INTEREST JINR PROJECT

Wave 8

Radiation Protection and the Safety of Radiation Sources

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(13 February - 26 March 2023)

Abstract

This report summarizes the work done throughout the wave 8 in INTEREST JINR program under the project "Radiation Protection and the Safety of Radiation Sources". The knowledge gained from this project can be classified into two main sections, firstly theoretically in which we learnt about 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. Secondly, a hands-on experience in dealing with radiation data through identifying 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.

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Introduction

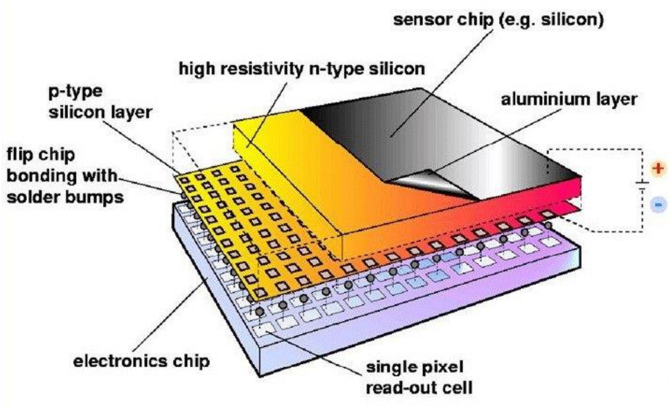
Radiation is a regular phenomenon that can be found in our daily lives, and it has both beneficial and harmful effects. Radiation sources, whether natural or man-made, can pose a significant threat to human health and the environment if not appropriately managed. Therefore, radiation protection and the safety of radiation sources have become critical issues of concern globally. The INTEREST JINR project “Radiation Protection and the Safety of Radiation Sources” aims to develop a solid foundation in radiation protection and the fundamental safety of radiation sources. The project also intends to prepare those who will work in the field of radiation safety and the safe use of radiation sources in their nations with the fundamental knowledge, abilities, and tools. The project involves several laboratory experiments on fundamental nuclear physics, radiation-matter interaction, dosimetry, and shielding. This report is divided into three parts. The first part is theoretical information about the different definitions, terms, detectors used, and software. The second part contains the practical part, in which different data handling approaches were introduced during the tasks. A conclusion about the entire project is included in the final part.

Part 1 Theoretical definitions

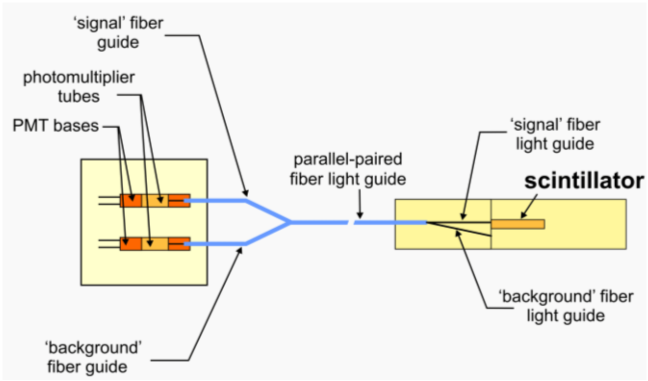
In this section we will provide some information about the different terms, in addition to an explanation for the different detectors and software that have been used during this report.

1. Nuclear radiation: It refers to the energy particles or electromagnetic waves that are released by the nuclei of atoms. This radiation can take many forms, including alpha particles, beta particles, gamma rays, X-rays, and neutrons. It has many beneficial applications, including in medicine, energy production, and scientific research.
2. Ionizing nuclear radiation: the radiation that has enough energy to remove electrons from atoms or molecules, which can have harmful effects on living organisms.
3. Radioactivity: It is the property of certain types of atomic nuclei to spontaneously emit particles or electromagnetic radiation. This emission of energy is a result of the unstable nature of the nucleus, which seeks to achieve a more stable configuration by releasing excess energy in the form of radiation.
4. Half-life time: The rate at which radioactive decay occurs is measured by the half-life of the radioactive material, which is the amount of time it takes for half of the original sample to decay.
5. Radiation dose: It is a measure of the amount of energy absorbed by an object or organism exposed to radiation.
6. Radiation gray (Gy): The unit of measurement for radiation dose which represents the absorption of one joule of energy per kilogram of matter.
7. Scintillation detectors: They are devices used to detect and measure ionizing radiation by converting the energy of the radiation into light. They consist of a scintillator material, which emits light when it is excited by ionizing radiation, and a photodetector, which converts the emitted light into an electrical signal. The scintillator material is typically a crystalline or plastic material that contains atoms with high atomic numbers, such as iodine, caesium, or sodium, that are capable of absorbing high-energy radiation and emitting light. They are used in a wide range of applications, including in nuclear medicine for imaging and detecting radioisotopes in the body, in high-energy physics experiments for particle detection and identification, and in radiation monitoring for environmental and occupational health and safety

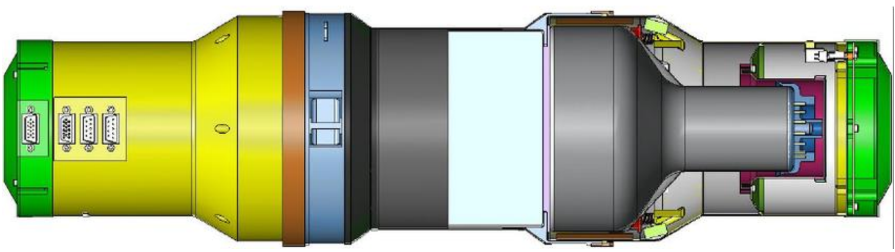
8. Pixel detectors: They are radiation detectors that consist of a two-dimensional array of individual detector elements, or pixels. Each pixel is sensitive to radiation and can detect the passage of charged particles or photons. Pixel detectors are used to make precise measurements of the position and energy of particles, and they are often used in particle tracking detectors.



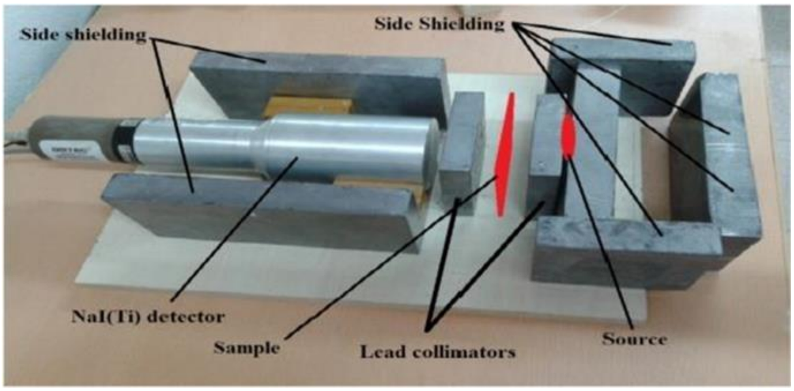
9. Plastic detectors: They are radiation detectors that use plastic materials as the sensitive medium. When radiation passes through the plastic, it causes the plastic molecules to ionize, producing a small electrical signal. The size of the signal is proportional to the energy of the radiation. Plastic detectors are often used in dosimetry and radiation protection, as they can provide a simple and inexpensive way to measure radiation exposure.



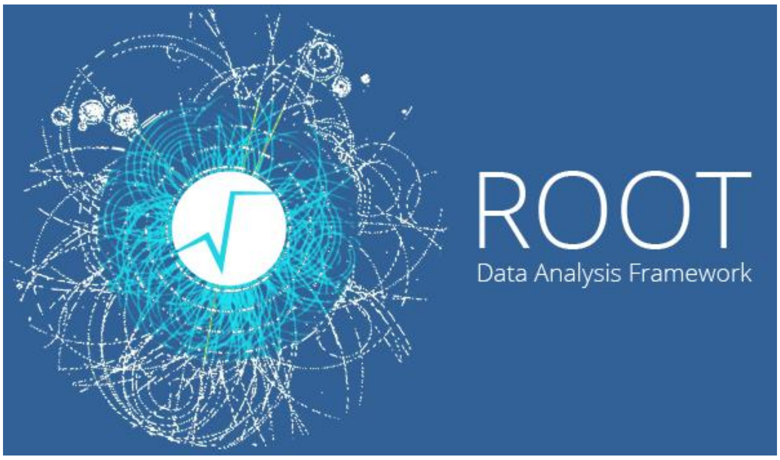
10. BGO detectors: BGO stands for bismuth germanate, which is a scintillation material used in detectors for detecting and measuring high-energy gamma rays and X-rays. BGO detectors consist of a crystal of bismuth germanate, which is a dense and high atomic number material that is capable of absorbing 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.



