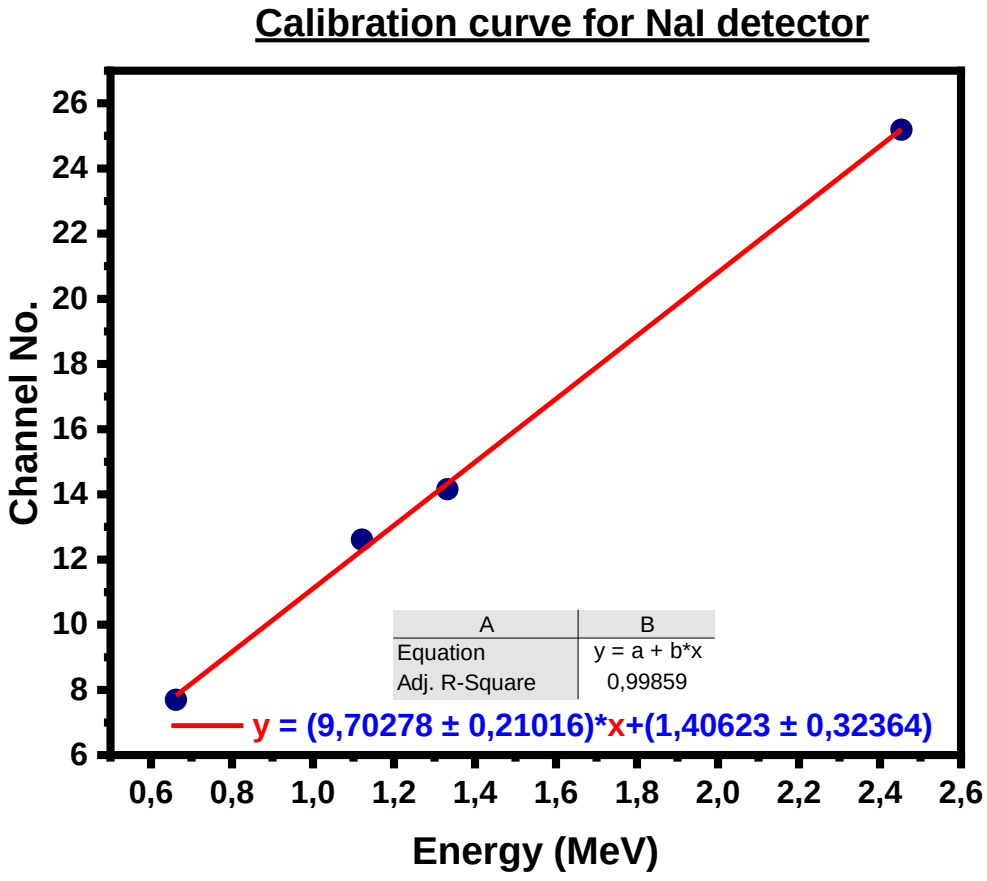

Figure 7: Calibration curve for NaI detector.

As can be seen in figure 7, the calibration curve is linear, which is as expected since radiation energy has a direct proportionality relationship with channel number. From this relationship, one can determine the corresponding energy of an unknown source when the channel numbers of its radiation energies are known. In this case our unknown source is identified as **Tm-150 or Tm-155**.

3. Attenuation

In this section, we determine the effect of shielding to radiation. Theoretically, we expect radiation to undergo attenuation as it passes through a shielding material. In this part of the report, we demonstrate the attenuation of Cs-137 source radiation as it passes through various thicknesses of Copper and Aluminum shields.

The attenuation is given by the following equation,

$$I = Io * \exp(-\mu * x)$$ ----------Equation 1

Where I and Io, are radiation intensities with and without shielding, respectively. And μ is the attenuation coefficient. This is the parameter of interest in the investigation, we aim to determine its value for Copper and Aluminum materials.

Equation 1 can be linearized to determine the value of μ, as follows

Firstly, by dividing both sides of the equation by Io, we get

$$\frac{I}{Io} = exp(-\mu * x)$$

Secondly, by taking the natural logarithm on both sides, we get

$$In\left(\frac{I}{Io}\right) = In\left(exp(-\mu * x)\right) = -\mu * x$$

Thus, if we plotted In(I/Io) values against the x values, we could expect a decreasing linear curve with μ as the gradient of the curve.

The figures show the determined values for the attenuation coefficients of both Copper and Aluminum.

