Experiment 4

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19MS063

Aim : To study the γ-ray energy spectrum of Cs^{137} (source) using scintillation detector with Multi Channel Analyzer (MCA)

Abstract

In this experiment, we study the absorption of γ particles emitted from the given $\mathbf{Cs^{137}}$ source using the scintillation detector with Multi Channel Analyzer in RADLAB simulation.

PART A :

- Calibrate the MCA by a known radioactive source i.e $\mathbf{Co^{60}}$ with a NaI(Tl) 2x2 detector.
- To find out the γ-ray energies of various different sources like (a) $\mathbf{Cs^{137}}$, (b) $\mathbf{Ba^{133}}$, and (c) $\mathbf{Na^{22}}$ using the same NaI(Tl) 2x2 detector.

PART B :

- Finding detector resolution +
- Photopeak efficiency of different type of detectors [(a) NaI(Tl) 2x2, (b) NaI(Tl) 3x3, (c) NaI(Tl) 5x5, (d) NaI(Tl) 7x7, (e) NaI(Tl) 2x2 Well-Type, (f) CdZnTe, (g) BgO, (h) HpGe] at 1.173 Mev and 1.332 Mev using Co60 radioactive source.

Theory

Nuclear decays occur at very small length scales (10^{-15} m). The interactions of alpha, beta, and gamma radiations with matter produce positively charged ions and electrons. Radiation detectors are devices that measure this ionization and produce an observable output.

Based on the purpose, various kinds of detectors are used. Some of them aare :

Gaseous ionization detectors

• Geiger counter

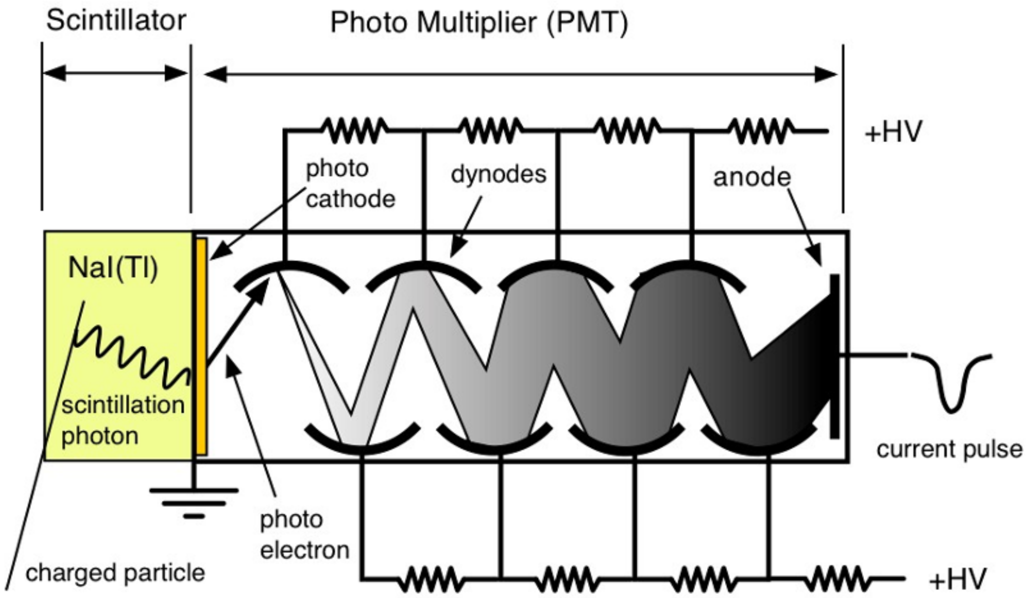
• Ionization chamber

• Proportional counter

Scintillation counters, Semiconductor detectors, Cherenkov detector etc.

In this experiment, we study about detection of γ particles by scintillator detector. There are two commonly used types of scintillators, inorganic crystals and organic scintillators. The scintillation mechanism is different for these two types. We will use an inorganic crystal scintillation detector. The scintillation mechanism depends on the structure of the crystal lattice. In a pure inorganic crystal lattice such as NaI, electrons are only allowed to occupy selected energy bands. The forbidden band or band gap is the range of energies in which electrons can never be found in the pure crystal.

Fig 1. Scintillation detector



In the pure crystal, absorption of energy can elevate electrons from the valence band to the conduction band leaving a gap in the valence band. However, the return of an electron to the valence band with the emission of a photon is an inefficient process. Few photons are released per decay, the energy is emitted by other mechanisms. In addition, band gap widths in pure crystals are such that the resulting emitted photon is too high to lie within the visible range. Small amounts of impurities are therefore added to the crystal. Tl is added to NaI in trace amounts. The impurities are called activators, they create special sites in the lattice at which the band gap structure, the energy structure, is modified. The energy structure of the overall crystal is not changed, just the energy structure at the activator sites.

At the few activator sites within the sample, the energy structure is modified. Energy states are created within what would be the forbidden band in the pure crystal. The electron can de-excite through these levels back to the valence band. This excitation energy is given off in various ways, one being emission of visible light (fluorescence). Thus a single high energy gamma ray entering the scintillator produces a flash or scintillation of low energy photons.

Working of scintillation counter

The Thallium impurity in NaI produces so-called activator centers, which allow the electrons and the holes to recombine quickly with the emission of visible light. This light is detected by a photo-multiplier that produces an electrical current pulse proportional to the number of photons observed. The electrons are collected in the photomultiplier and are amplified to yield a current pulse. It is then converted to a voltage pulse of height proportional to the number of photoelectrons collected which is proportional to the number of photons reaching the tube $\propto$ initial energy of the fast electron.

Photon detection

Cs^{137} decays into a metastable nuclear isomer of Barium, barium-137m (137m Ba, Ba-137m) to stable a stable barium isotope Ba-137 with emission of **γ rays** of energy 0.6617 M eV . And another prominent pathway is $Cs^{137} \rightarrow Ba^{137}$-m $\rightarrow Ba^{137}$ with subsequent emission of 32 k eV **X-rays.**

A scintillator is primarily sensitive to the passage of charged particles. High energy photons/ γ particles are not charged and can only be observed if they produce a fast moving charged particle which subsequently interacts with the scintillator material. The energy that is measured in a scintillator is therefore the energy deposited by charged particles, mostly electrons, that interacted with the incoming high energy photon. The main reactions between a photon and the electrons in the scintillator are:

- Photoelectric effect: a photon is absorbed by an electron which then interacts with the crystal when the incident photon energy hν exceeds the electronic binding energy. $Ke = E\gamma - Be$, where Ke is the kinetic energy of the electron, $E\gamma$ is the photon energy and Be is the electron's binding energy. the photomultiplier output pulse will correspond to the full gamma ray energy, if the photoelectron stops and no light escapes the crystal. Thus the photoelectric effect results in a peak, called the **photopeak**, at an energy equal to that of the incoming gamma ray.

  When the gamma rays undergoes photoelectric effect in surrounding materials (for example lead shield) the outgoing X-ray can be captured again by the detector. This gives an characteristic **X-ray peak** with an energy depending on the material it came from.