11. NAI detectors: 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. 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.



12. ROOT: It is a software framework developed by CERN (European Organization for Nuclear Research) for high-energy physics data analysis and visualization. It is an open-source project that is widely used by researchers in the field of particle physics and other related areas. It provides a comprehensive set of libraries and tools for storing, analysing, and visualizing large amounts of data. It supports a wide range of data formats and provides a variety of analysis and statistical methods.



13. SRIM: SRIM (Stopping and Range of Ions in Matter) is a computer program used to calculate the interactions of energetic ions with matter. It is widely used in the fields of materials science, nuclear engineering, and radiation physics. It is used to study the effects of ion irradiation on materials, such as the creation of defects, lattice damage, and ion implantation. It is also used to model the behaviour of ions in various materials, such as semiconductors, metals, and biological tissues.

Part 2 Practical tasks

In this section, we present the work we have done during the project's period. This work included the following tasks:

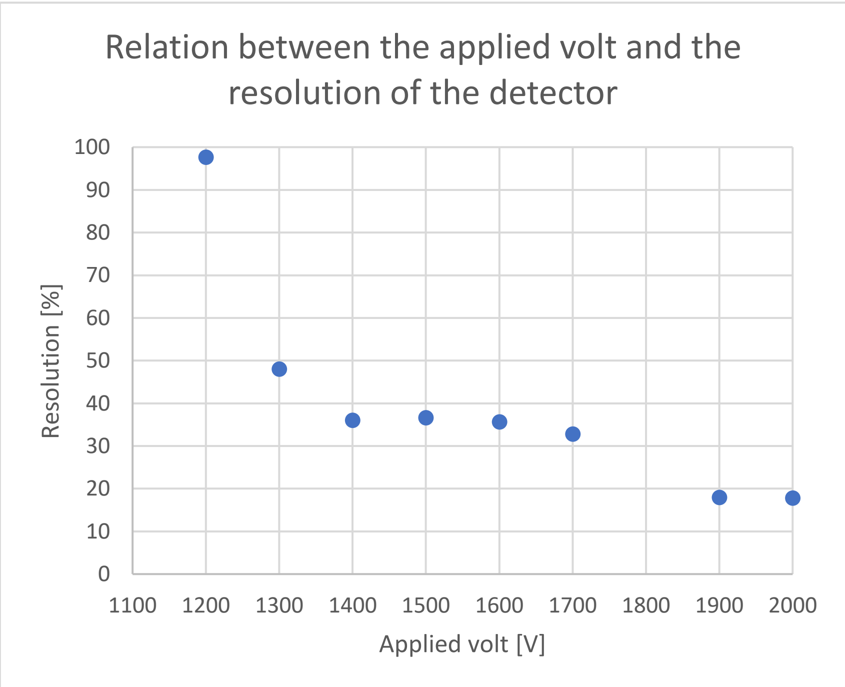
Task 1: The relationship between the resolution of BGO detector and the applied voltage.

Description: To analysis the given graphs of the detected Cobalt-60's radiation when different volt is applied using BGO detector. Then a relation between the applied voltage and the resolution of BGO detector to be plotted.

Steps: To calculate the resolution using this formula (BGO Resolution [%] = $\frac{\sigma * 2.35}{mean} * 100$), we need to find σ & mean from the graphs using the following steps:

1- Fit panel to the required area to be studied.
2- Choose the required Data Set to be same as the studied graph.
3- Crop the required area (from X-coordinate) then fit it.
4- Set the parameters to be able to see σ and mean.

Answer's summary:



	Applied volt	σ	Mean	Resolution [%]
1	1200	0.59	1.42	97.64
2	1300	0.395	1.935	47.97
3	1400	0.295	1.924	36.03
4	1500	0.465	2.984	36.62
5	1600	0.667	4.4	35.62
6	1700	0.849	6.083	32.80
8	1900	1.225	16.035	17.95
9	2000	1.55	20.49	17.78

Comment: From the relationship graph between the applied voltage and the resolution of the detector, we can see that the resolution of the OBG detector decreases as the applied voltage increases. Additionally, when one peak appeared on the graphs, there was a slight decrease in the resolution, however when two peaks appeared a significant decrease appeared as on points 2 and 7 on the graph. More details for the graphical representations can be found in the attachments.

Task 2: Distinguishing an unknown radioactive element.

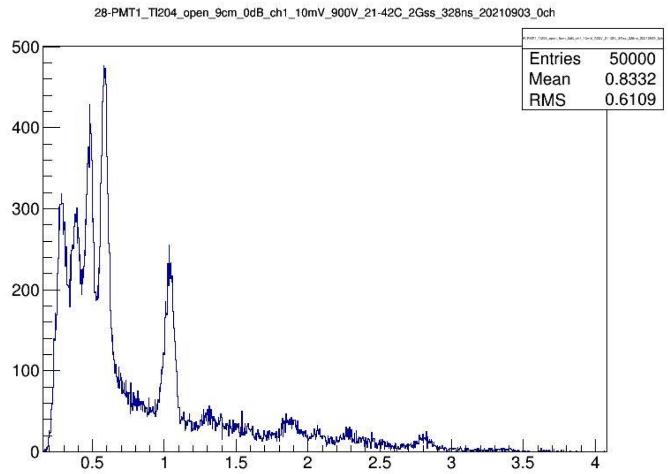
Description: Calibration (fitting) for the graph and distinguishing the unknown radioactive element.

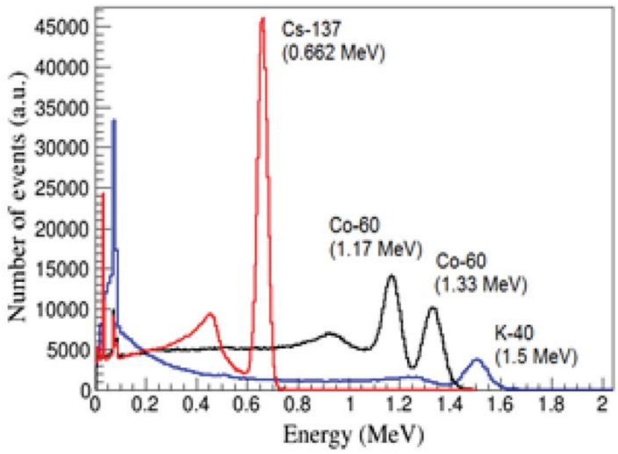
Steps: To the graph and get the equation we will use the following steps:

1- Neglect the noise at the beginning of the graph (1^{st} four peaks)
2- Fit panel to the required area to be studied.
3- Choose the required Data Set to be same as the studied graph.
4- Crop the required area (from X-coordinate) then fit it.
5- Set the parameters to be able to see the mean (Number of channels).
6- Get the energy value of the unknown element from the internet.

Answer's summary:

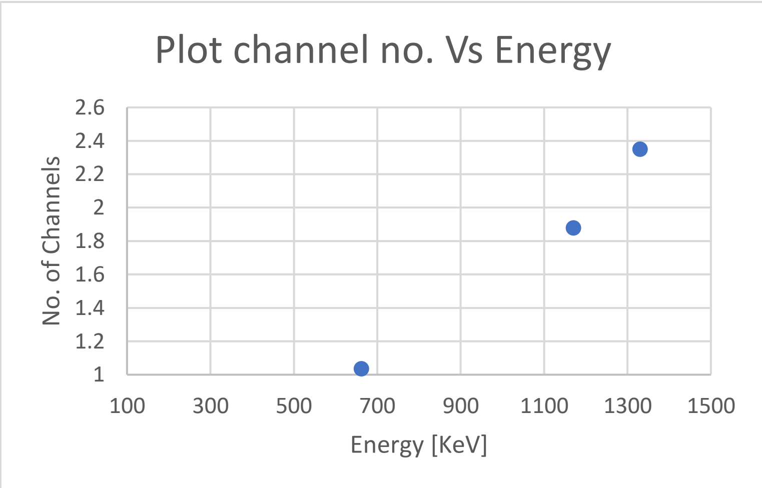
The given picture of the unknown source (left) in comparison to the expected source (Cs-137 and Co-60). Fitting of the graph can be found in appendix B.





The plot of the unknow radioactive element:

Peak	Element	Energy [keV]	Number of channels (The mean value of the peak from our graph)
1	Cs-137	662	1.035
2	Co-60	1170	1.879
3		1330	2.35



Task 3-A: Establishing the relation between the applied volt and the resolution of NaI detector.

Description: To analysis the given graphs of the detected Cobalt-60's radiation when different volt is applied using NaI detector. Then a relation between the applied voltage and the resolution of NaI detector to be plotted.

