FINAI REPORT ON THE INTEREST PROGRAMME

For

Radiation Protection and the Safety of Radiation Sources

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Wave 10

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Abstract

It’s interesting that radiation exists in everything of our lives, if you look anywhere, you’ll find radiation and their effect either it was positive effects like medical treatment or even it was negative effect like cancer caused by exposing to unplanned or unpredictable radiation which give the protection of radiation it’s importance to ensure the safety of working staff, public and environment.

The applications of radiation that human is imposed to deal with because of its benefits are multiple remembering that the radiation exists everywhere that means we need to plan for the protection from both acceptable and non-acceptable doses to reach the safe use of radiation.

In our program that’s what attract our attention so first we need to define what is radiation, its types and how we can detect it and then we will focus on scintillation detector specifically on BGO detector and NaI detector, our tasks will be determine and the resolution of both and calibrate them which can make a benefit in identifying unknown sources, then we will go to speak about alpha particles and it’s range in air using both NaI detector, rim and pixel detector

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Introduction

Radioactivity, an intrinsic characteristic of the cosmos, manifests through the spontaneous emission of energy or particles as unstable atoms transition to stability. This process, termed radiation, is bifurcated into ionizing and non-ionizing categories, distinguished by their capacity to permeate matter. Ionizing radiation, possessing enough energy to liberate electrons from atoms or molecules, can induce alterations at the atomic scale upon interaction with matter, including living tissues. This category encompasses alpha and beta particles, neutrons, gamma rays, and x-rays, all of which, at elevated doses, can inflict cellular damage, compromise organ function, or even culminate in fatality.

Conversely, non-ionizing radiation, characterized by lower energy levels, primarily provokes molecular vibrations and heat generation. This group includes microwave radiation, ultraviolet light, radio waves, and infrared light.

Despite the inherent perils, radiation is indispensable across various sectors, offering life-saving potential. Its applications span medicine, energy generation, industry, agriculture, space exploration, and law enforcement. When managed judiciously, with precise dosing and stringent safety protocols, ionizing radiation's myriad benefits can be safely harnessed.

Nevertheless, the assessment and mitigation of radiation risks are imperative to safeguard workers, the public, and the environment. Regulatory frameworks dictate the safe conduct of activities involving ionizing radiation, encompassing medical interventions, nuclear facility operations, the handling and transit of radioactive substances, and the stewardship of radioactive waste.

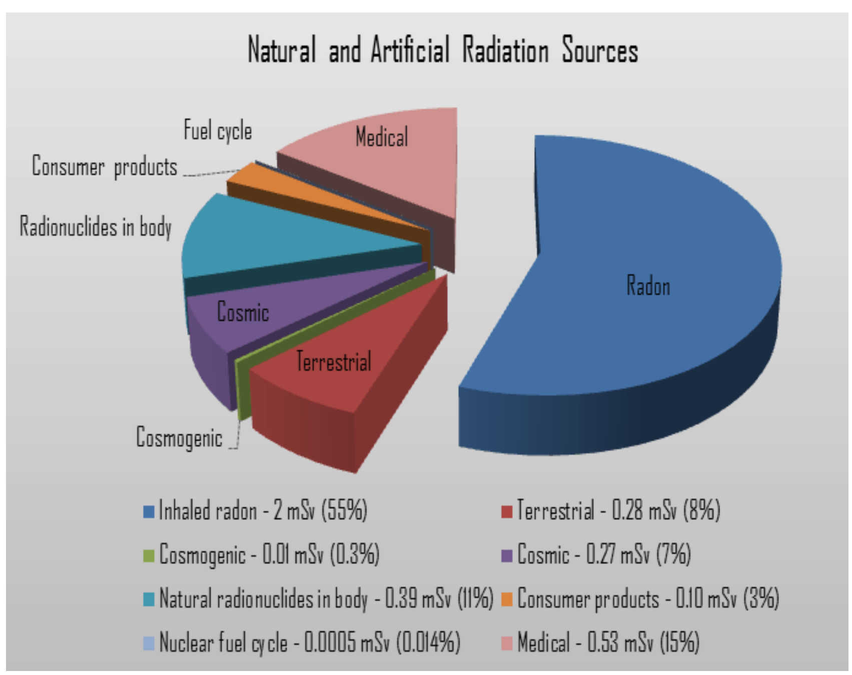
Considering these concerns, radiation protection measures have been instituted to curtail unnecessary radiation exposure and attenuate the deleterious impacts of ionizing radiation. The foremost goal of this initiative is to lay a robust groundwork in radiation protection and the knowledge of radiation sources. Moreover, it endeavors to equip individuals with the practical skills and essential tools requisite for careers in radiation protection and the prudent use of radiation sources, facilitated through a sequence of laboratory exercises.

Background

Sources and Types of Radiation

Radiation can be found everywhere which means that we are surrounded by radiation and this radiation can be divided in two types: Natural radiation and artificial radiation, Natural radiation can be from three sources: cosmic radiation in space, terrestrial radiation from environment, even human body has internal radiation from its birth although it is very small dose.

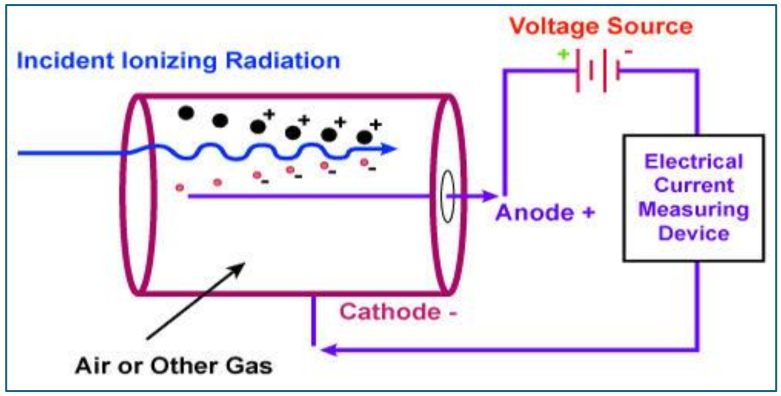
Artificial radiation can come from nuclear weapons, medical diagnostic and treatment, consumer products.



Radiation detectors

A radiation detector is referred to as a measuring instrument with the capability of evaluating the spectrum of energy of radiation. It is mainly considered to recognize the materials of radioactivity that are releasing the radiation and for doing this they use different techniques and so that detectors are categorized into different types as we have gas filled detector, Gieger Counter and what we interested in this program scintillation detector.

Gaseous Ionization Detectors

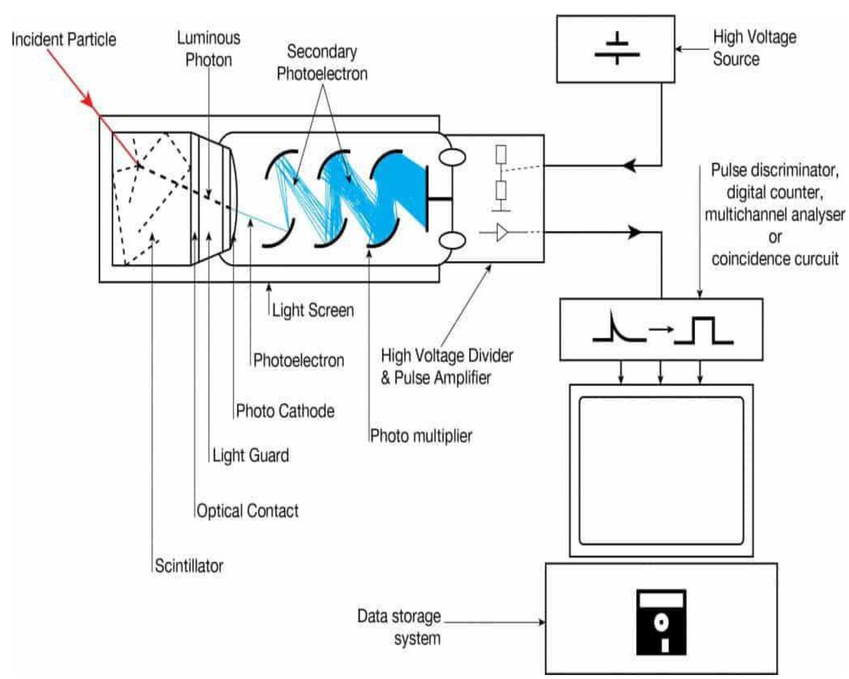


First let's talk about gas filled detector, Gaseous Ionization Detectors consists of a chamber filled with a suitable medium (air or a special fill gas) that can be easily ionized, inside the chamber exactly at the center there is a wire that considered to be the anode which means it has positive charge and the outer cylinder is also considered to be the cathode so the work principle is the utilizing of the ionization process of the gas inside the chamber after interaction with radiation which result in forming positive ion goes to the outer cylinder and electrons goes to the center wire which produce a electronic pulse on the detector signal that can be amplified and then recorded.

Gieger Counter

known as a **Geiger–Müller counter** or **G-M counter**, it is a type of gas filled detector and exactly like ionization chamber in work principle and design except that the ionization is considerably amplified within the tube by the Townsend discharge effect to produce an easily measured detection pulse, which is fed to the processing and display electronics. This large pulse from the tube makes the Geiger counter relatively cheap to manufacture.

Scintillation detector



A scintillation counter or scintillation detector is a radiation detector that uses the effect known as scintillation and to truly understand this detector we should know what scintillation is, when a particle (an electron, an alpha particle, an ion, or a high-energy photon) pass through transparent material it produces a flash of light which called scintillation and that process happen in the scintillator. 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.

It's working principle is When ionizing radiation (such as gamma rays, X-rays, or charged particles) interacts with the scintillator material, it absorbs energy and becomes excited, as a result this excited atoms emit visible light or ultraviolet (UV) photons- this light emission is proportional to the energy deposited by the radiation- The emitted photons are then collected by a photodetector, which converts them into an electrical sigNaI which then amplified and filtered and passed through analog to digital converters.

The process of converting photons into electronic signal is done by Photo Multiplier Tube using photo electric effect, (PMT) which consist of Photocathode (Converts photons to electrons), Dynodes (Electron multiplication stages), Final Anode (Generates pulses proportional to incident radiation energy), one of the detectors we are interested in are BGO detector and NaI detector.

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

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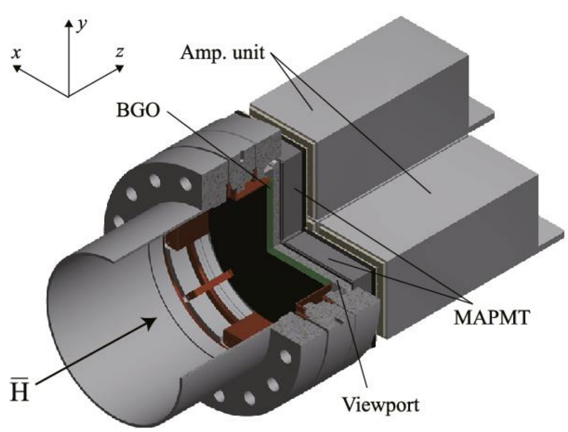
BGO Detector

BGO is a high Z, high-density scintillation material which make it a very efficient gamma-ray absorber, also due to its very high atomic number it results that it's photo fraction for gamma-ray absorption is high which results in using BGO detectors in applications where a high photo fraction is required like PET scanners or because of its high detection efficiency like Compton suppression spectrometers and it has very good peak-to-total ratios are observed.