- Compton scattering: a photon scatters off an atomic electron, the electron recoils and has kinetic energy, the original photon changes direction and loses energy corresponding to the recoil energy of the electron. Me is the mass of the electron and the energy of the recoiling electron is given by $Ke = E_\gamma - E_\gamma'$, while energy of the scattered photon is given by $E\gamma\prime = \dfrac{E_\gamma}{1 + \frac{E_\gamma}{mc^2}(1 - cos\theta)}$

If a Compton scattered photon leaves the scintillator without further interaction then the maximum energy deposited in Compton scattering would correspond to a photon scattering angle of 180 degrees. And this energy is called the **Compton edge**.

It can happen that a photon does a 180^0 scattering outside the detector (e.g. in the thick glass of the PMT) and this backscattered photon is then detected. Find its energy and locate the corresponding peak. The recoiling electron from the backscattering process is not detected and the gamma particle is detected by photoelectric effect instead, giving rise to **backscattering peak**.

- Pair production: a photon (with an energy > 1.2 MeV) converts into an electron – positron (anti-electron) pair. The electron is stopped in the crystal, the positron eventually annihilates with an atomic electron and produces two 0.511 MeV photons which may or may not be detected.

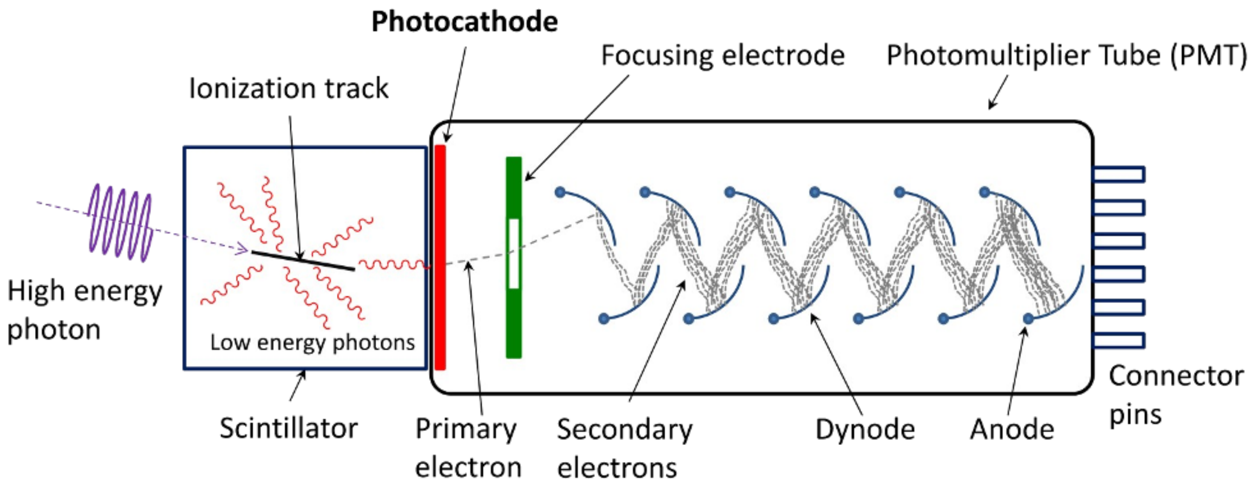


Fig 2. Photomultiplier Tube (PMT)

Photomultiplier Tube

Photomultiplier tubes are vacuum tubes in which the first major component is a photocathode. A light photon may interact in the photocathode to eject a low-energy electron into the vacuum. This process can be thought to occur in three steps, absorption of the photon and energy transfer to the electron in the photocathode material then the migration of the photoelectron to the surface of the photocathode and the escape of the electron from the photocathode surface.

A PMT takes the electrical signal from the photocathode and amplifies through a dynode chain by the process of electron multiplication. Electrons are ejected from the photocathode into the vacuum with an energy of $\approx$ 1 eV and are accelerated by a voltage of a few hundred volts toward an electrode. The accelerated electron has an energy of a few hundred electron volts upon arrival at the electrode; this deposition of kinetic energy can result in the remission of secondary electrons. It typically takes 2-3 eV to excite an electron in the dynode, so 100 V can theoretically create ≈ 30 electrons. A large number of electrons are produced, which leads to a current, which is then converted into a voltage pulse.

Multi Channel Analyzer

The amplified output pulses are sent to the MCA which sorts the signals according to their height and counts the pulses. For example, pulse A is put into channel number 1, pulse B into channel number 2, pulse C and D into number 3, and so on. One thus obtains a histogram of the pulse height distribution for all detected gamma quanta. Since the pulse height is proportional to the gamma energy, the histogram reproduces the distribution of the corresponding gamma energies. The histogram is usually referred to as an energy spectrum. The praportionality constant can be determined experimentally. Since we know two energy values E_A = 1.17 MeV and E_B = 1.33 MeV for $\mathbf{Co^{60}}$, we can find corresponding channel number A and B to find this praportinality constant α,