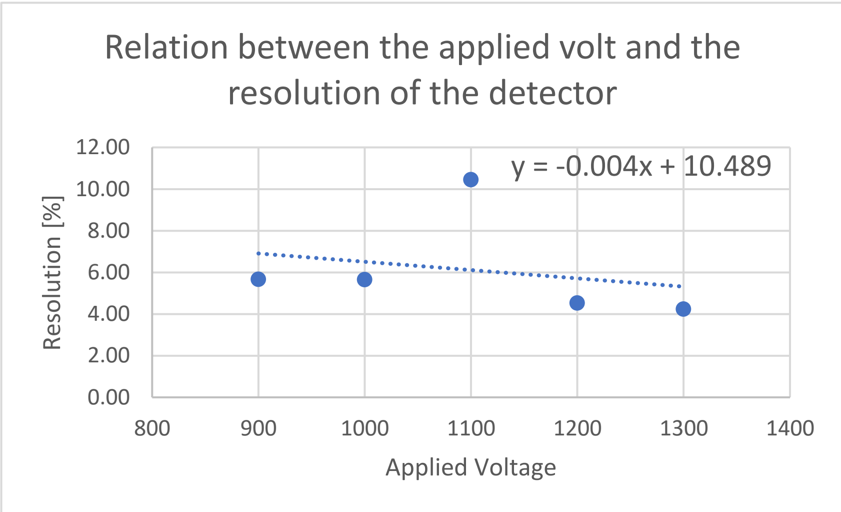
Steps: To calculate the resolution using this formula

(NaI Resolution [%] = $\frac{\sigma * 2.35}{mean} * 100$), we need to find σ & mean from the graphs using the following steps:

1- Fit panel to the required area to be studied.
2- Choose the required Data Set to be same as the studied graph.
3- Crop the required area (from X-coordinate) then fit it.
4- Set the parameters to be able to see σ and mean.

Answer's summary:

	Applied volt	σ	Mean	Resolution [%]
1	900	0.6065	25.115	5.67
2	1000	1.035	43.045	5.65
3	1100	3.091	69.505	10.45
4	1200	1.997	103.6	4.53
5	1300	2.584	143.05	4.24



Comment: From the relationship graph between the applied voltage and the resolution of the detector, we can see that the resolution of the NaI detector slightly decreases as the applied voltage increases. Except when a 1100V is applied, we saw an increase in the resolution of the NaI detector. The graphical fitting can be found in appendix C.

Task 3-B: distinguishing an unknown radioactive element using NAI detector.

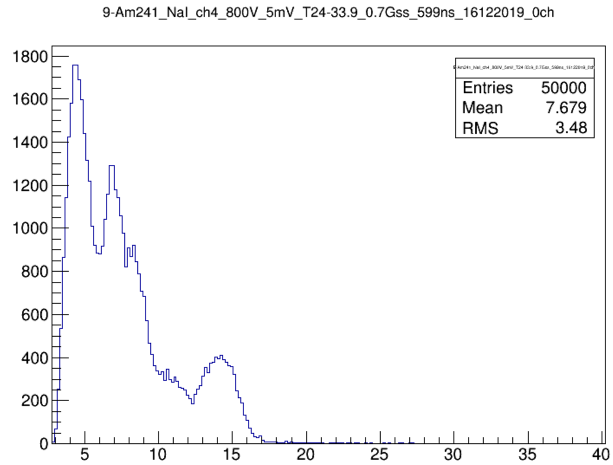
Description: Calibration (fitting) for the graph and distinguishing the unknown radioactive element.

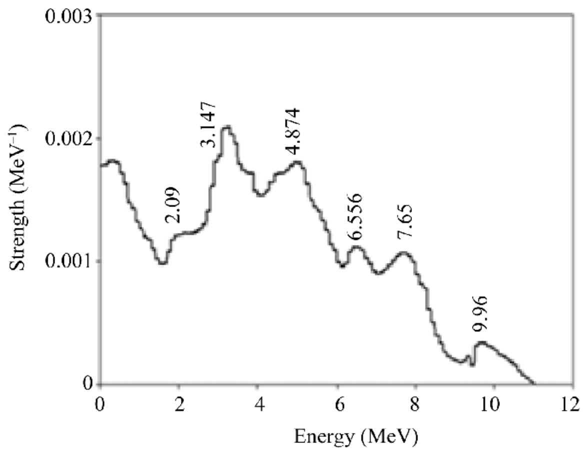
Steps: To the graph and get the equation we will use the following steps:

1- Fit panel to the required area to be studied.
2- Choose the required Data Set to be same as the studied graph.
3- Crop the required area (from X-coordinate) then fit it.
4- Set the parameters to be able to see the mean (Number of channels).
5- Get the energy value of the unknown element from the internet.

Answer's summary:

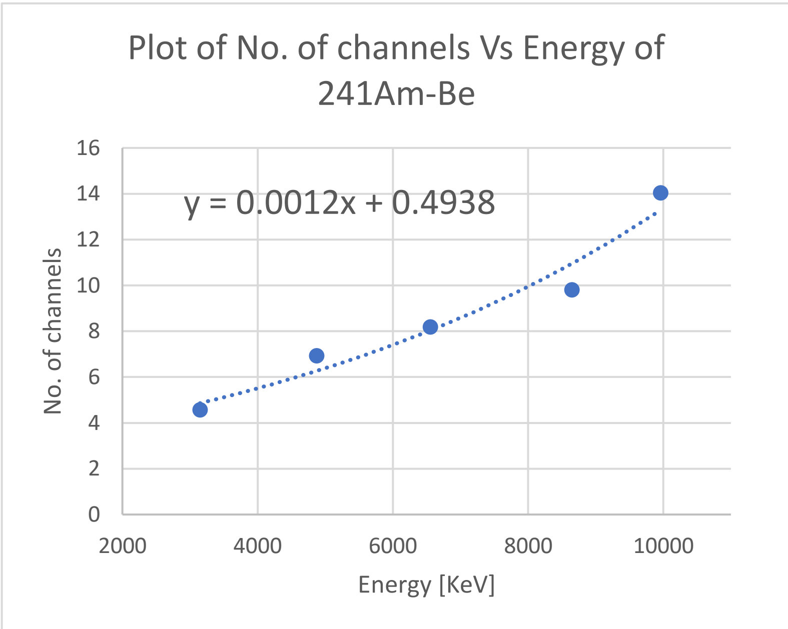
The given picture of the unknown source (left) compared to the unknow source (241Am-Be). The graphical fitting can be found in appendix D.





The plot of the unknow radioactive element:

Peak	Element	Energy [keV]	Number of channels (The mean value of the peak from our graph)
1	241Am-Be	3147	4.56
2		4874	6.93
3		6556	8.18
4		8650	9.81
5		9960	14.04



Task 4: Plotting of the relation between the radiation intensity ratio (I/I_0) of a radiation source and a barrier's thickness.

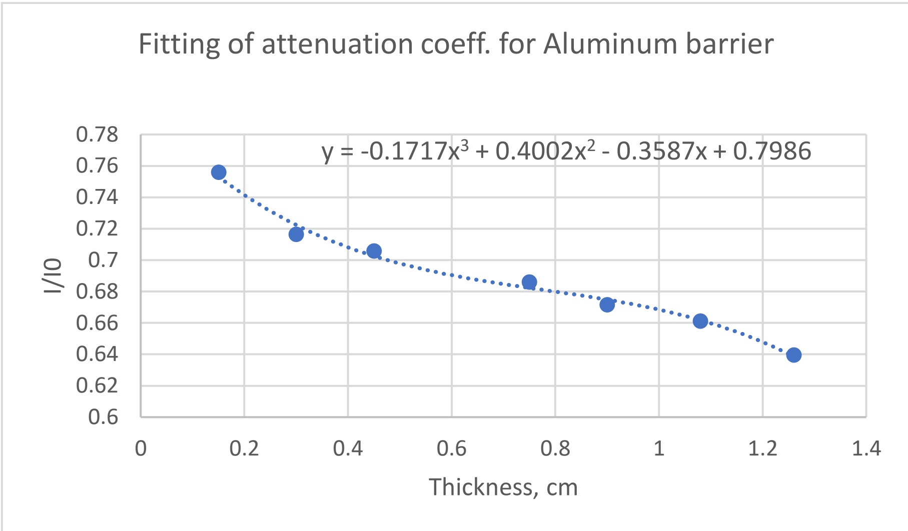
Task: Plotting of the relation between the radiation intensity ratio (I/I0) of a radiation source and a barrier's thickness in case of using aluminium and copper barriers.