BGO scintillator crystals are useful in diverse applications such as:

- Positron Emission Tomography (PET)
- Compton suppression spectrometers
- Specialist applications in high energy, nuclear, space and medical physics

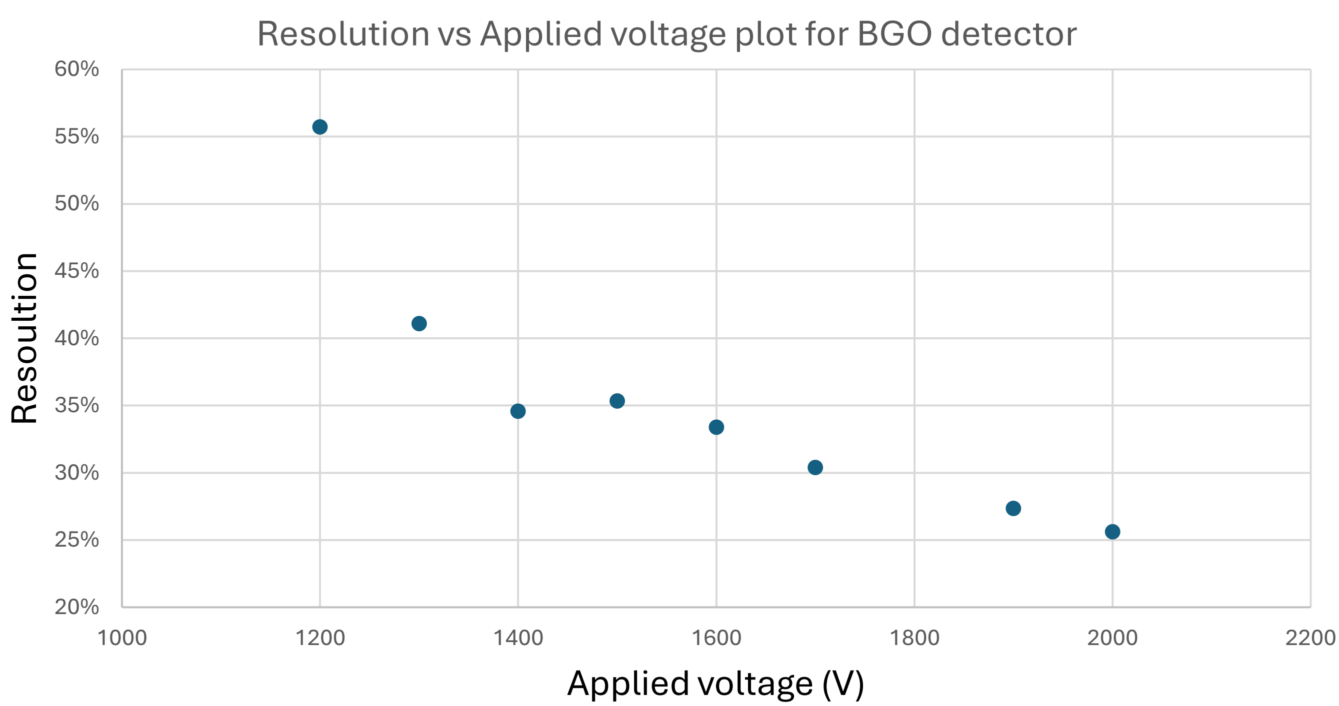
Task 1

in this task we applied different values of voltages (from 1200 V to 2000 V) to get the required information to calculate the resolution of the detector so each peak of the detector should give different Sigma(ɞ) and Mean at different voltage so we can calculate the resolution by

$$Resolution = \frac{\sigma}{Mean} \times 2.35$$

Applied Voltage	Sigma (ɞ)	Mean	Resolution (%)
1200	0.388363	1.6377	55.73
1300	0.23724	1.35642	41.10
1400	0.283154	1.92347	34.59
1500	0.4493	2.988	35.34
1600	0.626797	4.41265	33.38
1700	0.790699	6.11162	30.40
1900	1.24268	10.6781	27.35
2000	1.49012	13.6672	25.62

After we calculate the resolution now, we want to plot the relation between the resolution vs applied voltage.

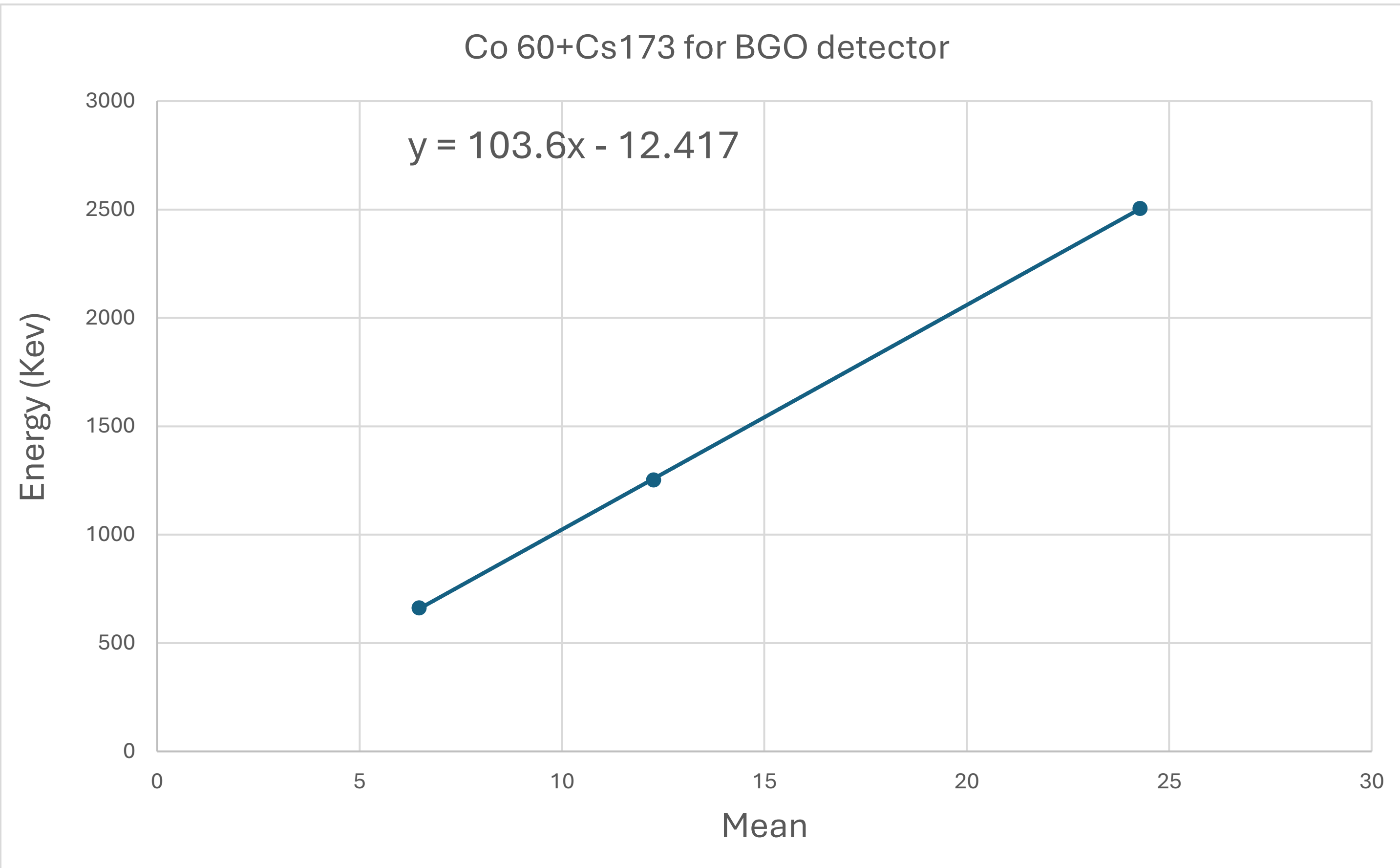


Task 2

- **Calibration of BGO detector**

  in this task our goal is to calibrate the BGO detector by using peaks of both Co 60 and Cs 137 like the previous task we will fit each peak of Cs 137 and Co 60 but this time to get the Mean only and from the spectrum of both CS 137 and Co 60 we know the energy of each peak, so we now have a table of Mean and energy of each peak.

Mean	6.47135	12.2664	24.2806
Energy (Kev)	662	1252.5	2505



So now we have the equation of the detector **y = 103.6x - 12.417** as (X) represent the mean or channel of the detector and (Y) represent the energy of the peak which we can use to know which isotope we have.

- **Unknown source experiment**

Now we have an unknown source that we need to know which isotope is it, so by using Root we can fit a Gauss function into the spectrum of the unknown energy to get the channel number or mean then we can substitute in the BGO detector's calibration line equation in (x) to get the peak energy value.

Mean	Energy (Kev)	Element
0.291655	17.495208	Pd-103
0.383419	27.0029529	Ba-140 or Sn-199m
0.47864	36.8688804	Br-80m or Te-125m
0.582593	47.6395379	Pb-210
1.03364	94.3728954	Dy-165 or Th-234

NaI detector

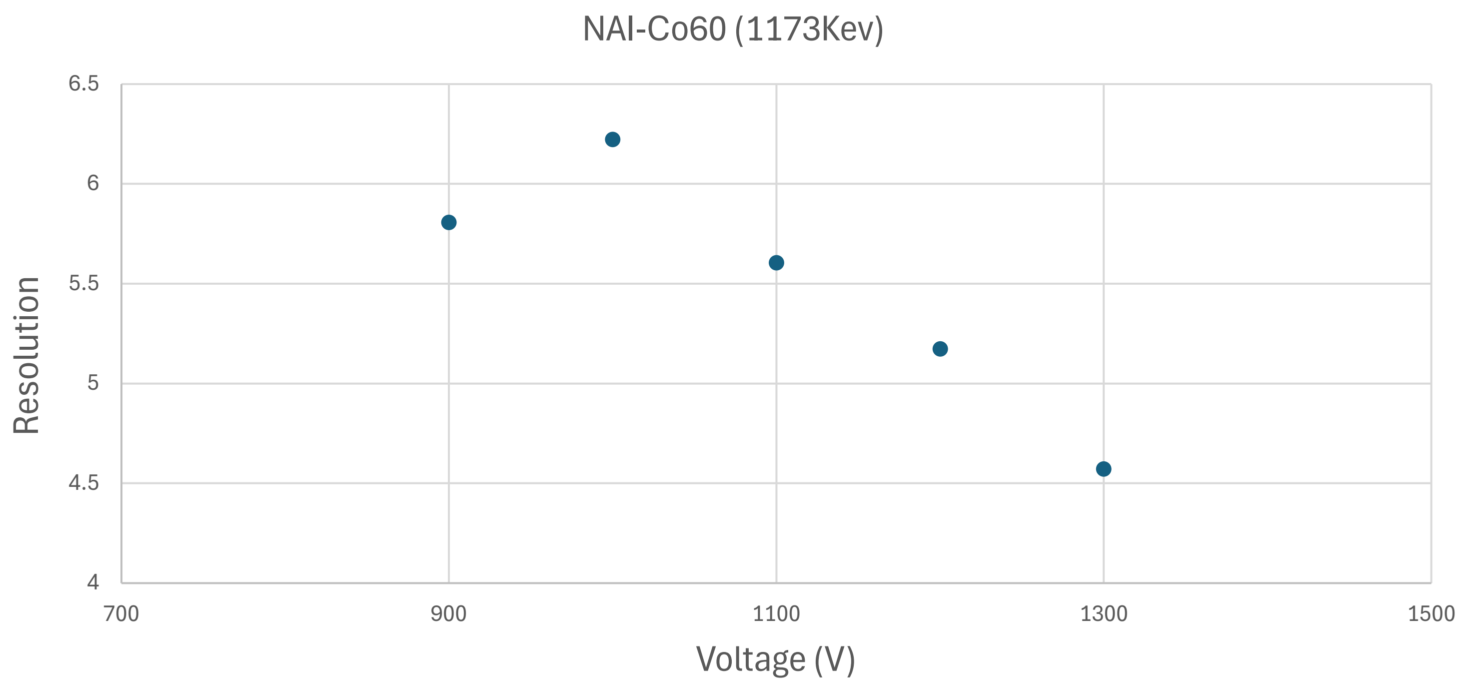
NaI detectors are a kind of radiation detector where the scintillator material is a crystal of sodium iodide doped with thallium (NaI (Tl)) and they are widely used in radiation detection due to their high scintillation efficiency. These detectors, available in various sizes and forms, are adept at detecting low to intermediate energy gamma rays. The scintillation process within the NaI crystal is triggered by gamma ray interaction, resulting in light emission as electrons return to their ground state. This light is then converted into electrical signals by a Photomultiplier Tube (PMT), making NaI detectors essential for applications like Time-of-Flight measurements, positron lifetime studies, PET scans, and nuclear physics research. Their versatility and efficiency make them invaluable in fields such as nuclear medicine, environmental monitoring, and radiation safety.