$$\alpha = \frac{E_A - E_B}{A - B} = \frac{1.17 - 1.33}{A - B}$$

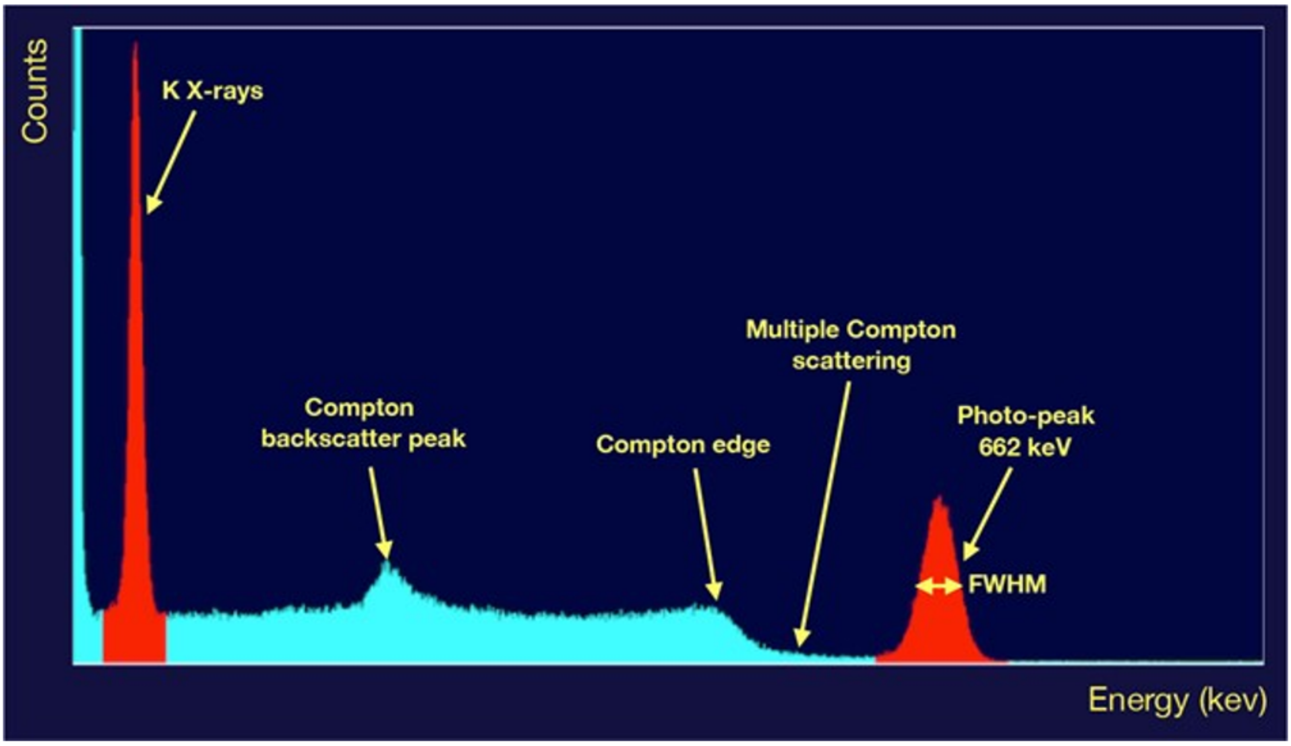


Fig 3. Energy spectrum of NaI:Tl detector for Cs^{137}

Table 1. Source Energy with % of Intensity

Sl no.	Nuclide	Half life (years)	Intensity (%)	Energy (MeV)
1	Co^{60}	5.27	100	1.173
			100	1.332
2	Cs^{137}	30	100	0.662
3	Ba^{133}	10.66	8	0.382
			34	0.08
			69	0.356
			14	0.302
			7	0.276
4	Na^{22}	2.6	100	1.275
			$e_+ e_-$ annihilation	0.511

Photopeak efficiency

It is the ratio of the area under the peak to the area under the entire spectrum. Since the width of each channel is fixed,

$$Photopeak\ Efficiency\ =\ \frac{Sum\ of\ counts\ in\ the\ peak}{Total\ counts\ in\ the\ spectrum}$$

Resolution of photopeak

On plotting the energy spectrum data obtained from the MCA, we can observe the photoelectric peak, Compton edge and backscatter peak. By fitting the photopeak with Gaussian function, we can obtain the centroid of the peak, **E** and the full width at half maxima (**δE**). The resolution of the MCA is then given by

$$R\ =\ \frac{\delta E}{E}\ \times\ 100\%$$

Procedure

In the RADLAB simulation, we set up an apparatus using various γ-ray sources ie. **Cs^{137}**, a NaI:Tl detector, a high voltage source, pre amplifier, amplifier, a multi channel analyzer. We connect the equipments with suitable wires and complete the circuit then place the source in line with the detector window.

A. Calibrate the MCA by a known radioactive source i.e **Co^{60}** with a NaI(Tl) 2x2 detector and find out the γ-ray energies of various different sources like (a) **Cs^{137}** , (b) **Ba^{133}** , and (c) **Na^{22}** using the same NaI(Tl) 2x2 detector.

B. Finding detector resolution and photopeak efficiency of different type of detectors **[** (a) NaI(Tl) 2x2, (b) NaI(Tl) 3x3, (c) NaI(Tl) 5x5, (d) NaI(Tl) 7x7, (e) NaI(Tl) 2x2 Well-Type, (f) CdZnTe, (g) BgO, (h) HpGe **]** at 1.173 MeV and 1.332 MeV using **Co^{60}** radioactive source.

Data Analysis (PART A)

Collected the spectrum data for the 4 different gamma sources, plotted the spectrum of **Co^{60}** first and fit it with the gaussian function to find the channel number as centroid of the peaks with known energies and found the proportionality constant which is used for calibration and finding out the energies of other sources.

A. Table 1

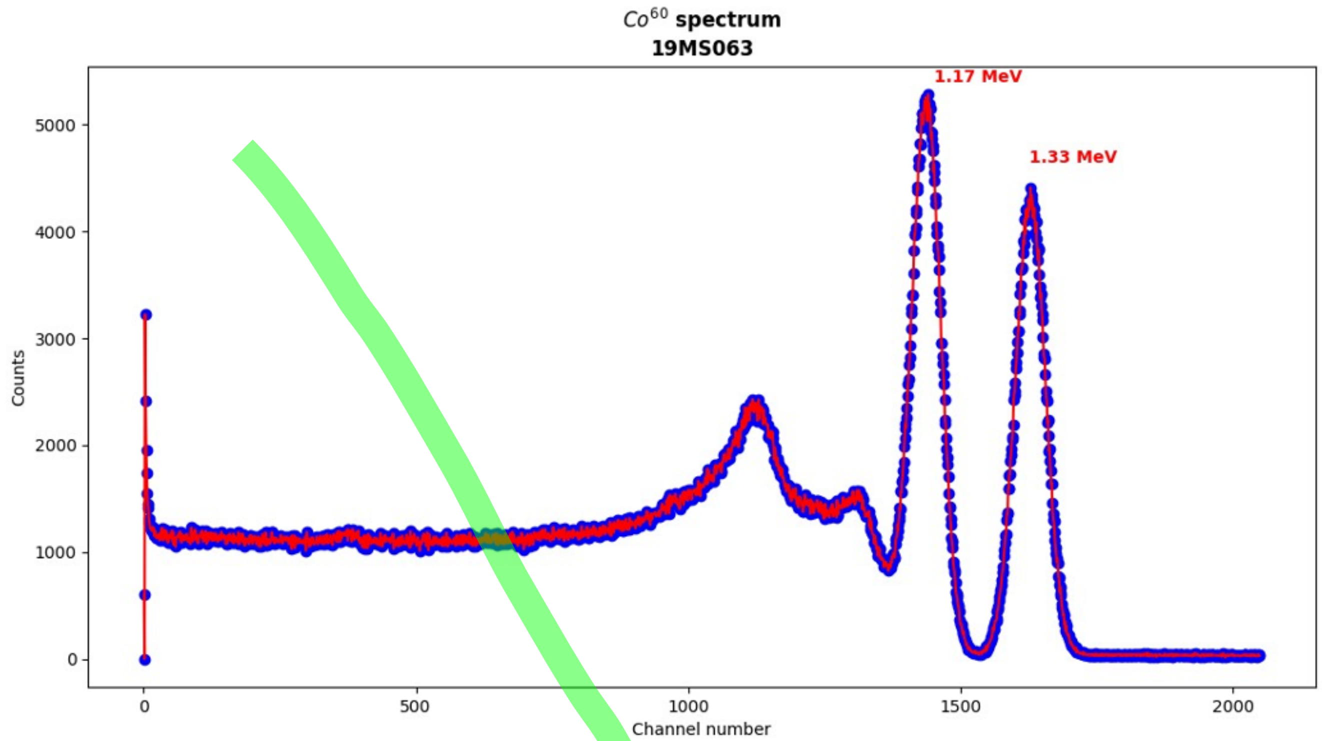
Co^{60}	**1.17 MeV peak centroid**	**1.33 MeV peak centroid**	**A – B**	**Alpha**
	1435.0452	1627.6278	192.5826	0.00082561976
	1435	1628	193	0.000823834