Steps: To create a relationship between the transmitted intensity of the radiation from a Cs-137 and the thickness of the barrier used, we need do the following steps:

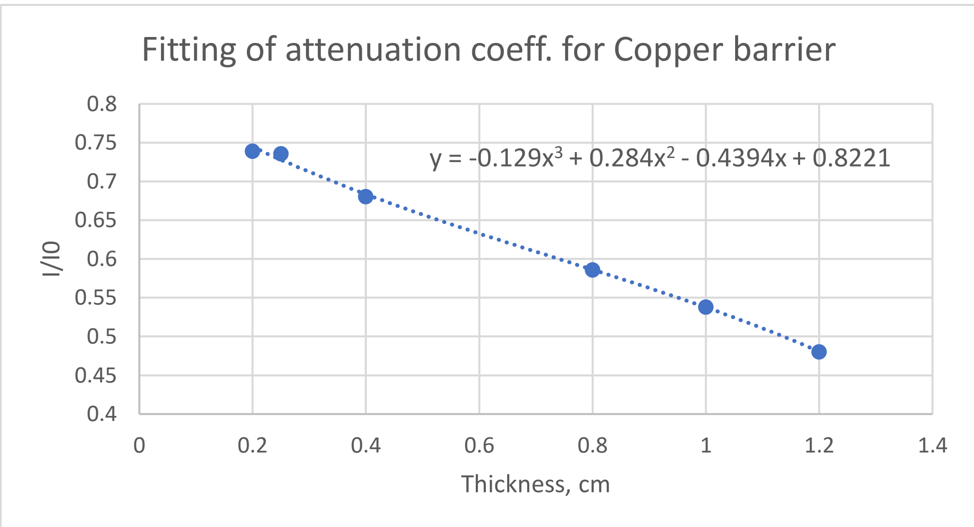
1- The attenuation formula: $I = I_0.e^{-\mu x}$, where: I: Transmitted intensity, x: thickness of the barrier, μ is the linear attenuation coefficient.
2- We make two tables between the transmitted intensity ratio (I/I_0) and the thickness of the barrier (Al and Cu).
3- Two graphs one when we use Al barrier and the other when we used Cu.
4- We get the equations of each trendline using a 3rd order polynomial function.

Answer's summary:

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



Cu	
Thickness, cm	I/I0
0.2	0.73931
0.25	0.7357
0.4	0.68065
0.8	0.58611
1	0.53827
1.2	0.48042



Task 5: Calculation of Alpha range in Air

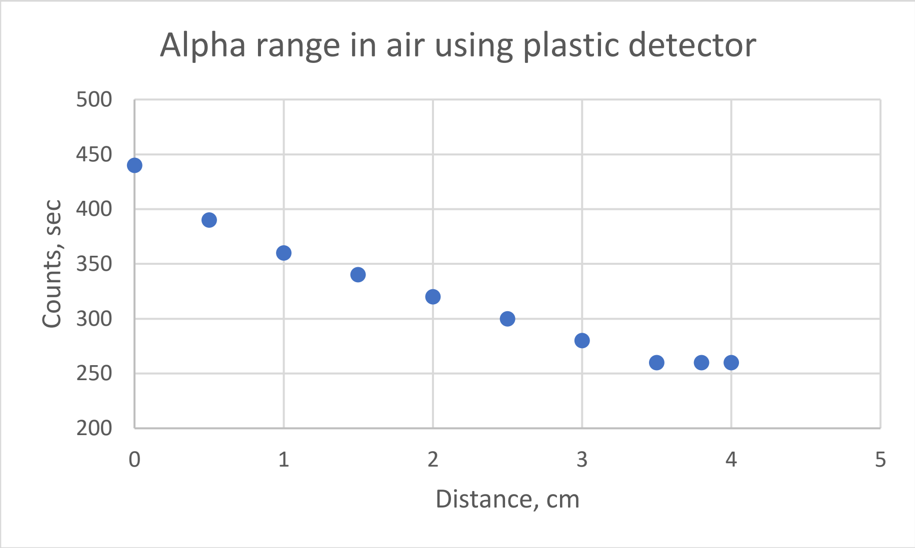
Description: Plotting the alpha particle in air which is the relation between the number of counts and the distance between the detector and the source

Steps:

- A plastic detector was used to measure the alpha particles in air.
- Energy of Alpha particle is 5.5 MeV.
- Source used: Plutonium 239.
- Applied voltage= 2000V

Answer's summary:

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



Comment: From the graph, we can see that the ability of the plastic detector to detect the alpha particles in air decrease as the distance between the source and the detector increases.

Part 3: Conclusion

In conclusion, the topic of radiation protection and the safety of radiation sources is a matter of great importance, not only in the field of nuclear research but also in our daily lives. Through this project, we have learned about the various topics theoretically and experimentally through the hands-on experience through the different tasks. The following skills and experience were gained during the program:

- Different types of radiation sources, and detection of radiation.
- Limit dose and recommended radiation protection protocol.
- Radioactivity and naturally occurring radioactive materials NORM.
- Energy calibration of some scintillation detectors by using Standard sources.
- Identify 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.
- Assessment the ranges and energy of alpha particles using Monto Carlo simulation SIRM software.

Overall, this project has demonstrated the significance of radiation protection and the safety of radiation sources, and the importance of promoting a culture of safety and responsibility in all activities involving radioactive materials.

Appendices

Appendix A

(The σ & mean values from the graphs)

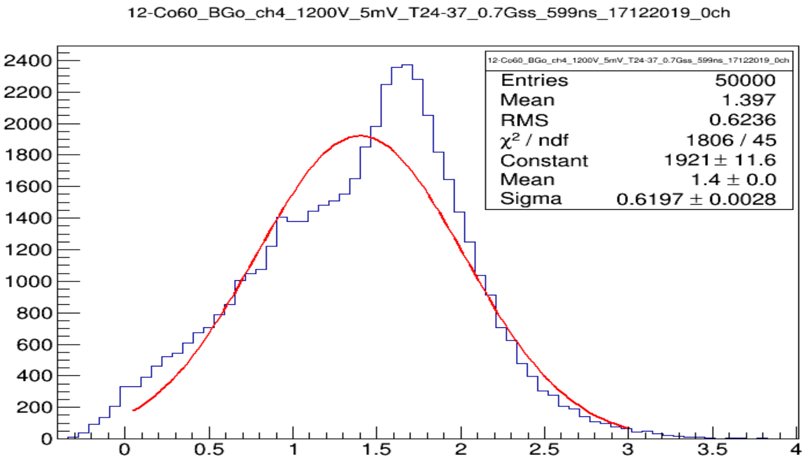
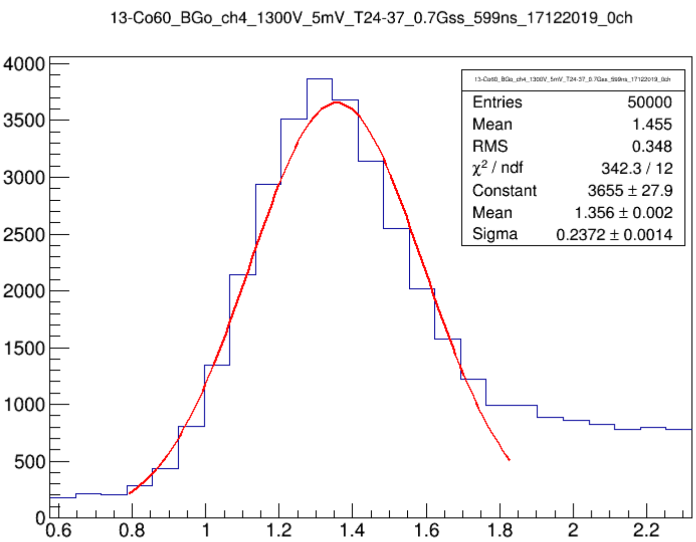