Task 3

Like the first task of BGO detector here we need to plot the relationship between the Resolution and applied voltage (from 900 volt to 1300 volt) and that after getting the mean and sigma values and calculating the resolution but the problem is that unlike BGO detector we will find that there are two peaks at 1173 Kev and at 1333 Kev so we will find the resolution for both of them at each value of applied voltage

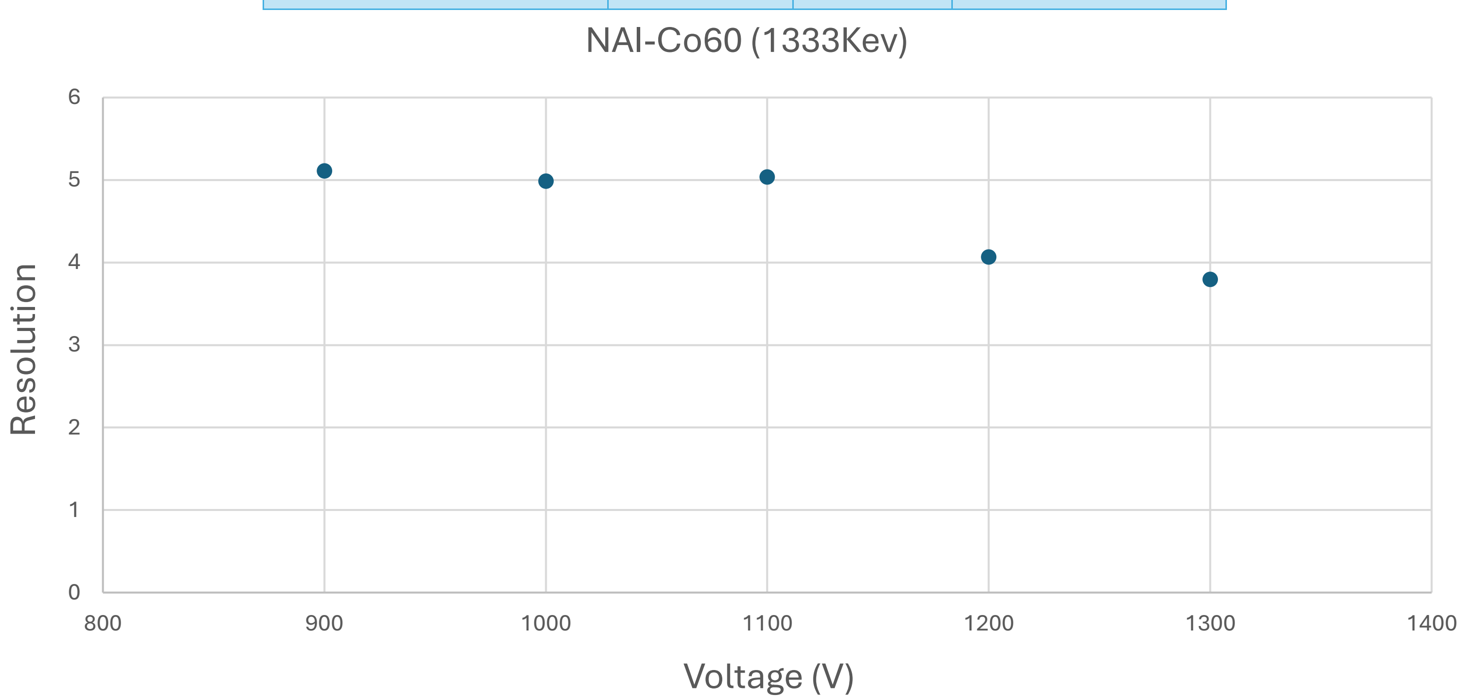
1. For energy 1173 Kev peak:

Applied voltage (V)	Sigma (σ)	Mean	Resolution (%)
900	0.585338	23.6912	5.8061
1000	1.07462	40.5891	6.2218
1100	1.56844	65.7633	5.6047
1200	2.17185	98.6794	5.1722
1300	2.67253	137.374	4.5718



2. For 1333 Kev peak:

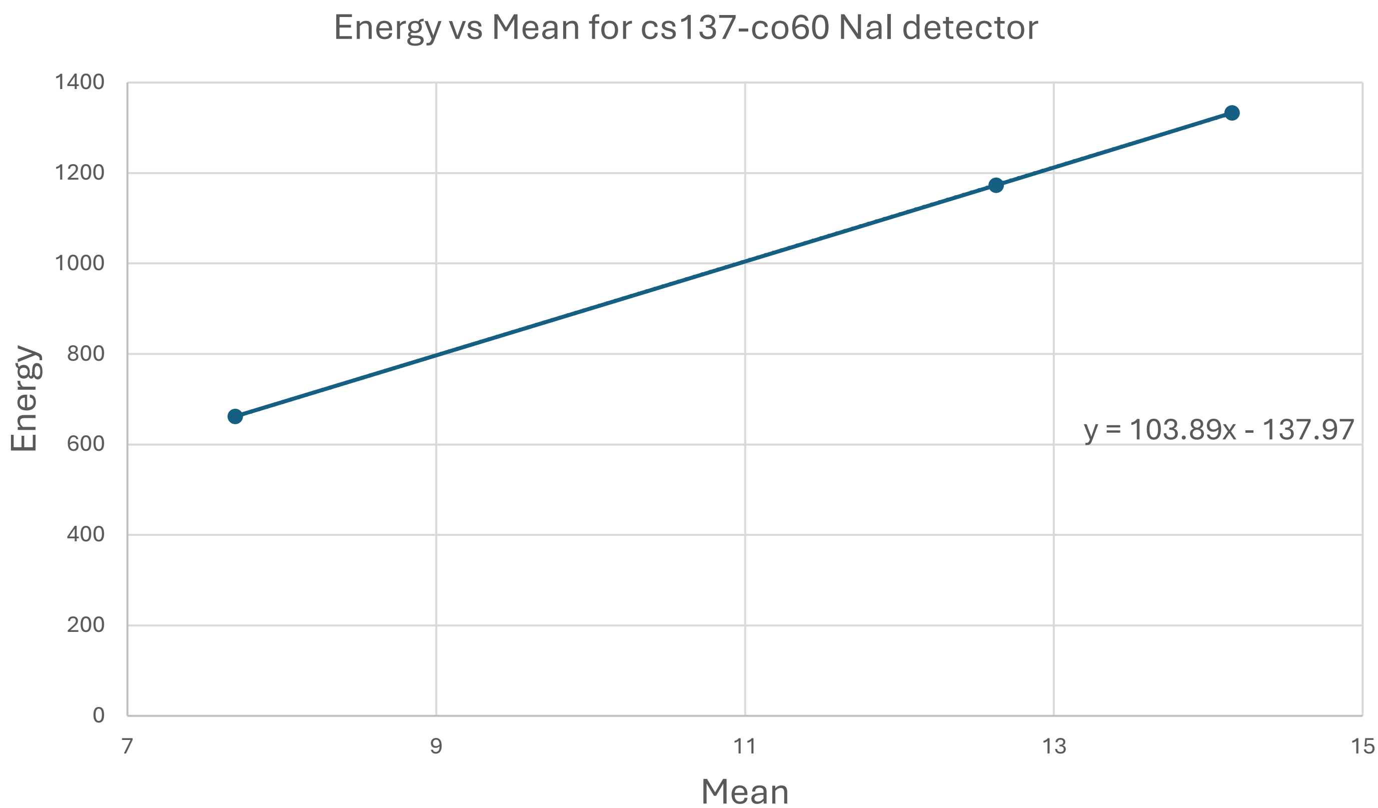
Applied voltage (V)	Sigma (σ)	Mean	Resolution (%)
900	0.578083	26.5717	5.1126
1000	0.965397	45.4703	4.9894
1100	1.57075	73.2639	5.0383
1200	1.87908	108.506	4.0697
1300	2.40536	148.826	3.7981



- ## Calibration of NaI detector

In the calibration of NaI detector, we will do the same steps as BGO First we will get the mean or channel number by fitting the gaussian plot and we know the energy of this peak and plot them to get the detector line equation.

Energy (Kev)	662	1173	1333
Mean	7.69885	12.6256	14.1544



So now we have the equation of the detector y = 103.89x - 137.97as (X) represent the mean or channel of the detector and (Y) represent the energy of the peak which we can use to know which isotope we have.

- ## Unknown source experiment

Now we have an unknown source that we need to know which isotope is it, so by using Root we can fit a Gauss function into the spectrum of the unknown energy to get the channel number or mean then we can substitute in the NaI detector's calibration line equation in (x) to get the peak energy value.

Mean	Energy (Kev)	Expected Source
4.53693	333.4	Hf-180m
6.93023	582.0	Tl-208
8.18248	712.1	Sb-124
14.0138	1317.9	Ca-47

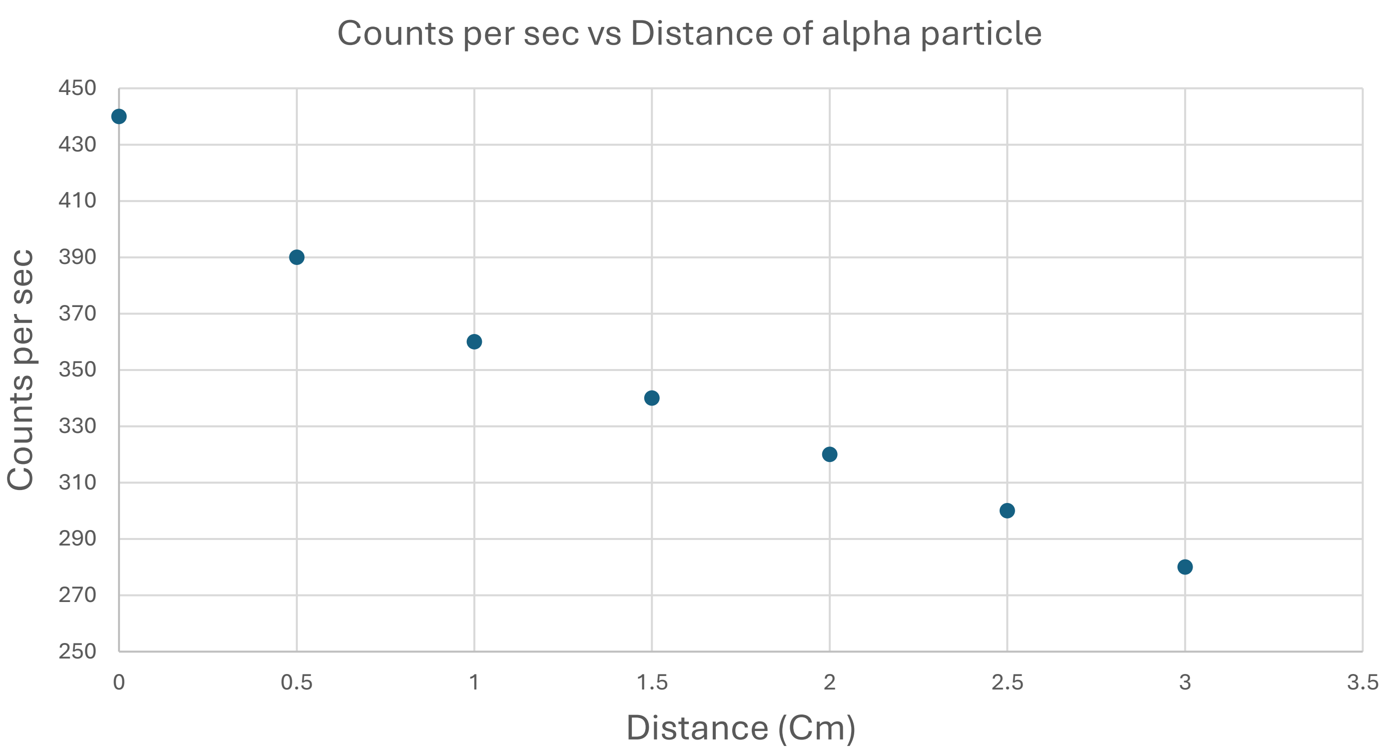
Alpha Particles

Alpha particles are a type of ionizing radiation composed of two protons and two neutrons, the same as a helium-4 nucleus. They are commonly produced through the process of alpha decay, where an unstable atomic nucleus releases an alpha particle to become a more stable element. Due to their relatively large mass, alpha particles have a low penetration depth and can be stopped by a sheet of paper or even the outer layer of human skin. However, they can cause significant damage to biological tissues if ingested or inhaled. Alpha particles have been instrumental in advancing our understanding of atomic structure and are utilized in various applications, from smoke detectors to cancer treatment.