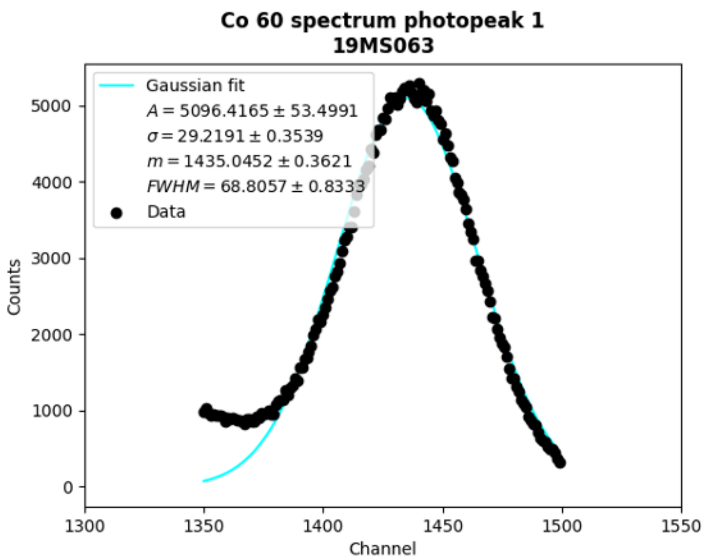
$$\alpha = 0.000823834$$

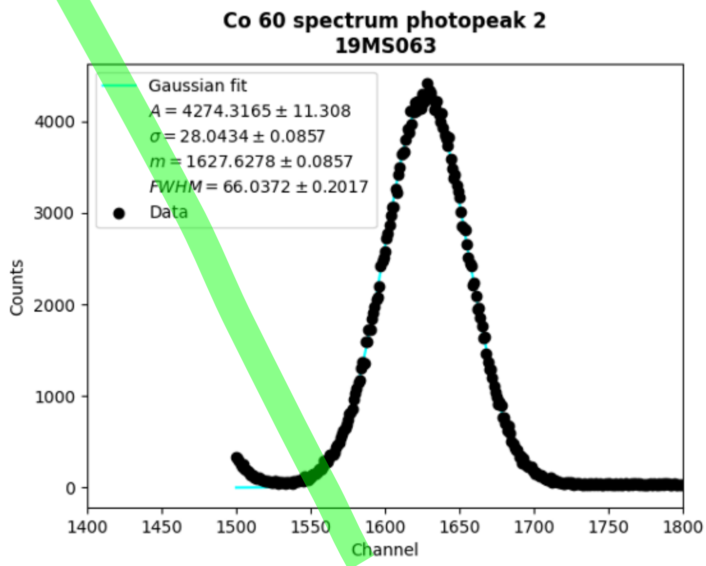
*

* Note : Data can be found at

A. Graph 1

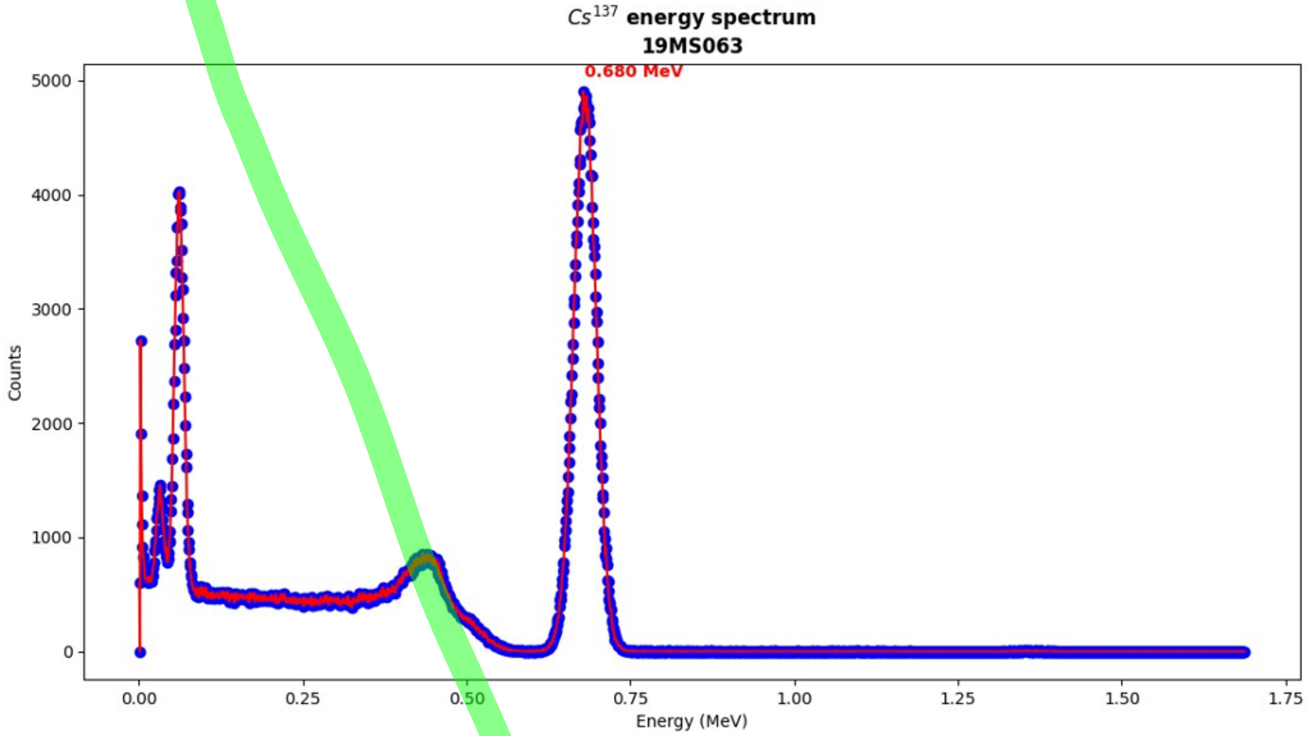




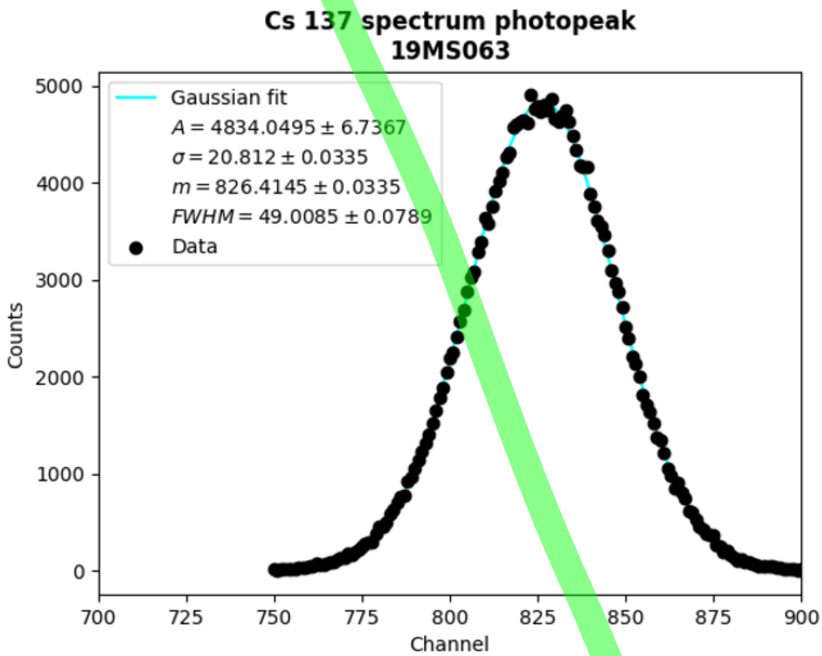


Now, the energy spectrum for other sources is plotted,

A. Graph 2

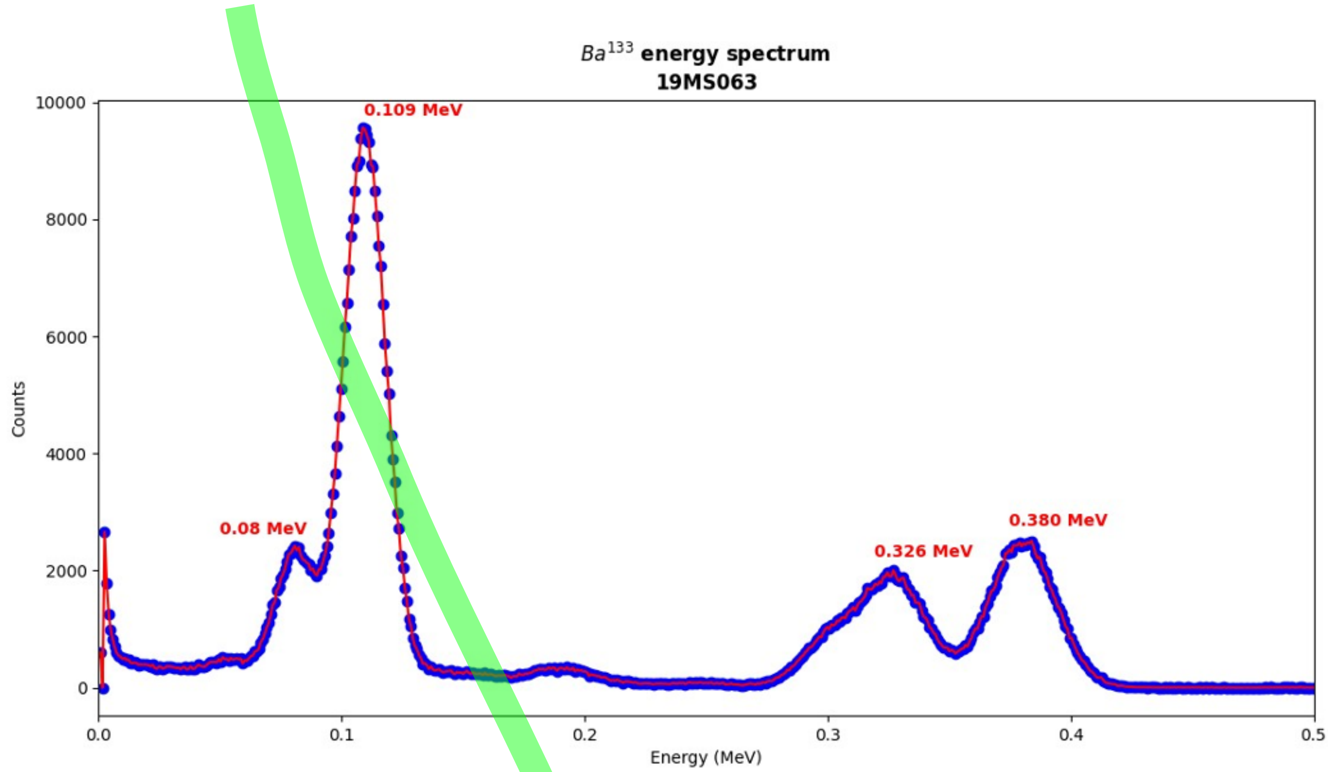


Cs^{137} energy spectrum
19MS063
0.680 MeV
Counts
Energy (MeV)