Figure 1 Applied voltage 1200V



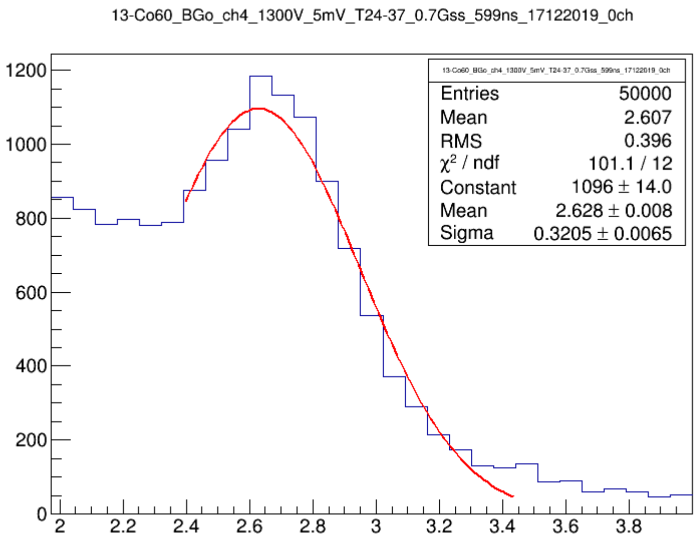


Figure 2 Applied voltage 1300 V

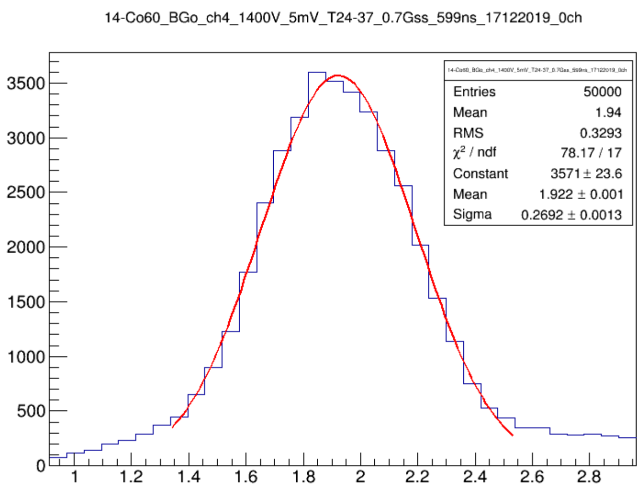


Figure 4 Applied voltage 1400 V

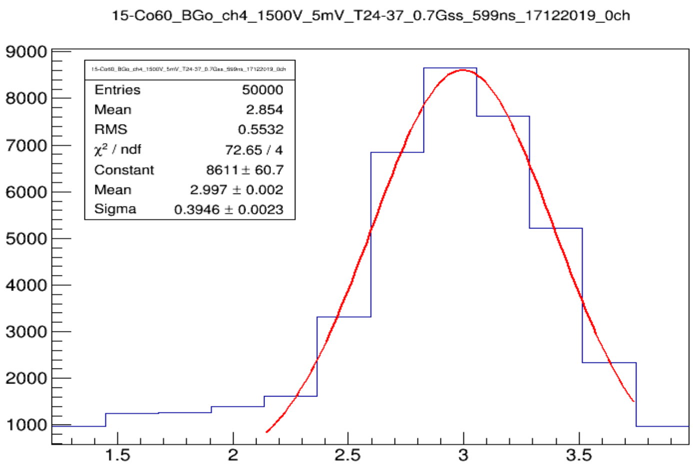


Figure 4 Applied voltage is 1500 V

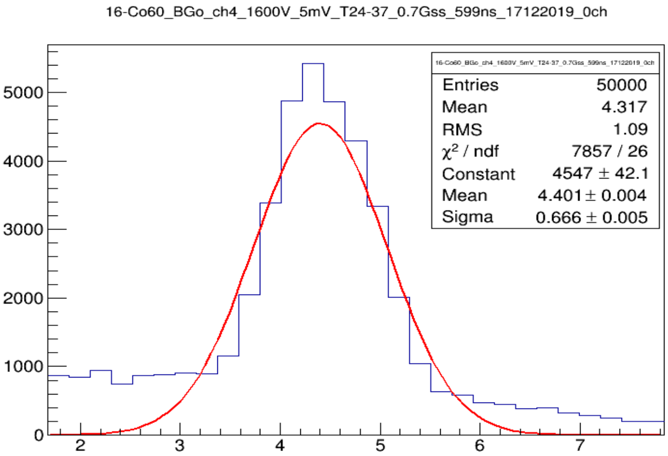


Figure 7 Applied voltage is 1600 V

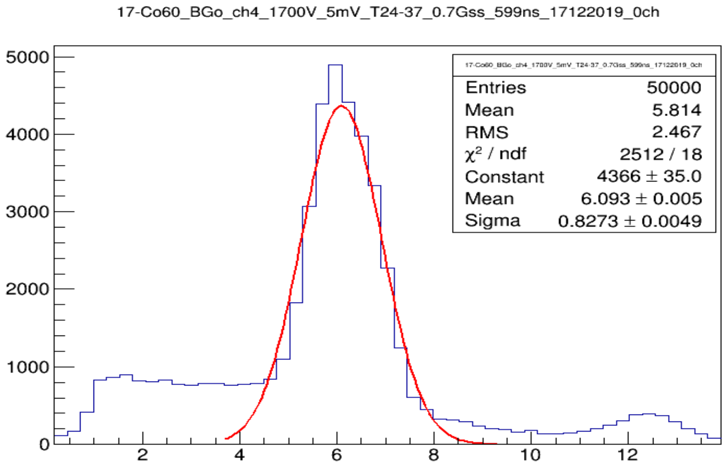


Figure 7 Applied voltage 1700 V

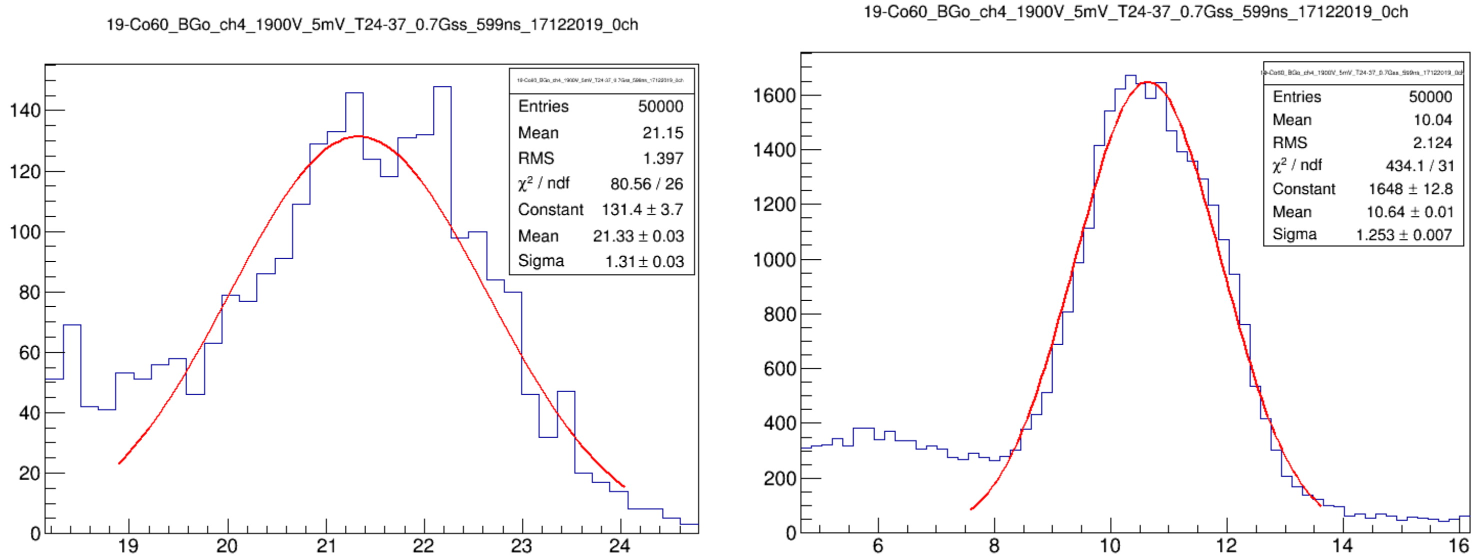


Figure 5 Applied voltage 1900 V