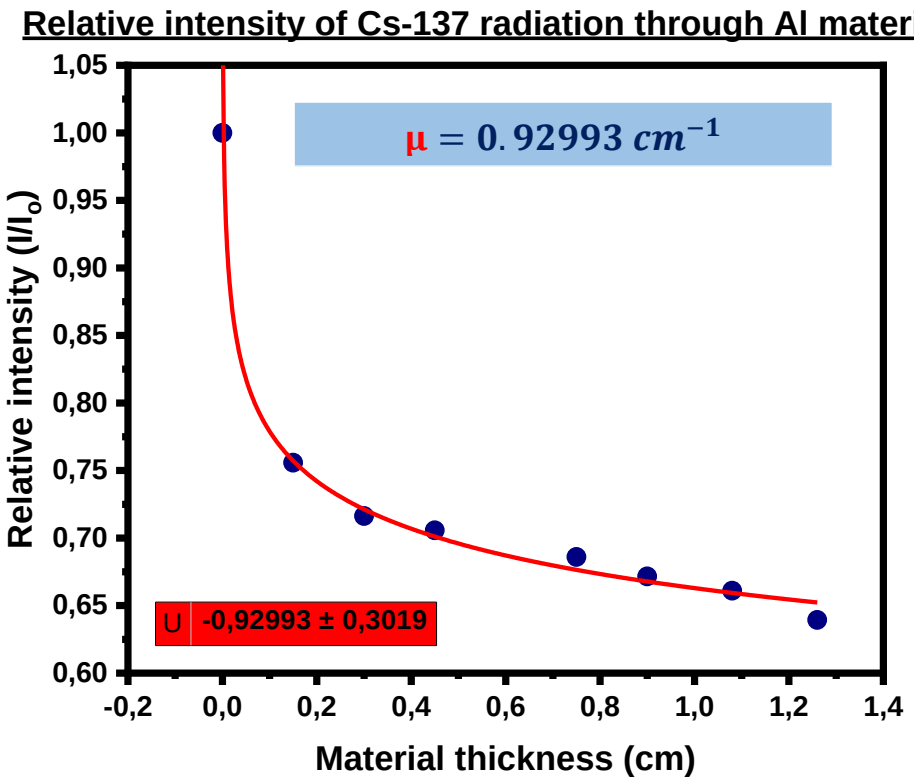

Figure 8: Attenuation of Cs-137 radiation through Aluminium shielding.

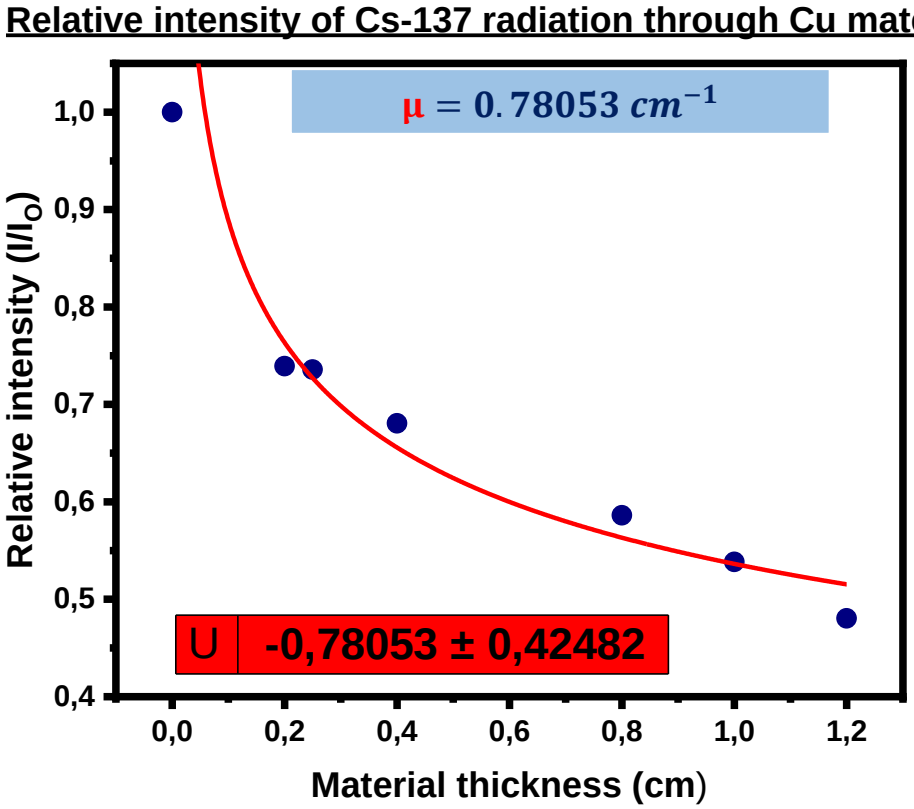

Figure 9:Attenuation of Cs-137 radiation through Copper shielding.

4. The range of the Alpha particle in the Air.

The figure below shows the counts of alpha radiation detected with a plastic detector as a function of measurement distance from the detector. From the figure, one can see that at zero distance from the detector, the counts observed is high. However, at approximately 3.5 cm, the counts observed is low. That is, alpha detection is highest closest to the detector and lowest farther from the detector.