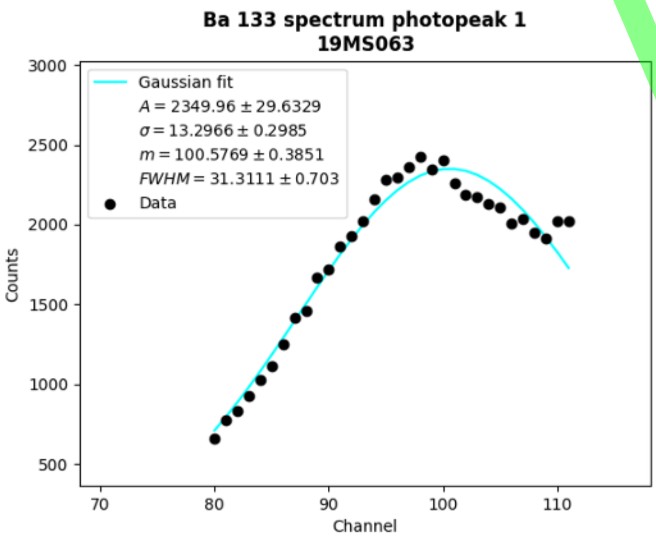


Cs 137 spectrum photopeak
19MS063
Gaussian fit
$A = 4834.0495 \pm 6.7367$
$\sigma = 20.812 \pm 0.0335$
$m = 826.4145 \pm 0.0335$
$FWHM = 49.0085 \pm 0.0789$
Data
Counts
Channel

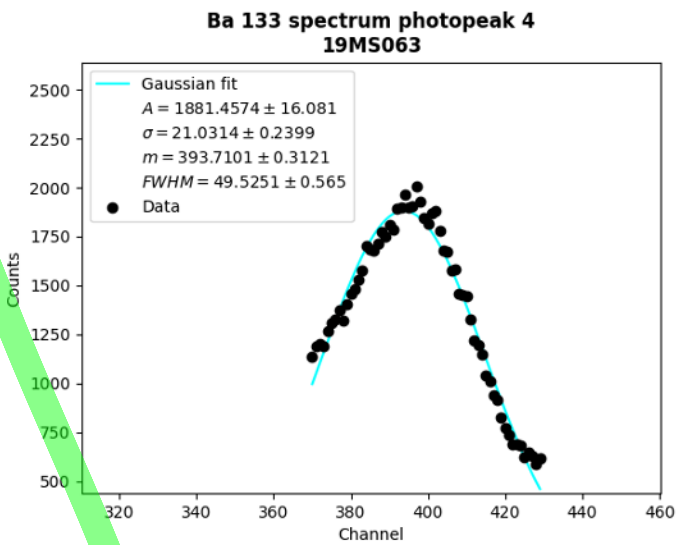
A. Graph 3



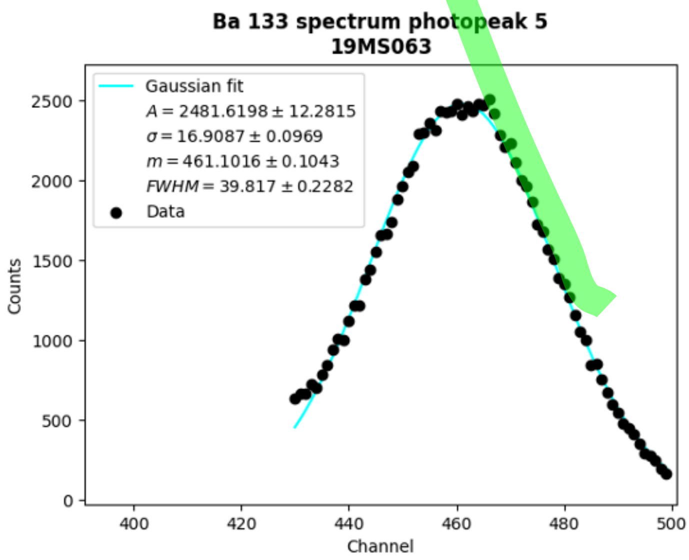
Ba^{133} energy spectrum
19MS063
0.109 MeV
0.08 MeV
0.326 MeV
0.380 MeV
Counts
Energy (MeV)