<u>Task 4</u>

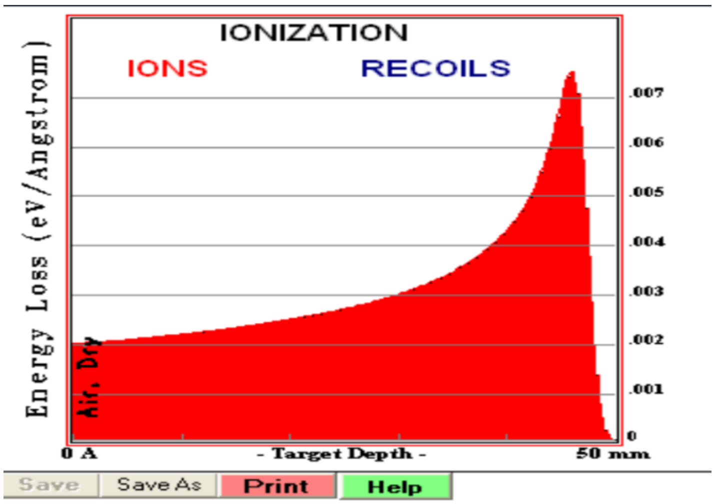
In this task we want to determine the range of alpha particle in air and the source of this alpha particles is Pu-239 and the energy of alpha particles is 5.5 MeV and it will be detected by Plastic detector with applied voltage 2000V and we will increase the distance between the source and detector to see the impact of changing the distance between them on the number of alpha particle that will reach the detector as it's expected that if the distance increase the number of alpha particles that reach the detector will decrease

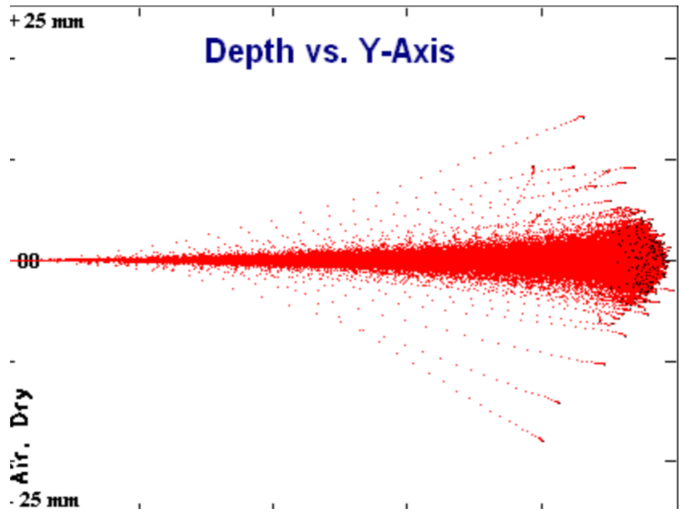
Counts/sec	440	390	360	340	320	300	280
Distance(cm)	0	0.5	1	1.5	2	2.5	3



Using SRIM in calculating α the depth vs. y-axis and the ionization (Bragg peak/curve)

The Stopping and Range of Ions in Matter (SRIM) is a software package used to calculate the stopping and range of ions passing through various materials. It's based on a Monte Carlo simulation method and is widely used in the fields of ion implantation, radiation damage, and material science research. SRIM provides valuable data on ion interactions, including penetration depth, sputtering rates, and energy deposition. (this results at energy of α = 1500 Kev)





Attenuation coefficient

Its known that gamma rays can go through anything which make it import when designing shields as the material of the shield should stop gamma rays before reaching the body so we need to define something named attenuation coefficient which represent the rate of reducing in the number of gamma rays as they pass through material and it's not the same values for all material so we need to calculate it by the equation

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

As: **(**I) represent the current intensity of gamma rays

(I_0) represent the initial intensity of gamma rays.

(μ) represent the attenuation coefficient.

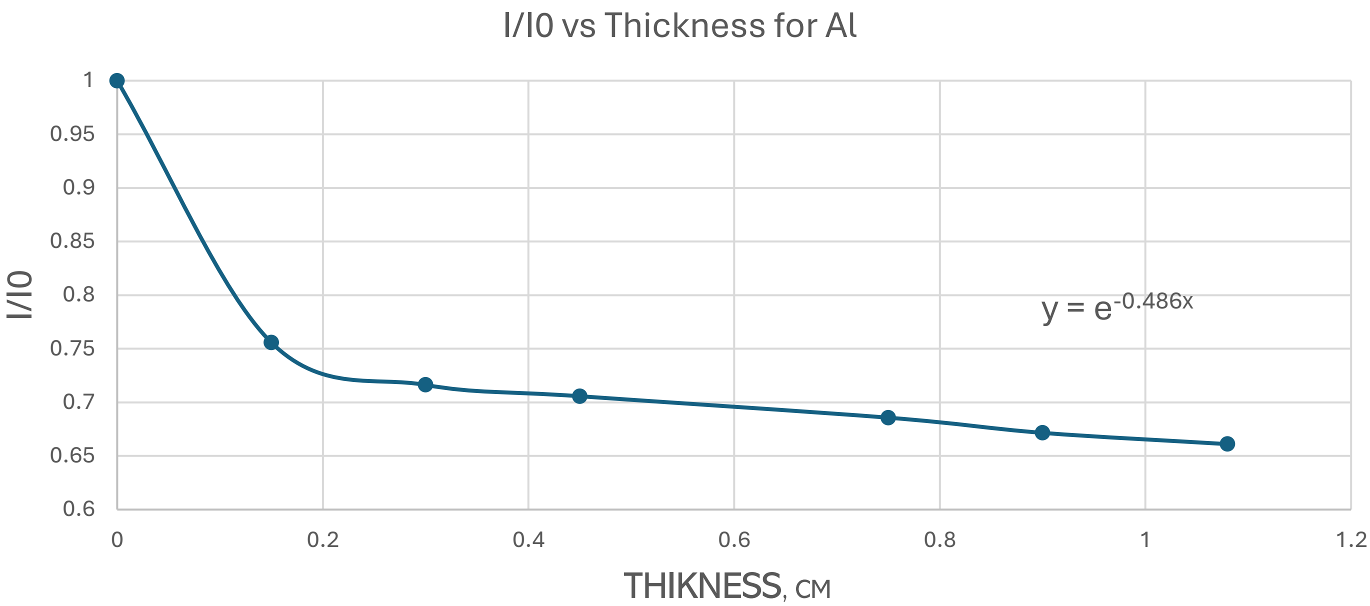
(X) represent the thickness of the material

Task 5

We have some values of I/I_0 and X for Al and Cu and we need to plot the relation between them as the slope will be the attenuation coefficient

- **For Al**

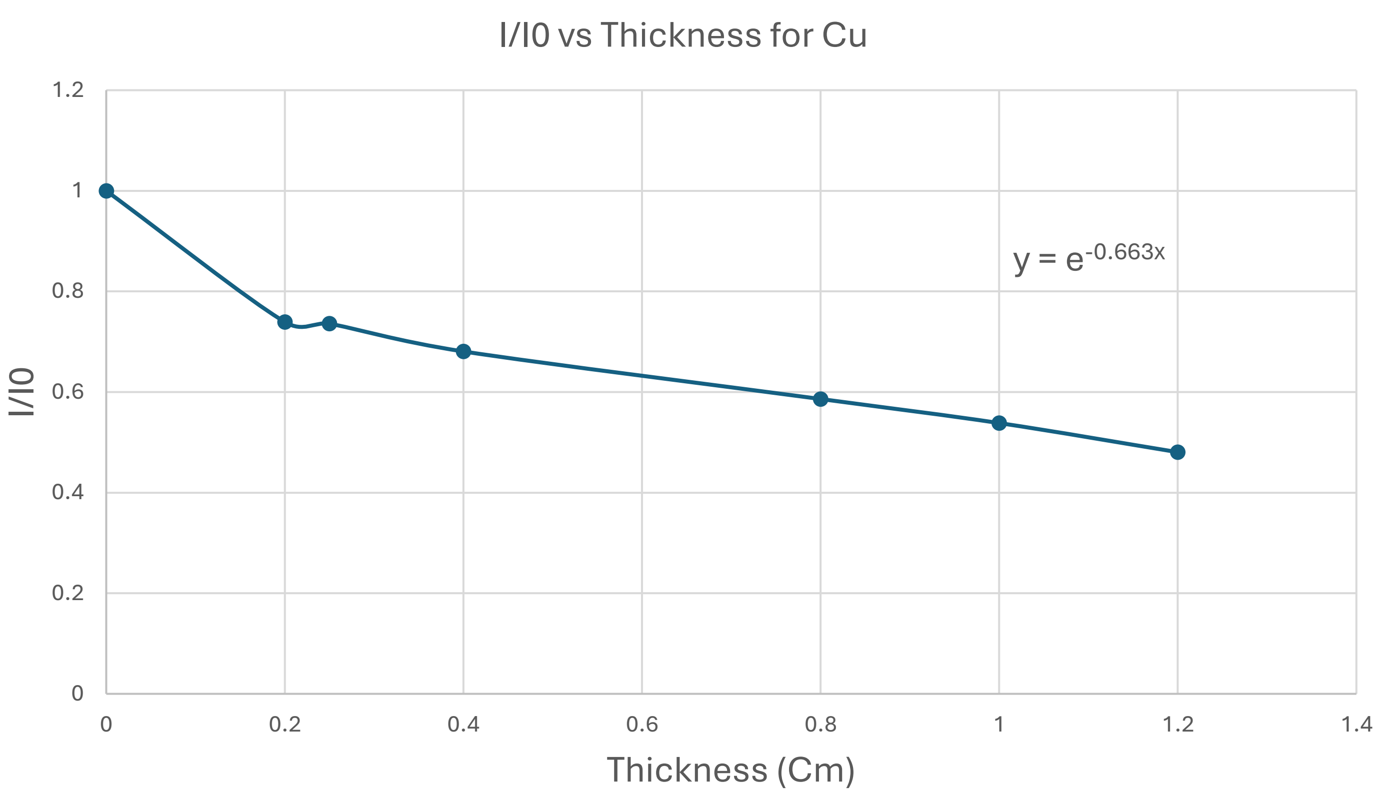
$\frac{I}{I_0}$	0	0.15	0.3	0.45	0.75	0.9	1.08
Distance(cm)	1	0.75573	0.71623	0.70569	0.68569	0.67155	0.66103



The slope is the Attenuation coefficient μ=0.486 cm2 /gm

- **For Cu**

$\frac{I}{I_0}$	0	0.2	0.25	0.4	0.8	1	1.2
Distance(cm)	1	0.73931	0.7357	0.68065	0.58611	0.53827	0.48042