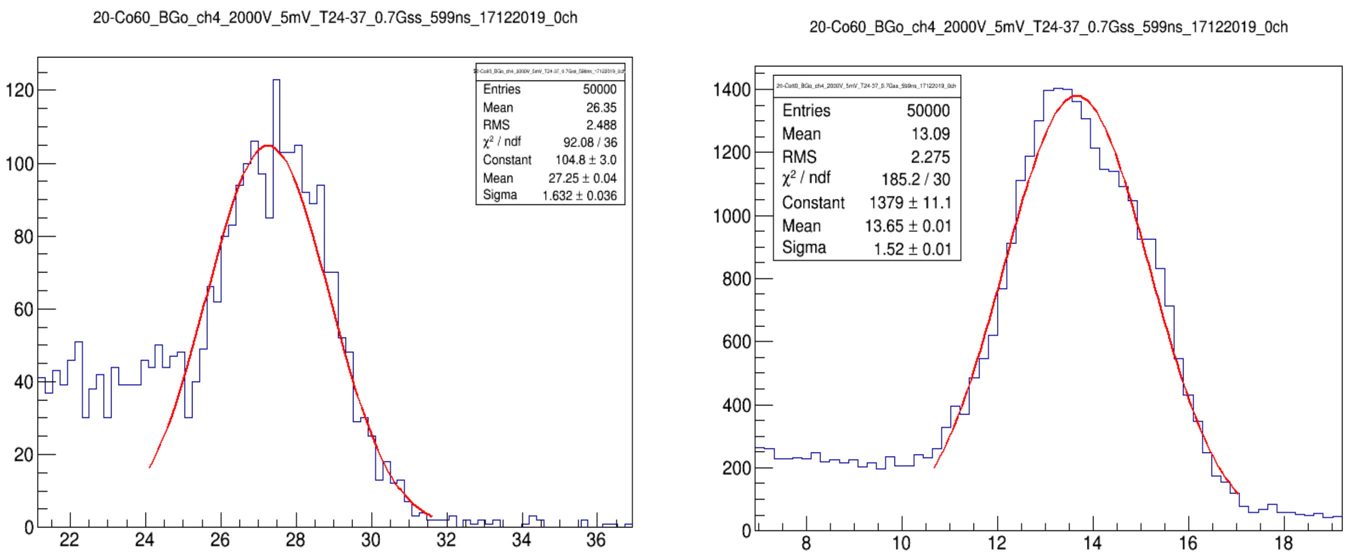
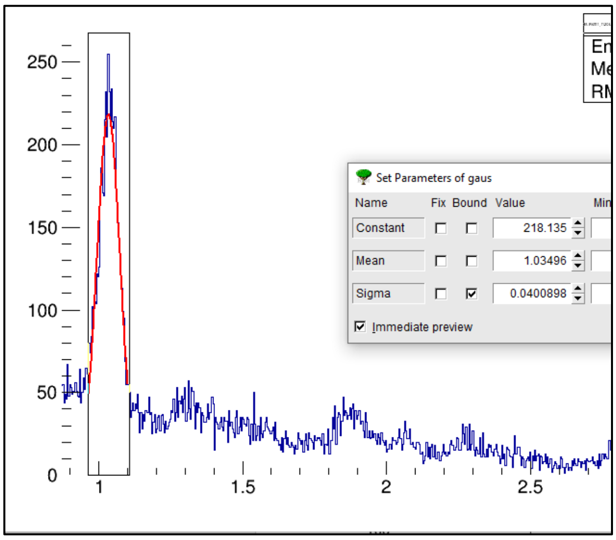


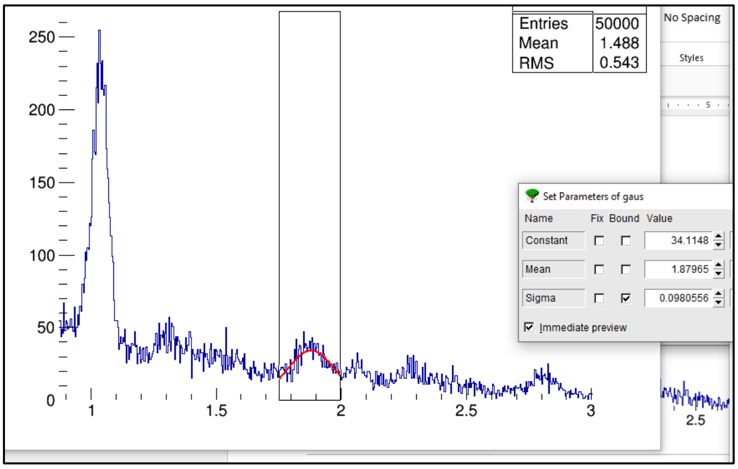
Figure 8 Applied voltage 2000 V

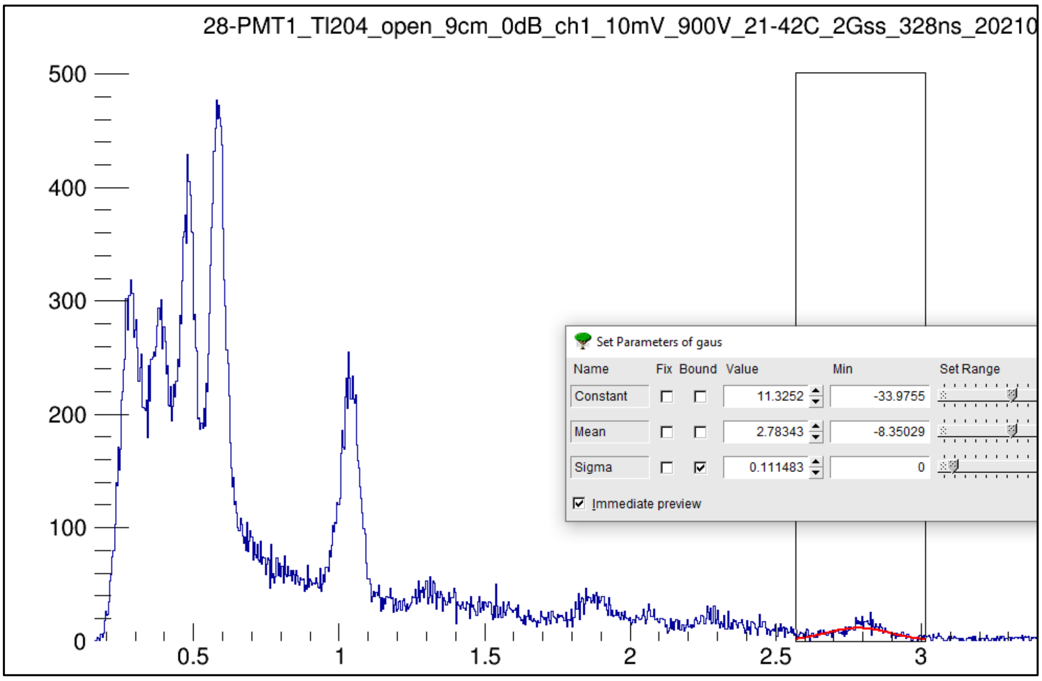
Appendix B

Answer in detail (The mean values from the graphs)

Two peaks were chosen to get the number of the channel, since we have only two peaks in the Na-22 element's energy spectrum that we got from the internet.







Appendix C

(The σ & mean values from the graphs)