Ba 133 spectrum photopeak 1
19MS063
Gaussian fit
$A = 2349.96 \pm 29.6329$
$\sigma = 13.2966 \pm 0.2985$
$m = 100.5769 \pm 0.3851$
$FWHM = 31.3111 \pm 0.703$
Data
Counts
Channel

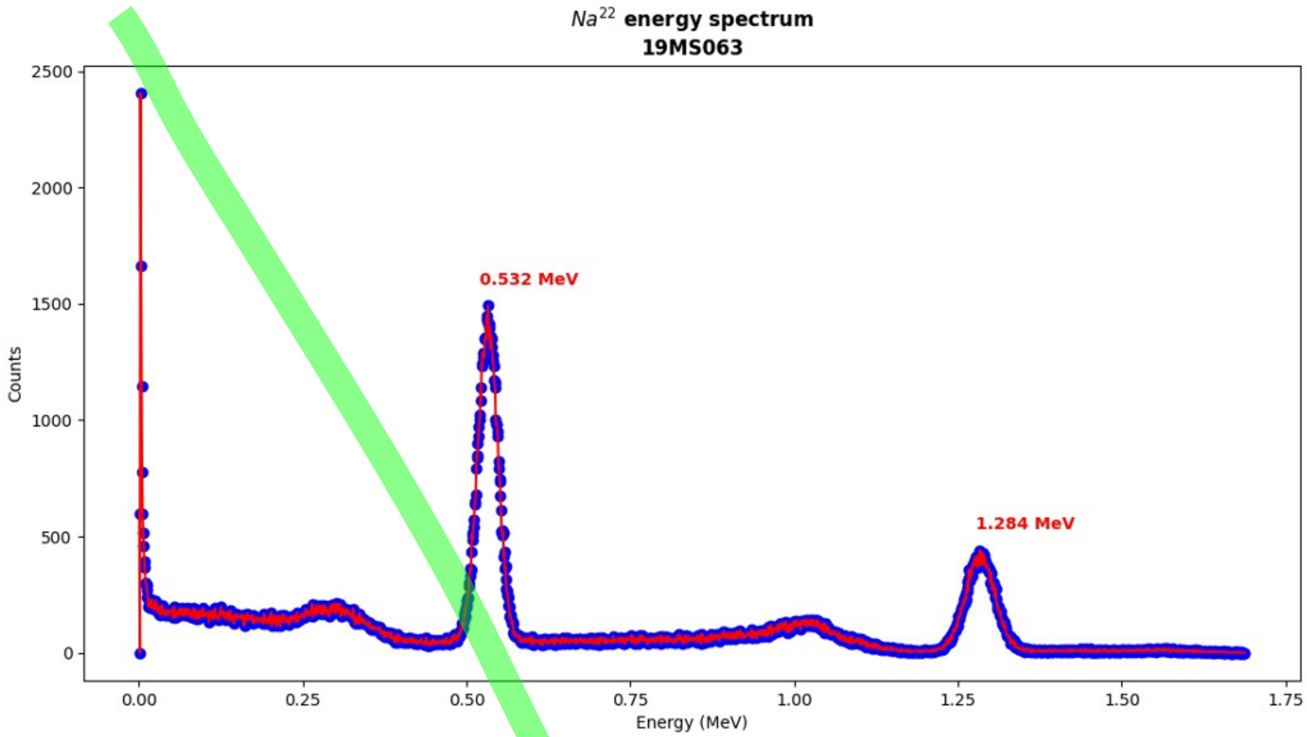


Ba 133 spectrum photopeak 4
19MS063
Gaussian fit
$A = 1881.4574 \pm 16.081$
$\sigma = 21.0314 \pm 0.2399$
$m = 393.7101 \pm 0.3121$
$FWHM = 49.5251 \pm 0.565$
Data
Counts
Channel

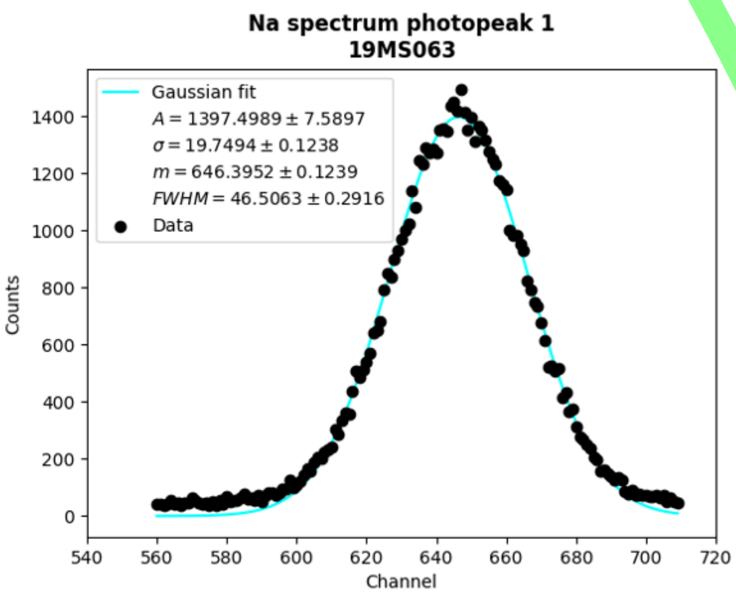


Ba 133 spectrum photopeak 5
19MS063
Gaussian fit
$A = 2481.6198 \pm 12.2815$
$\sigma = 16.9087 \pm 0.0969$
$m = 461.1016 \pm 0.1043$
$FWHM = 39.817 \pm 0.2282$
Data
Counts
Channel

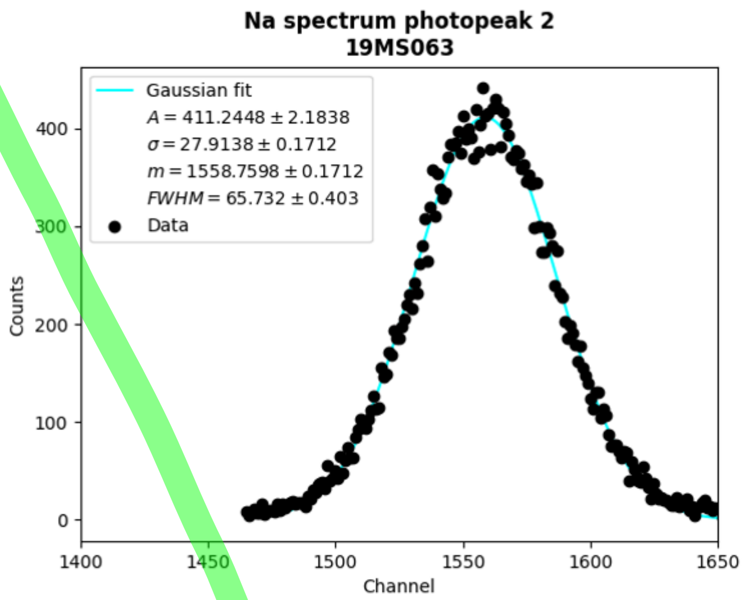
A. Graph 4



Na^{22} energy spectrum
19MS063
0.532 MeV
1.284 MeV
Counts
Energy (MeV)