The slope is the Attenuation coefficient μ=0.663 cm2 /gm

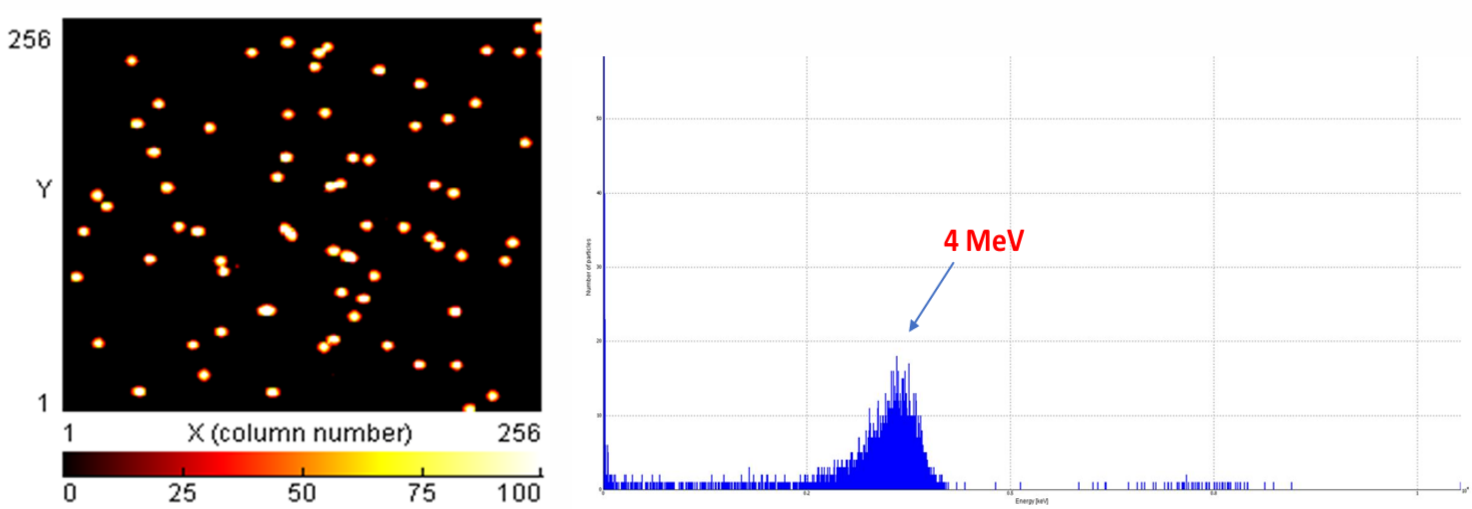
Pixel detector

Semiconductor pixel detectors are It is an advanced detector like a digital camera which has high resolution and they based on semiconductors (such as germanium or silicon) and operate by depleting a semiconductor diode with a reverse bias voltage. Incoming ionization particles create charge, which is collected by the electric field and processed by read-out electronics, it is used for registration different types of radiation (x- ray, gamma, electron, neutron and charged particles)

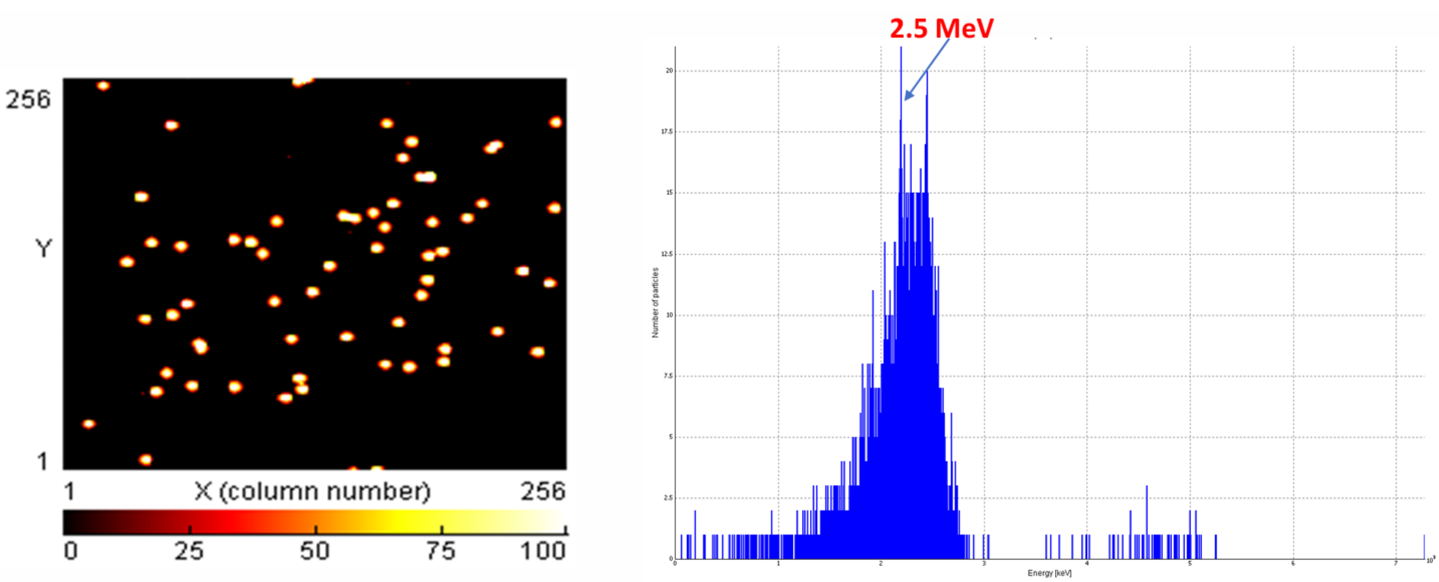
Task 6

General dimensions of a pixel detector:

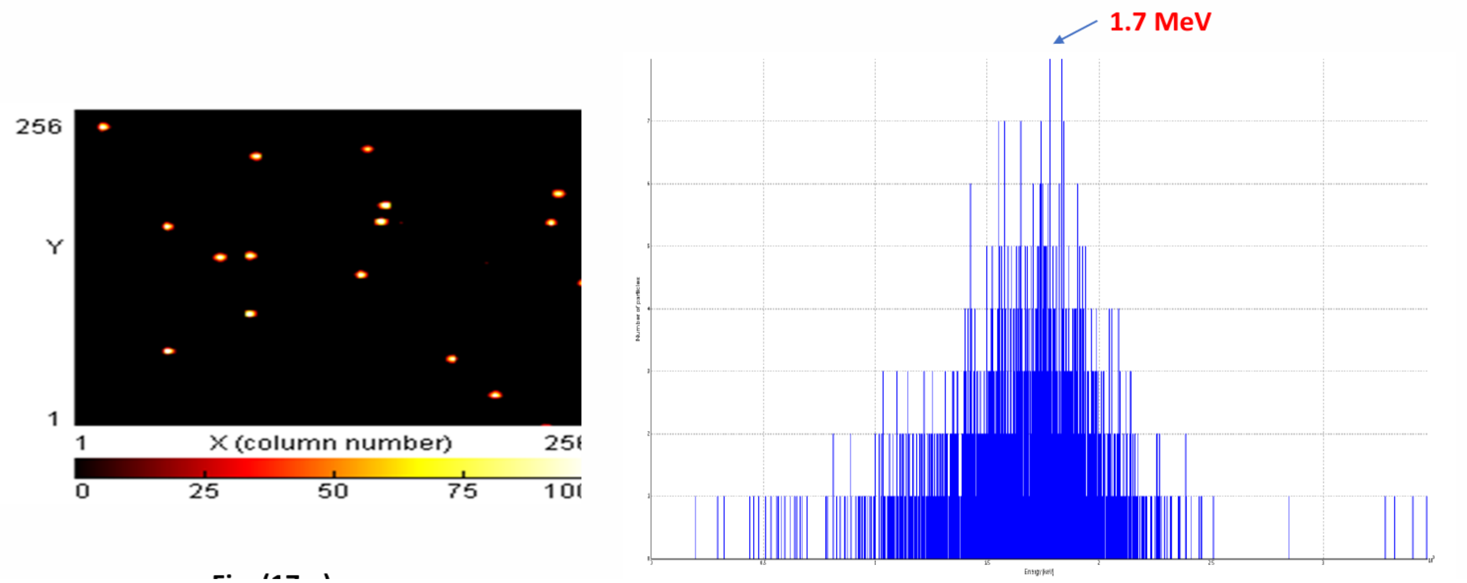
- Sensor size: 1.5 x 1.5 cm
- Number of pixels: 256 x 256 pixels (65,536 pixel)
- Pixel size: 55 µm x 55 µm



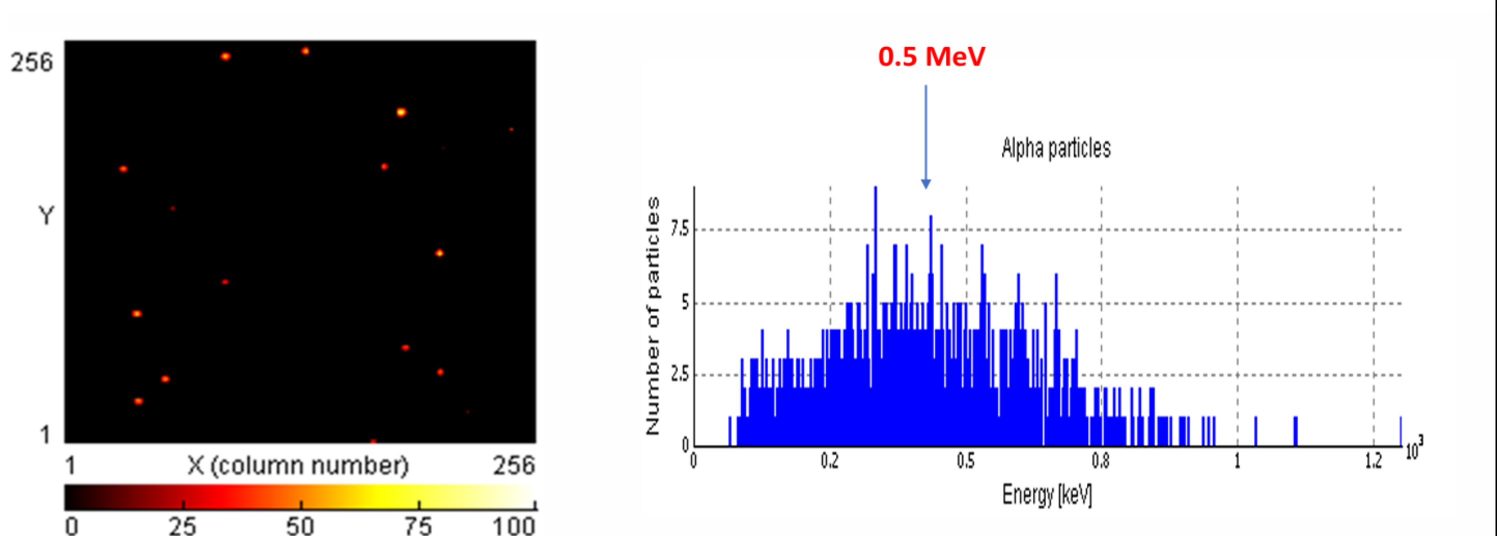
ABSORPTION OF ALPHA PARTICLE ENERGY IN THE AIR AT ZERO CM



ABSORPTION OF ALPHA PARTICLE ENERGY IN THE AIR BY MOVING THE THE ALPHA SOURCE AWAY BY 1 CM

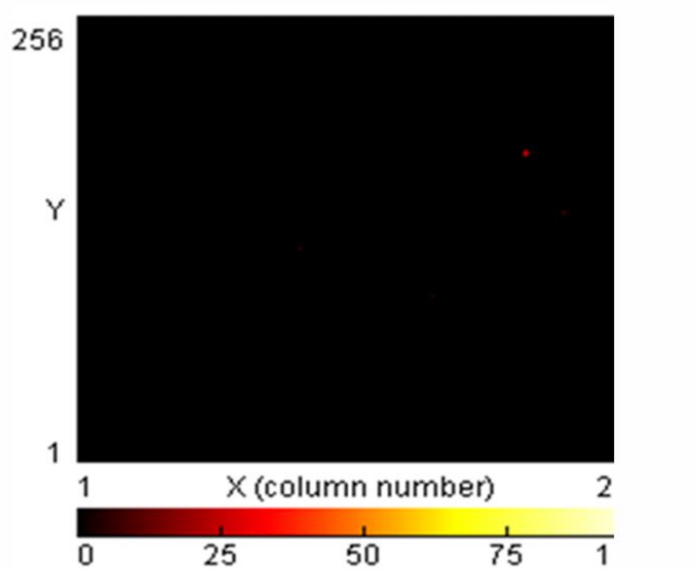


ABSORPTION OF ALPHA PARTICLE ENERGY IN THE AIR BY MOVING THE ALPHA SOURCE AWAY BY 2 CM



ABSORPTION OF ALPHA PARTICLE ENERGY IN THE AIR BY MOVING THE ALPHA SOURCE AWAY BY 2.5 CM

When the positioner blocks are about 3 cm away, no alpha particles are detected anymore which means that the maximum range for alpha particles is 3 Cm.