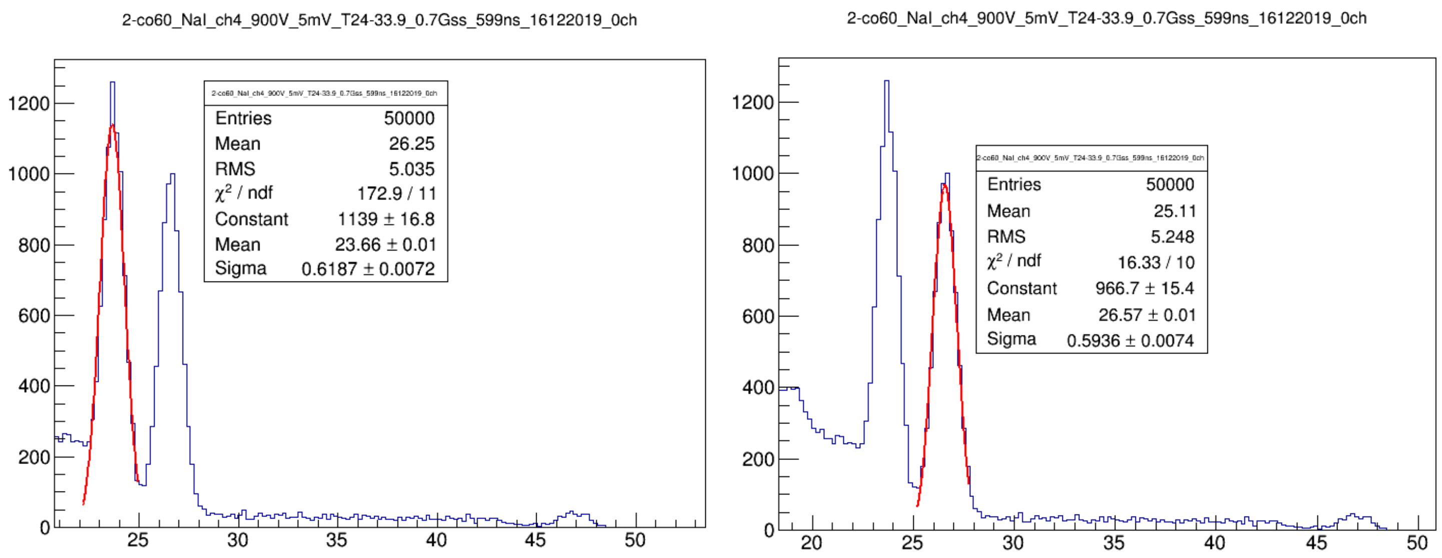


Figure 1 Applied volt is 900V

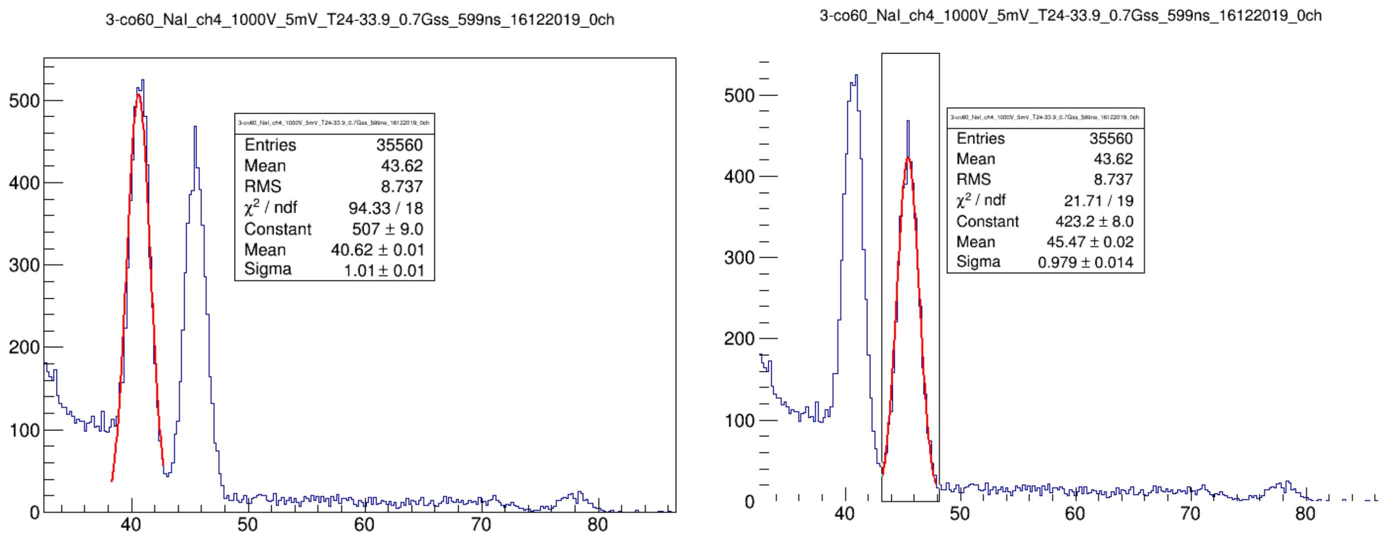


Figure 2 Applied voltage is 1000V

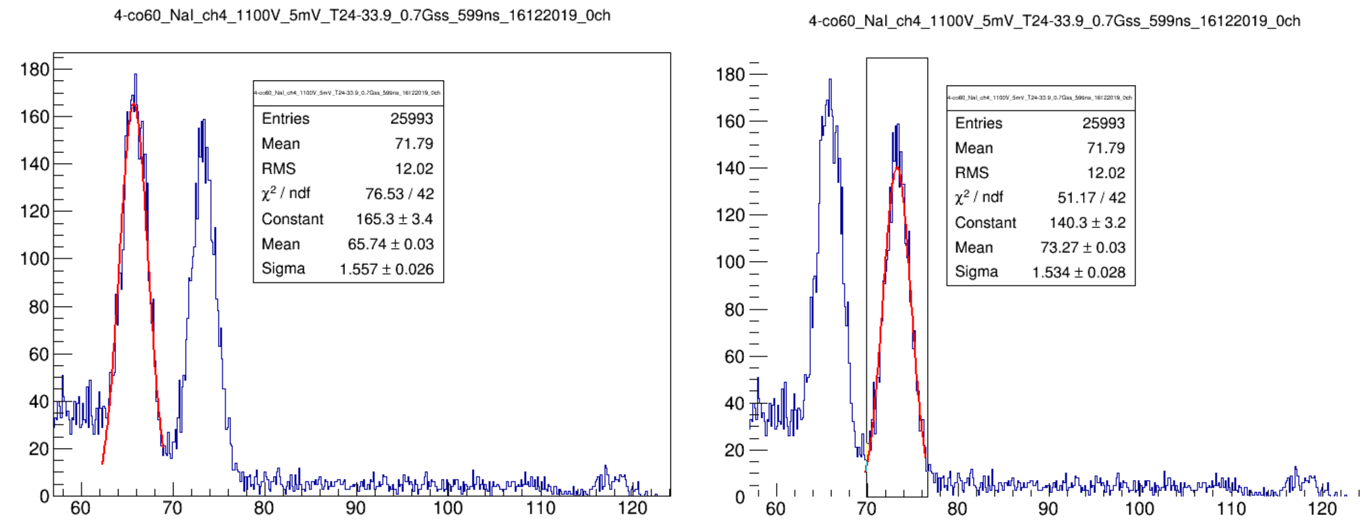


Figure 3 Applied voltage is 1100V

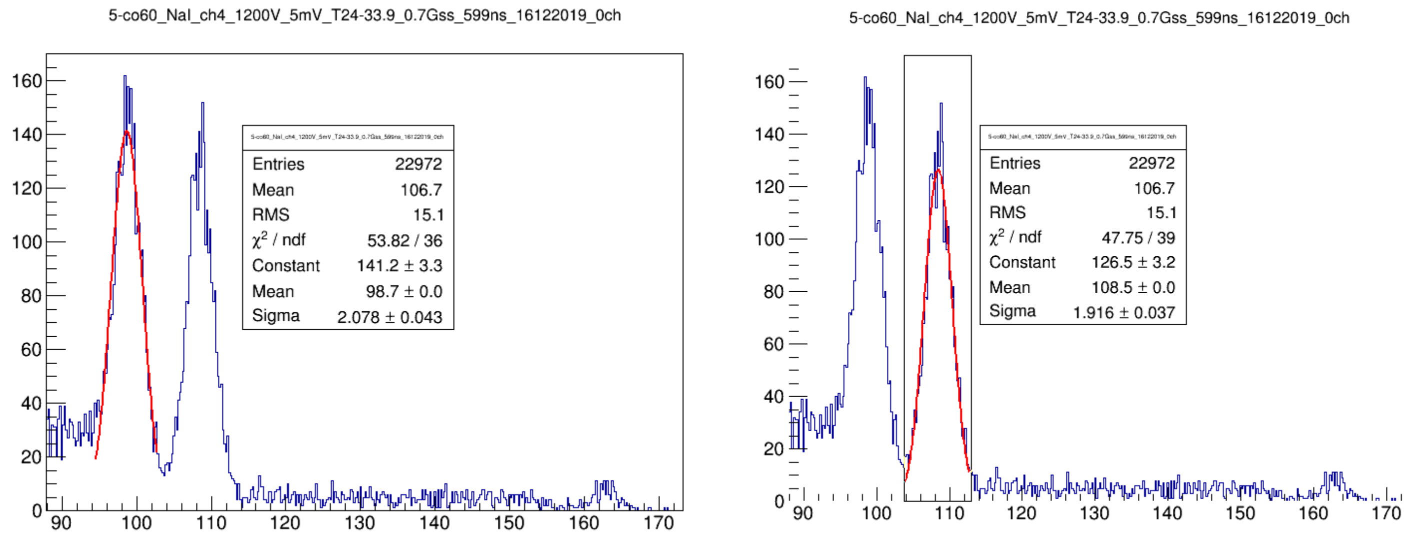


Figure 4 Applied voltage 1200V

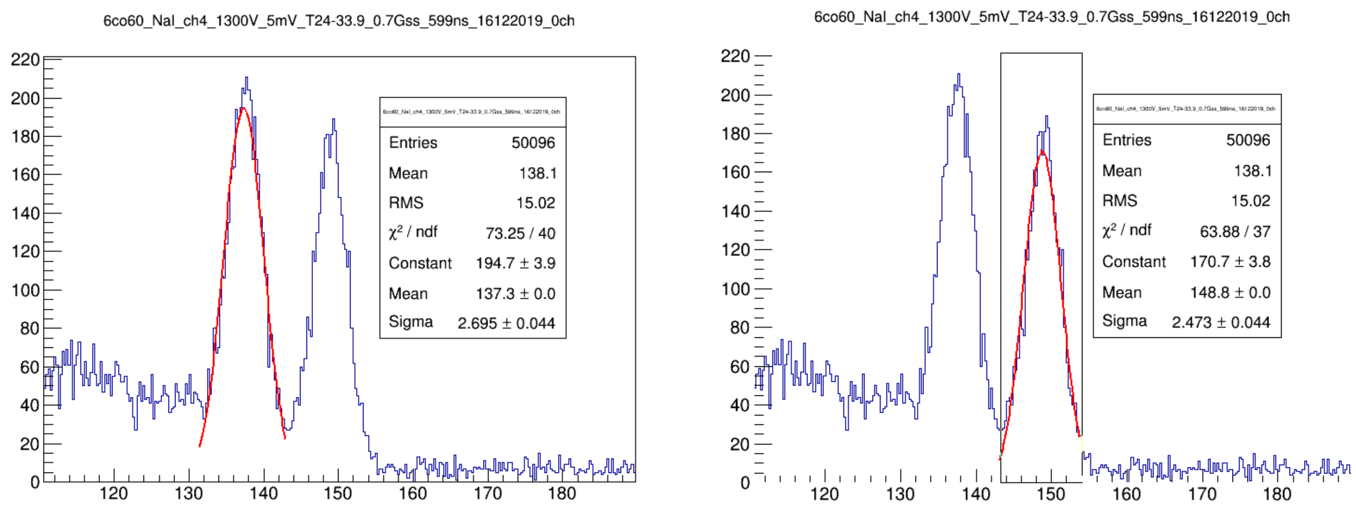
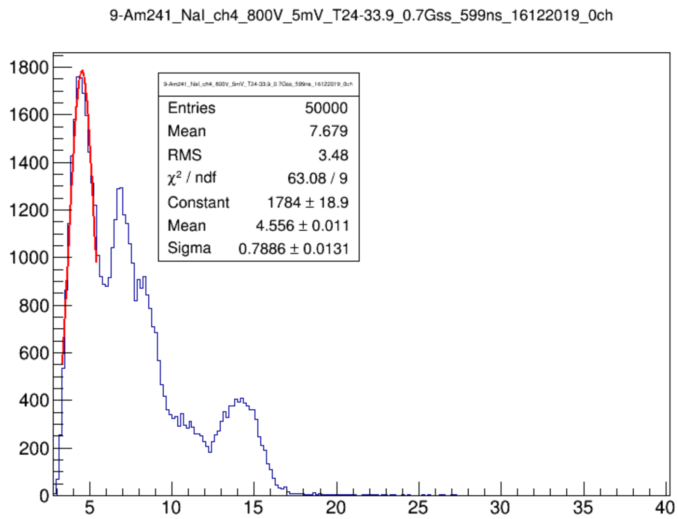
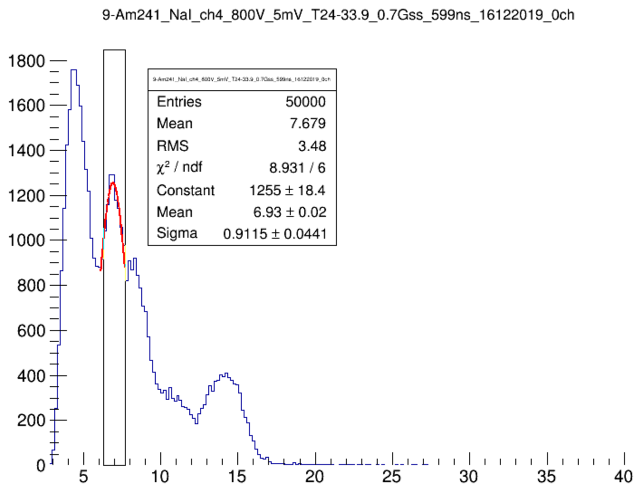
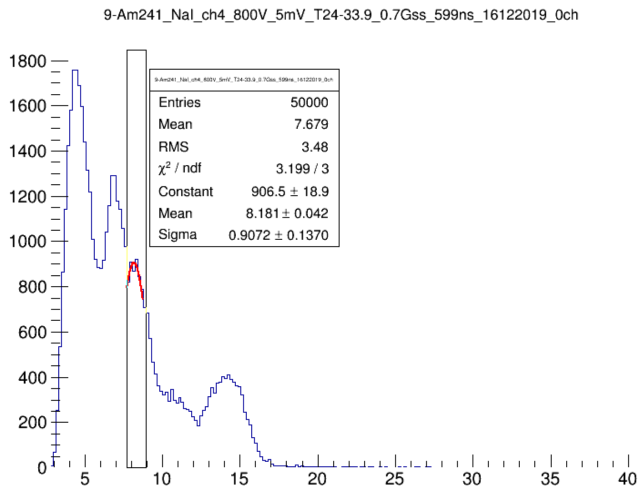


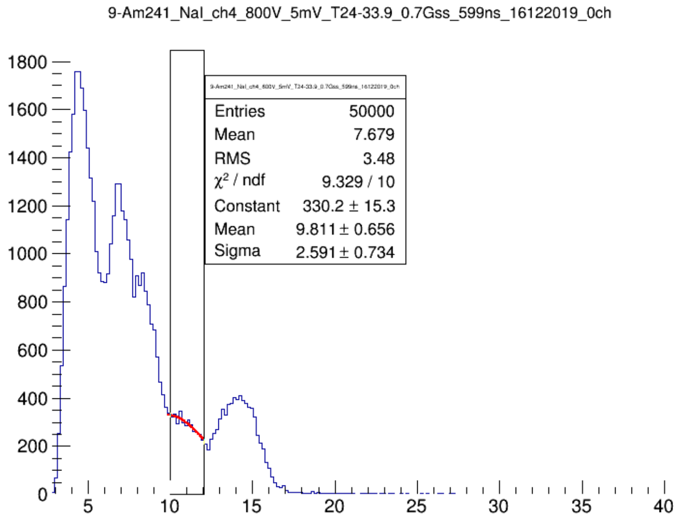
Figure 5 Applied voltage is 1300V

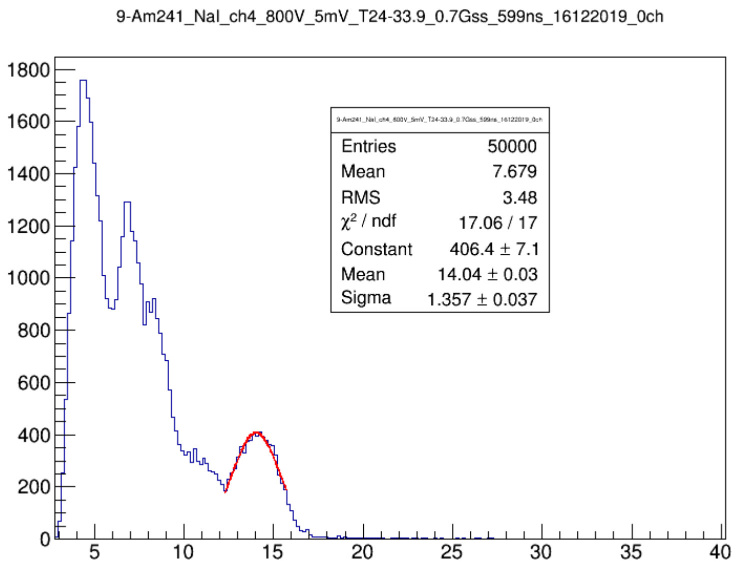
Appendix D


9-Am241_NaI_ch4_800V_5mV_T24-33.9_0.7Gss_599ns_16122019_0ch
Entries 50000
Mean 7.679
RMS 3.48
χ^2 / ndf 63.08 / 9
Constant 1784 ± 18.9