Na spectrum photopeak 1
19MS063
Gaussian fit
$A = 1397.4989 \pm 7.5897$
$\sigma = 19.7494 \pm 0.1238$
$m = 646.3952 \pm 0.1239$
$FWHM = 46.5063 \pm 0.2916$
Data
Counts
Channel



Na spectrum photopeak 2
19MS063
Gaussian fit
$A = 411.2448 \pm 2.1838$
$\sigma = 27.9138 \pm 0.1712$
$m = 1558.7598 \pm 0.1712$
$FWHM = 65.732 \pm 0.403$
Data
Counts
Channel

A. Table 2

		Centroid	Centroid (Rounded off)	Energy
Cs^{137}	**Peak 1**	826.4145	826	0.680486884
Ba^{133}		Centroid	Centroid (Rounded off)	Energy
	Peak 1	100.5769	101	0.083207234
	Peak 2	393.7101	394	0.324590596
	Peak 3	461.1016	461	0.379787474
Na^{22}		Centroid	Centroid (Rounded off)	Energy
	Peak 1	646.3952	646	0.532196764
	Peak 2	1558.7598	1559	1.284357206

A. Table 3 [Source energy (Theoretical and calculated)]

Sl no.	Nuclide	Half life (years)	Intensity (%)	Energy (MeV)	Energy (MeV) from experiment
1	Co^{60}	5.27	100	1.173	1.173
			100	1.332	1.332
2	Cs^{137}	30	100	0.662	0.68
3	Ba^{133}	10.66	8	0.382	0.38
			34	0.08	0.083
			69	0.356	0.324
			14	0.302	-
			7	0.276	-
4	Na^{22}	2.6	100	1.275	1.284
			e_+ e_- annihilation	0.511	0.532

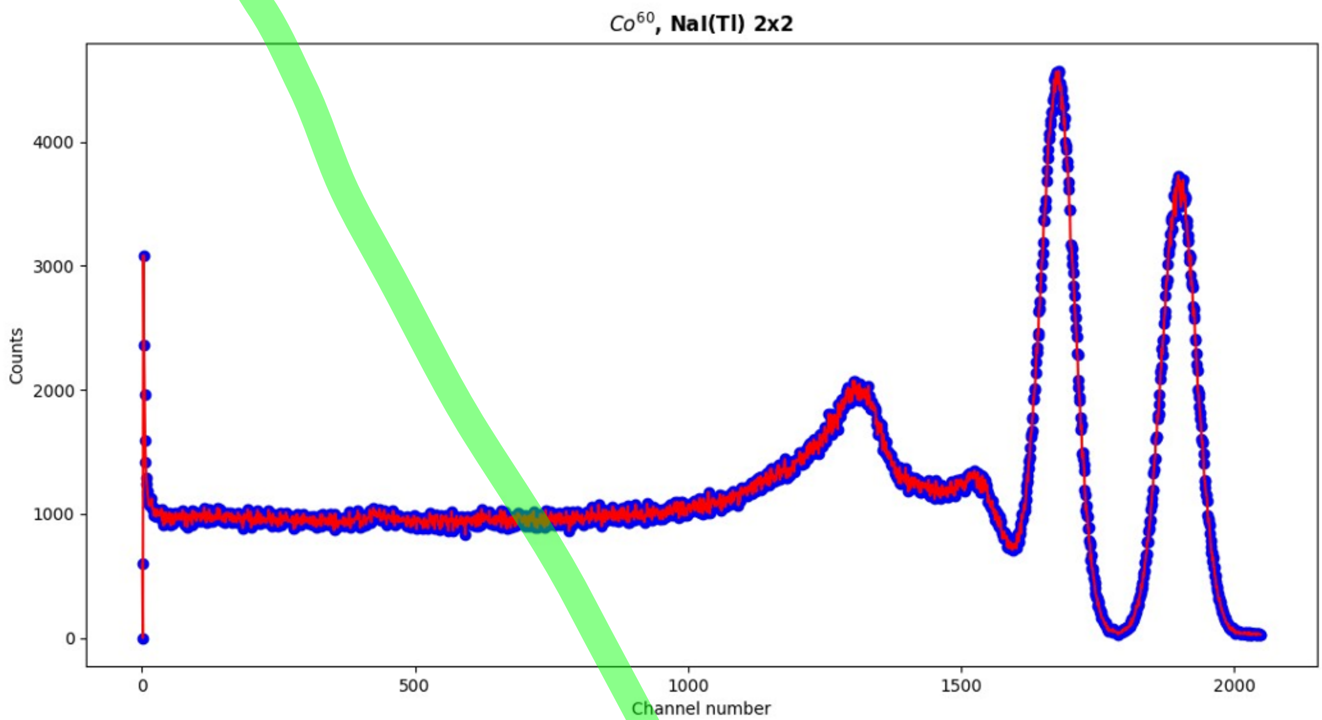
Clearly, the theoretical and experimental values are in good agrreement.

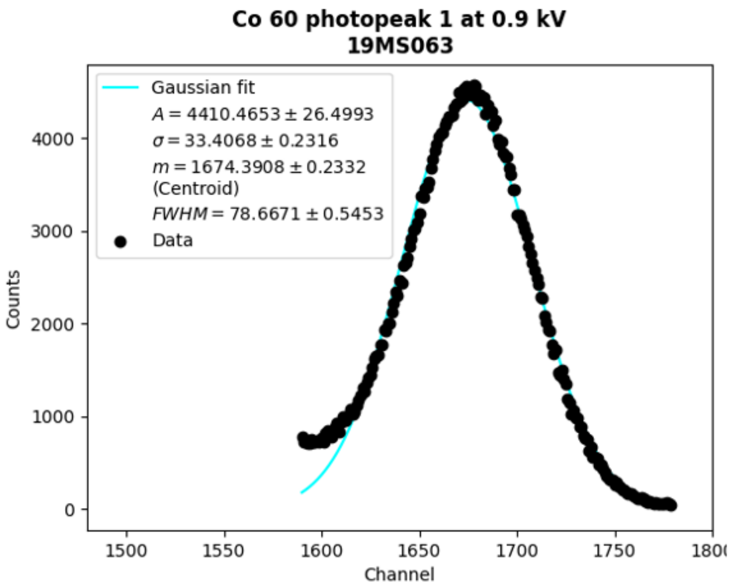
*Note : However, for **Ba^{133}** RADLAB could not produce the 5 photopeaks and we got only 3 peaks whose energies matched with the theoretical values.