ABSORPTION OF ALPHA PARTICLE ENERGY IN THE AIR BY 3 CM

Conclusion

The program was very useful as it provide the required information and skills about radiation protection and safety as first it give us a good introduction about radiation and it's types then started to introduce the detectors ,it's working principles and types and then learned us about using useful program like Root which is a program we used in fitting the gaussian spectrum to get important calculations for our next tasks in the program, the program learned us how to get the resolution of the detector, calibrate it and identifying the unknown sources focusing on the BGO detector and NaI detector .

It also discussed some information about alpha particle, it's characteristics and taught us how to calculate its range and introduce us to another useful program called Srim which illustrate that it's intensity decrease with increases the distance and finally with one of the most important and interesting tasks was the calculating of the attenuation coefficient especially for Aluminum and Copper which touched me that the intensity of gamma rays decreases while increasing the thickness of the shielding and taught me about pixel detector

Appendix

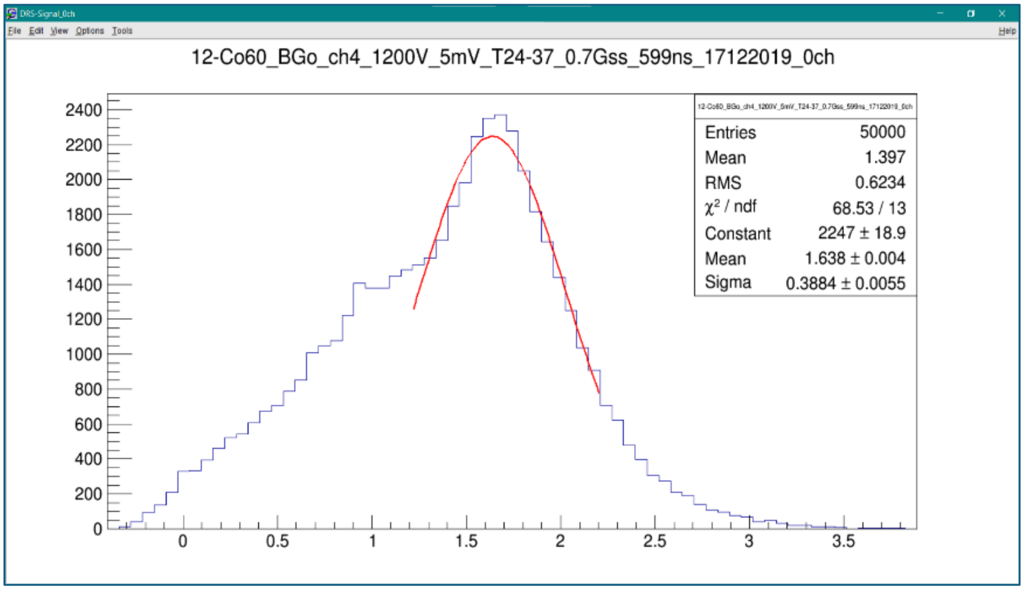


FIGURE 1:BGO DETECTOR1200 APPLIED VOLTAGE

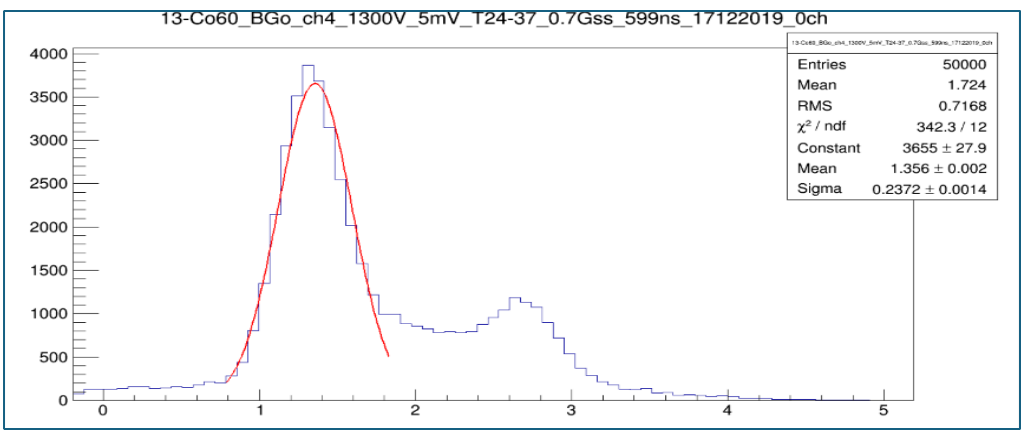


FIGURE 2:BGO DETECTOR 1300 APPLIED VOLTAGE

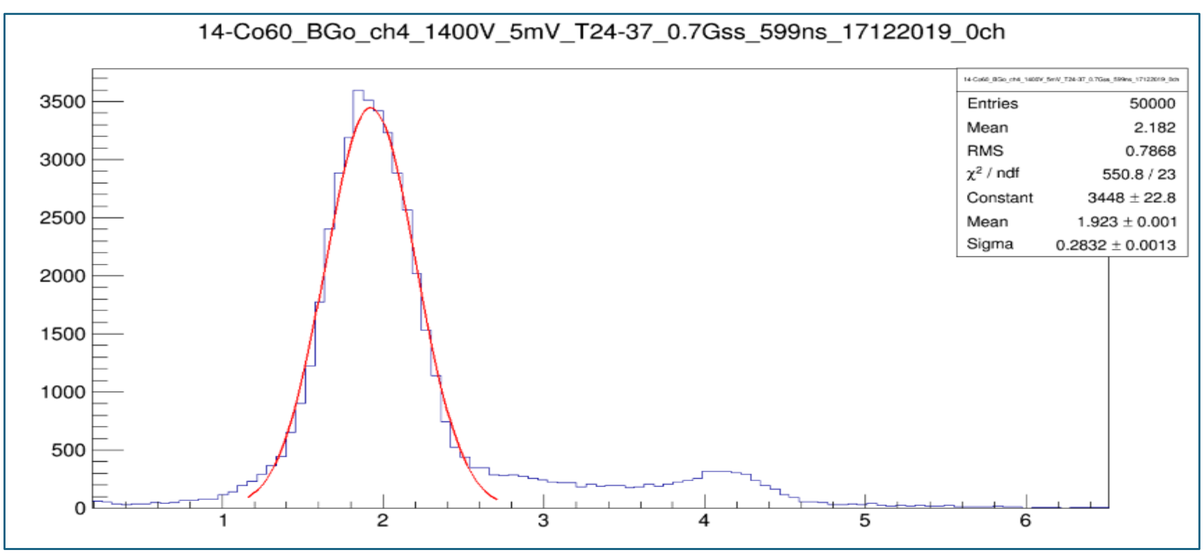


FIGURE 3:BGO DETECTOR1400 APPLIED VOLTAGE

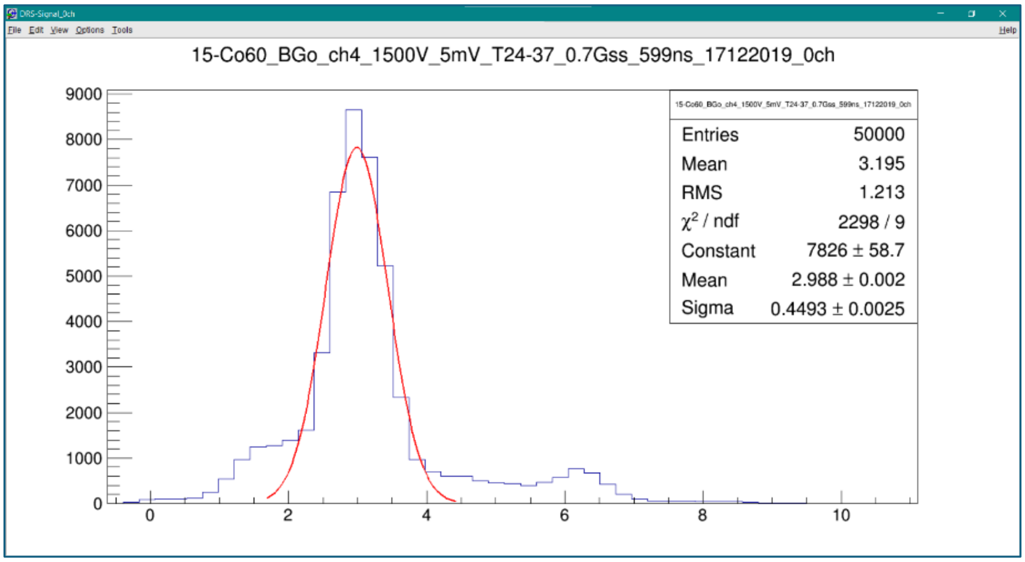


FIGURE 4:BGO DETECTOR 1500 APPLIED VOLTAGE

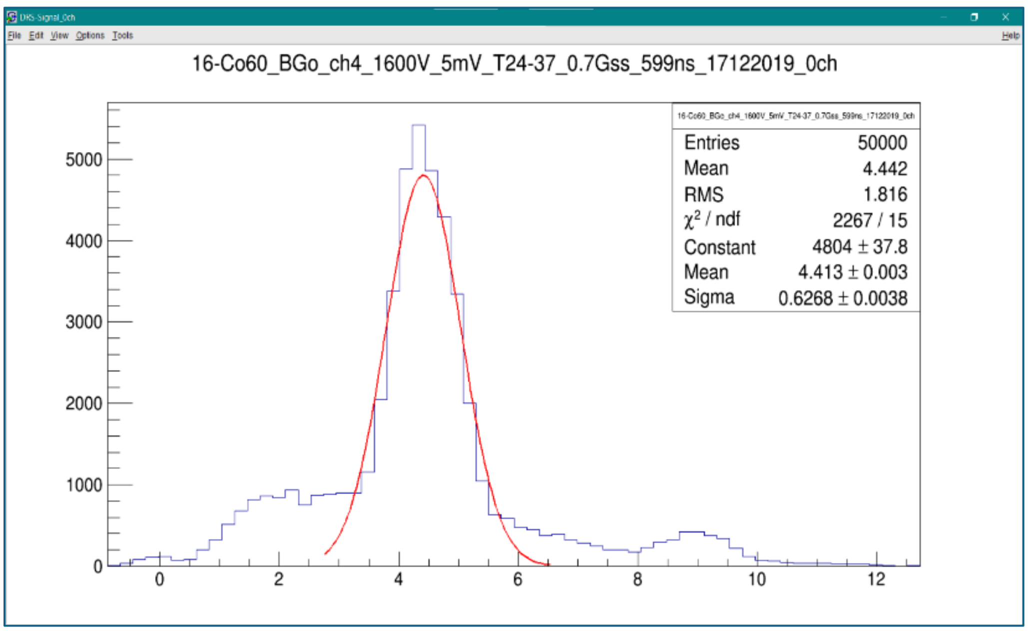


FIGURE 5:BGO DETECTOR 1600 APPLIED VOLTAGE

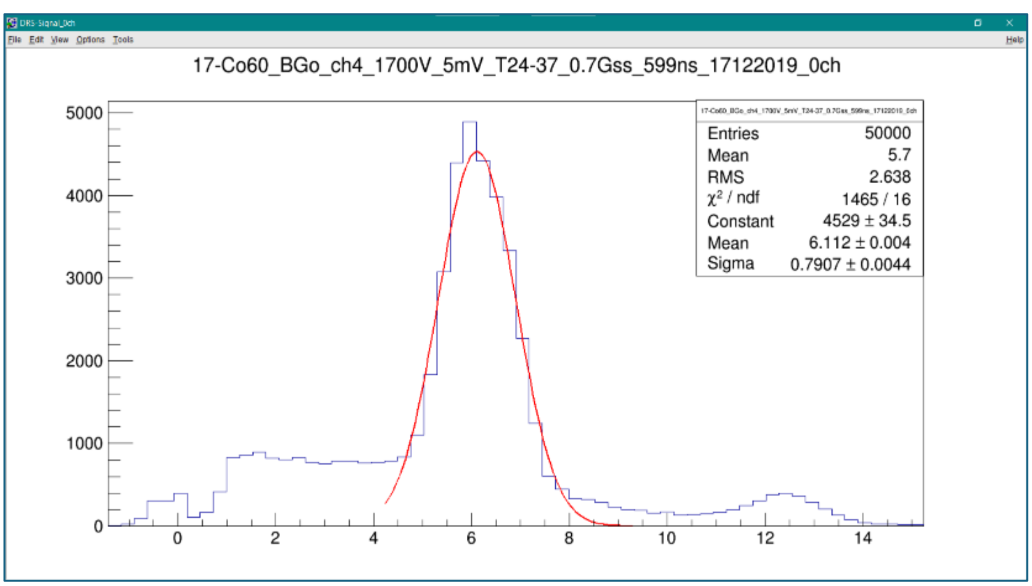


FIGURE 6: BGO DETECTOR 1700 APPLIED VOLTAGE

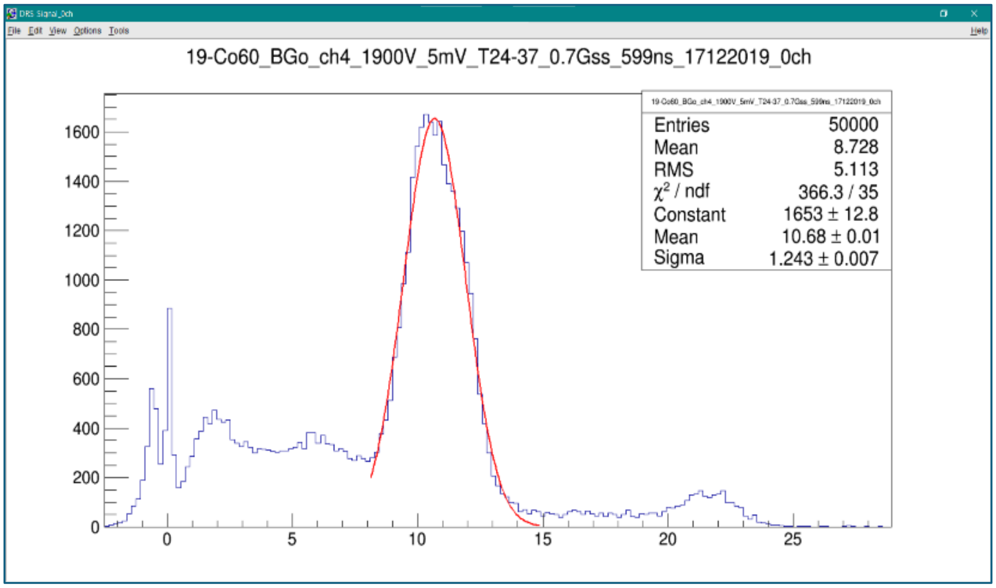


FIGURE 5:BGO DETECTOR 1900 APPLIED VOLTAGE

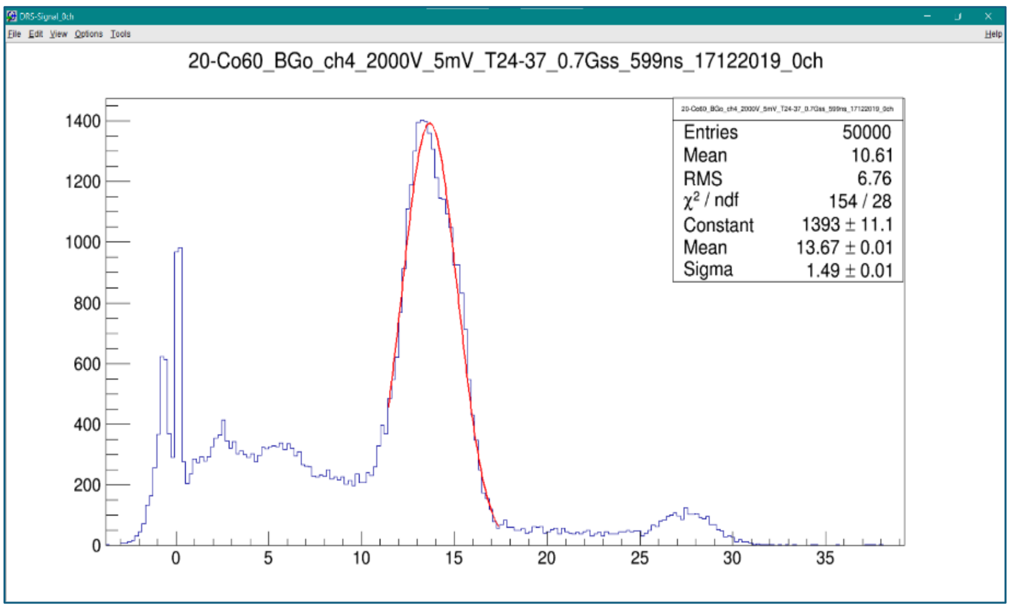


FIGURE 8: BGO DETECTOR 2000 APPLIED VOLTAGE

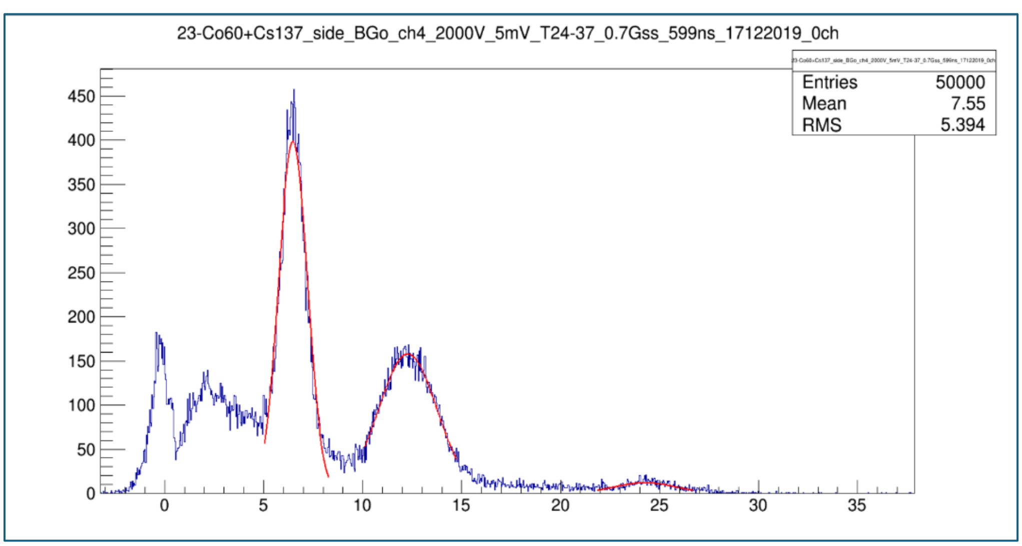


FIGURE 9: CALIBRATION OF BGO DETECTOR