Mean 4.556 ± 0.011
Sigma 0.7886 ± 0.0131


9-Am241_NaI_ch4_800V_5mV_T24-33.9_0.7Gss_599ns_16122019_0ch
Entries 50000
Mean 7.679
RMS 3.48
χ^2 / ndf 8.931 / 6
Constant 1255 ± 18.4
Mean 6.93 ± 0.02
Sigma 0.9115 ± 0.0441


9-Am241_NaI_ch4_800V_5mV_T24-33.9_0.7Gss_599ns_16122019_0ch
Entries 50000
Mean 7.679
RMS 3.48
χ^2 / ndf 3.199 / 3
Constant 906.5 ± 18.9
Mean 8.181 ± 0.042
Sigma 0.9072 ± 0.1370


9-Am241_NaI_ch4_800V_5mV_T24-33.9_0.7Gss_599ns_16122019_0ch
Entries 50000
Mean 7.679
RMS 3.48
χ^2 / ndf 9.329 / 10
Constant 330.2 ± 15.3
Mean 9.811 ± 0.656
Sigma 2.591 ± 0.734


9-Am241_NaI_ch4_800V_5mV_T24-33.9_0.7Gss_599ns_16122019_0ch
Entries 50000
Mean 7.679
RMS 3.48
χ^2 / ndf 17.06 / 17
Constant 406.4 ± 7.1
Mean 14.04 ± 0.03
Sigma 1.357 ± 0.037