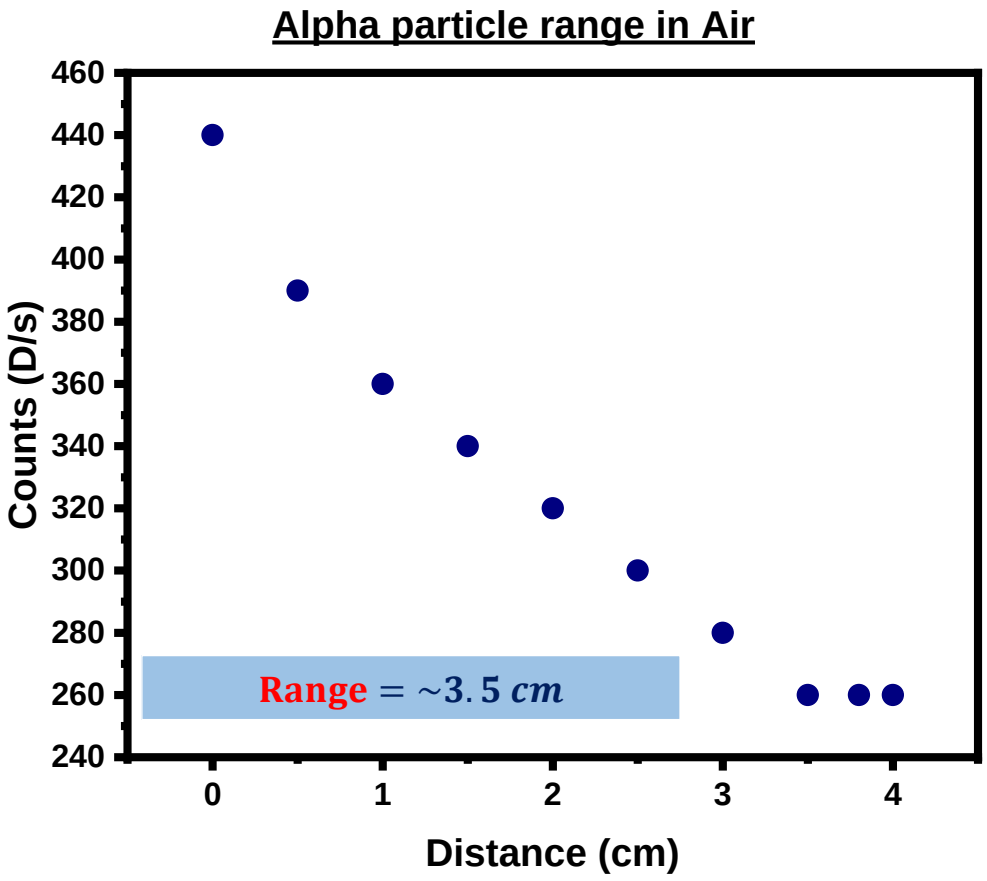

Figure 10: Alpha radiation counts observed by a plastic detector

Source: **Pu-239**, Energy **5.5 MeV**
Detector: **Plastic**
Applied voltage: **2000V**
Distance, cm

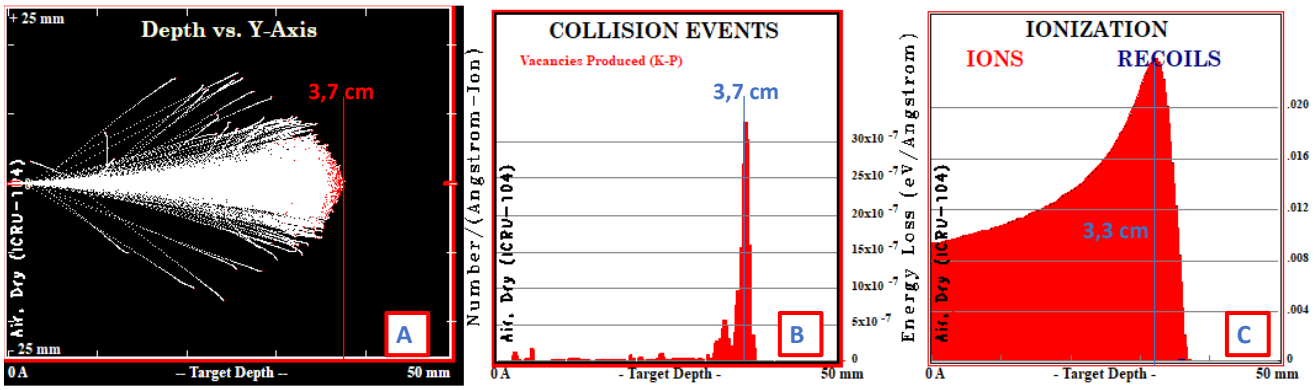

Figure 11: STIM simulating the propagation of Alpha particles in the air