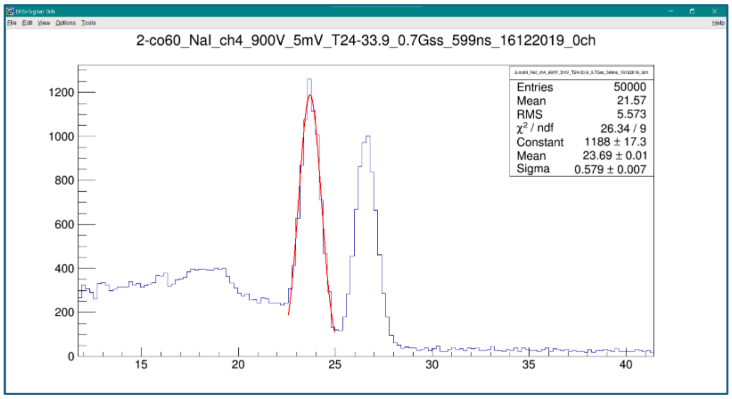


FIGURE 6:NAI DETECTOR 900 APPLIED VOLTAGE 1173 KEV

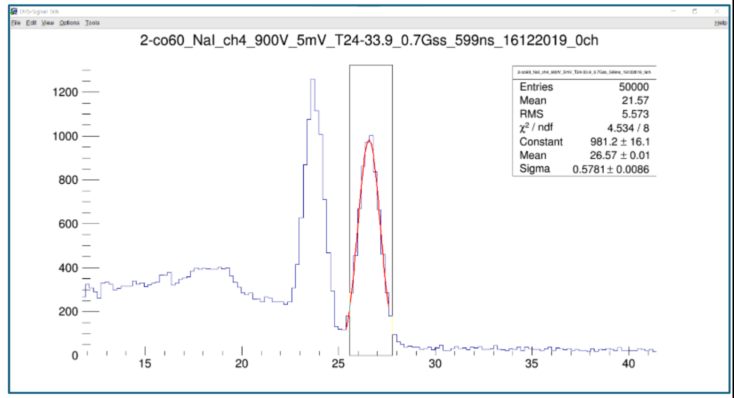


FIGURE 7:NAI DETECTOR 900 APPLIED VOLTAGE 1333 KEV

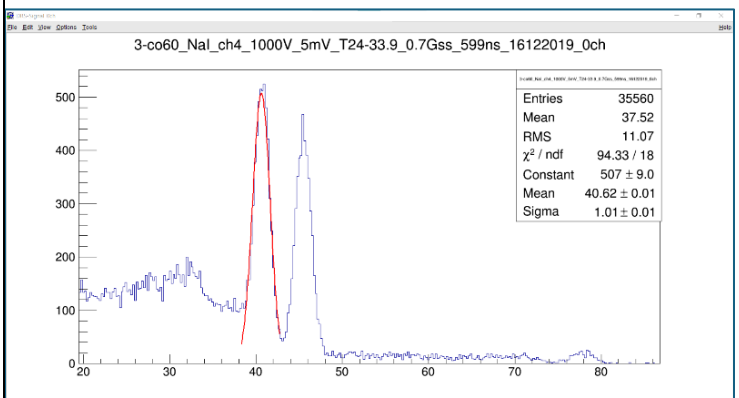


FIGURE 8:NAI DETECTOR 1000 APPLIED VOLTAGE 1173

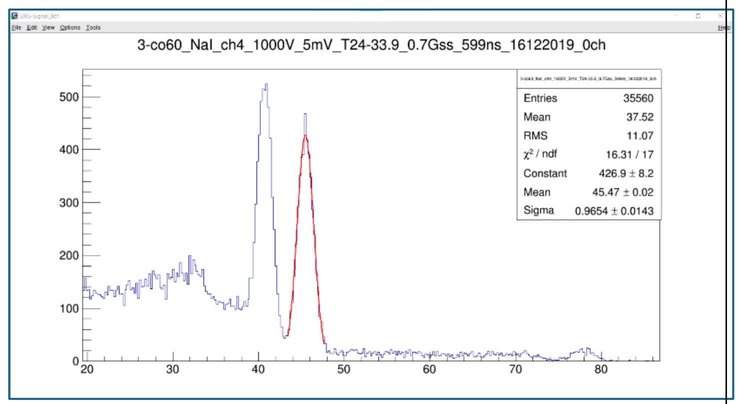


FIGURE 13: NAI DETECTOR 1000 APPLIED VOLTAGE 1333

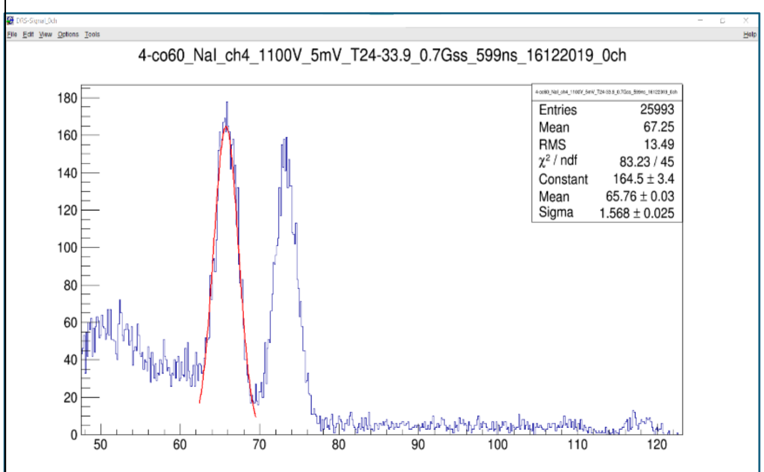


FIGURE 14: NAI DETECTOR 1100 APPLIED VOLTAGE 1173

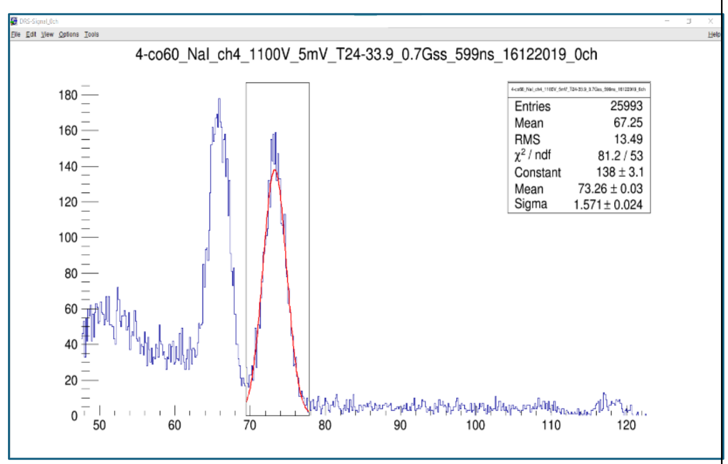


FIGURE 15: NAI DETECTOR 1100 APPLIED VOLTAGE 1333

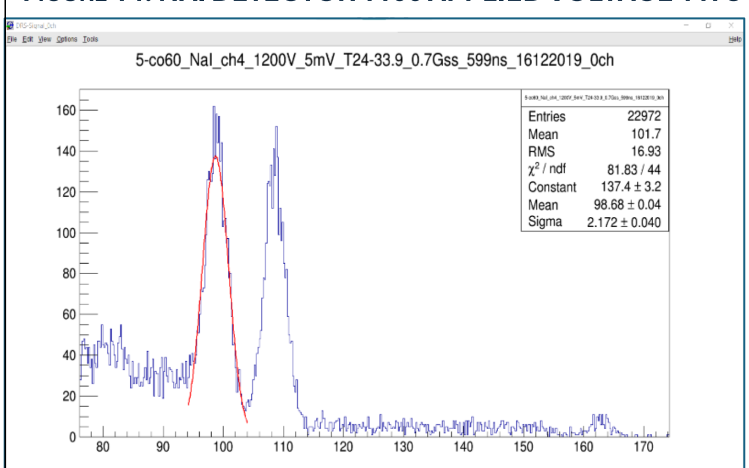


FIGURE 16: NAI DETECTOR 1200 APPLIED VOLTAGE 1173

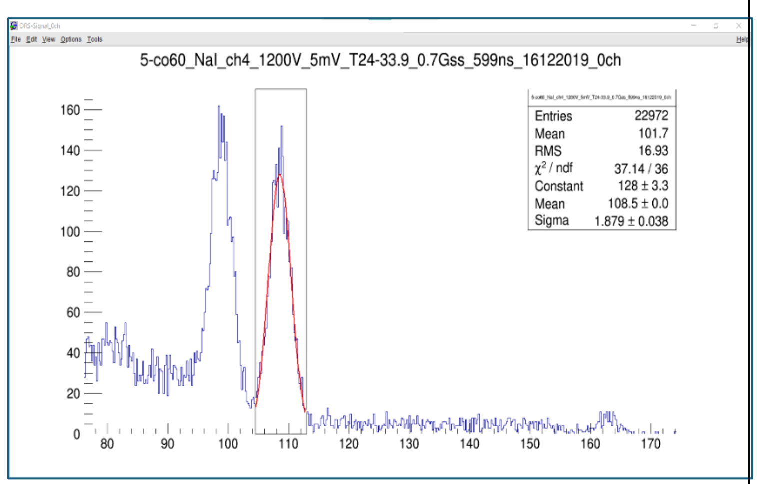


FIGURE 17: NAI DETECTOR 1200 APPLIED VOLTAGE 1333

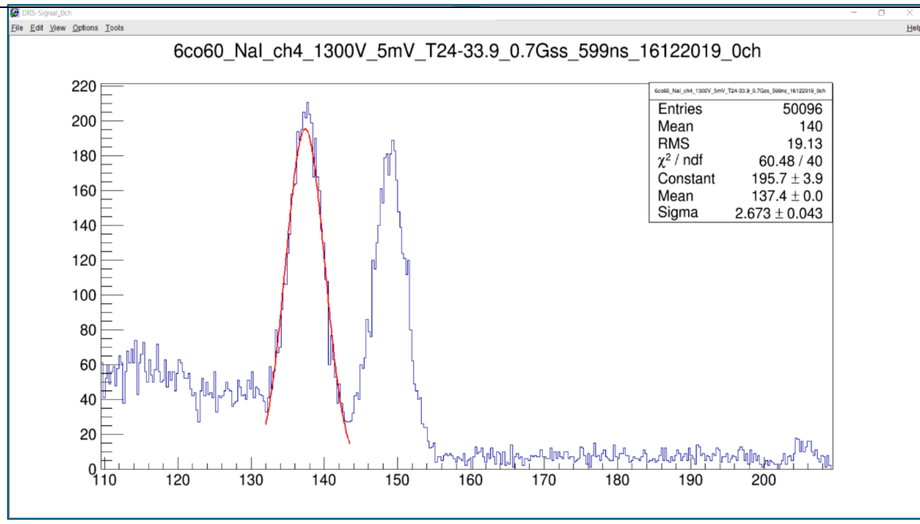


FIGURE 18: NAI DETECTOR 1300 APPLIED VOLTAGE 1173 KEV

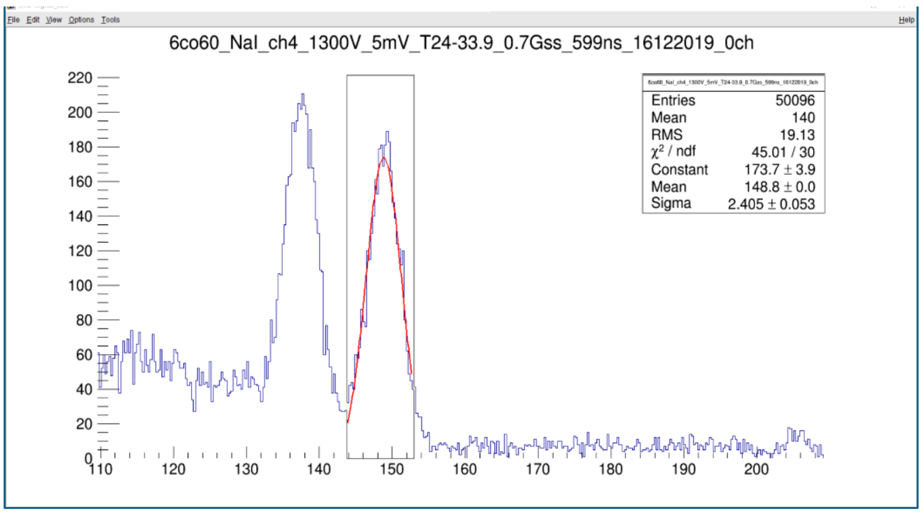


FIGURE 19: NAI DETECTOR 1300 APPLIED VOLTAGE 1333

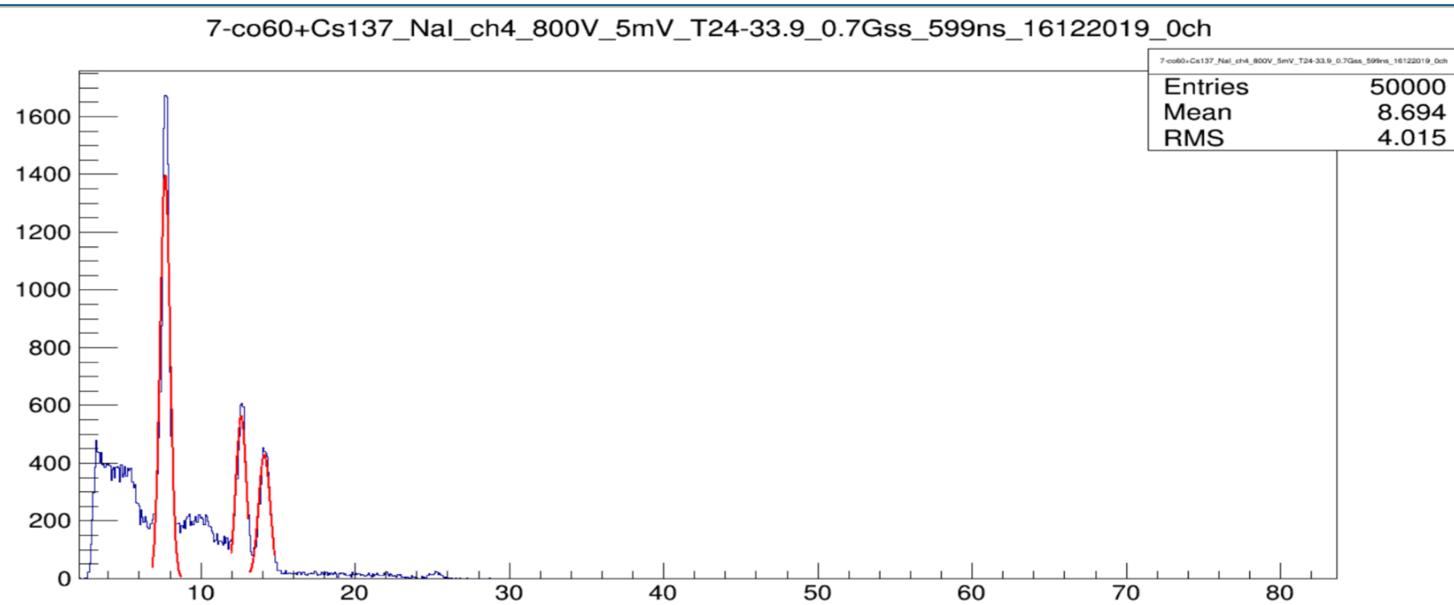


FIGURE 20: CALIBRATION OF NAI DETECTOR