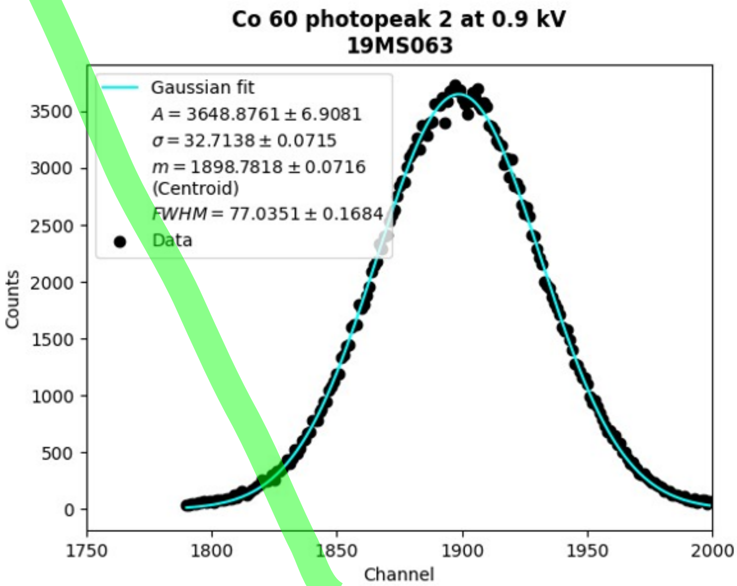
Data Analysis (PART B)

Using **Co^{60}** as source, we find out its energy spectrum using different detectors. The HV supply and amplifier gains were modified for each detector for optimum signal to noise ratio. For the **Co^{60}** γ-ray spectrum we fit the two peaks individually and obtain the centroid of each peak or **channel number** and **FWHM**. Then we calculate the photopeak efficiency and energy resolution of different detectors at 1.173 MeV and 1.332 MeV using the formulae provided in the theory section for different detectors.

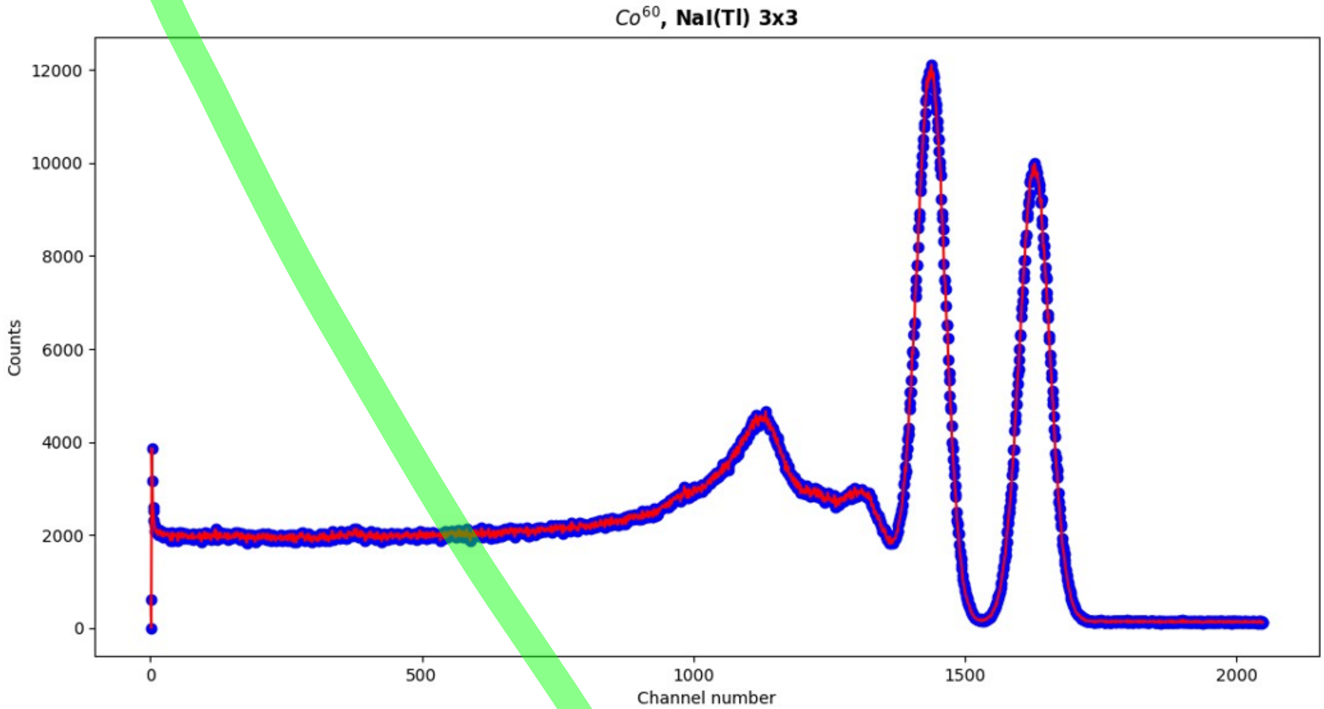
B. Graph 1

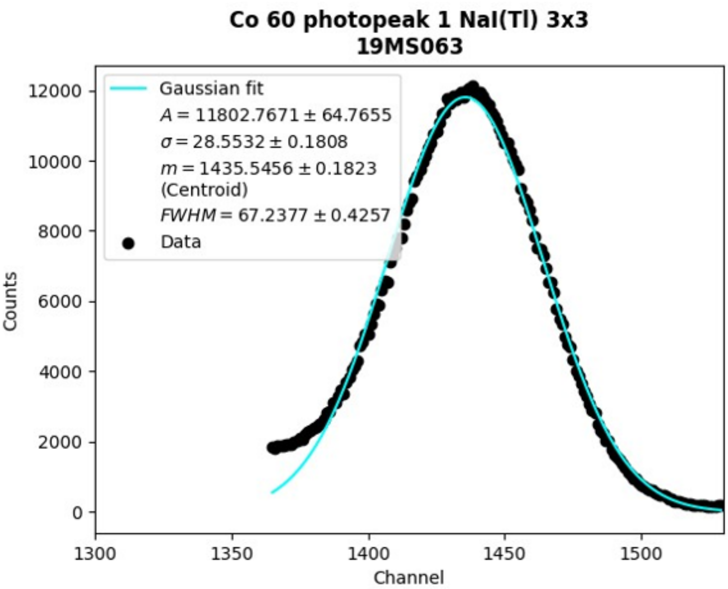


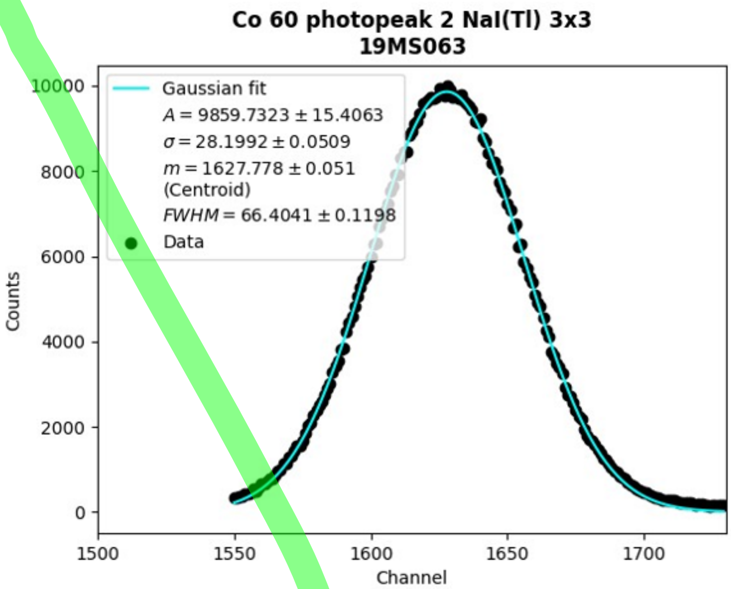




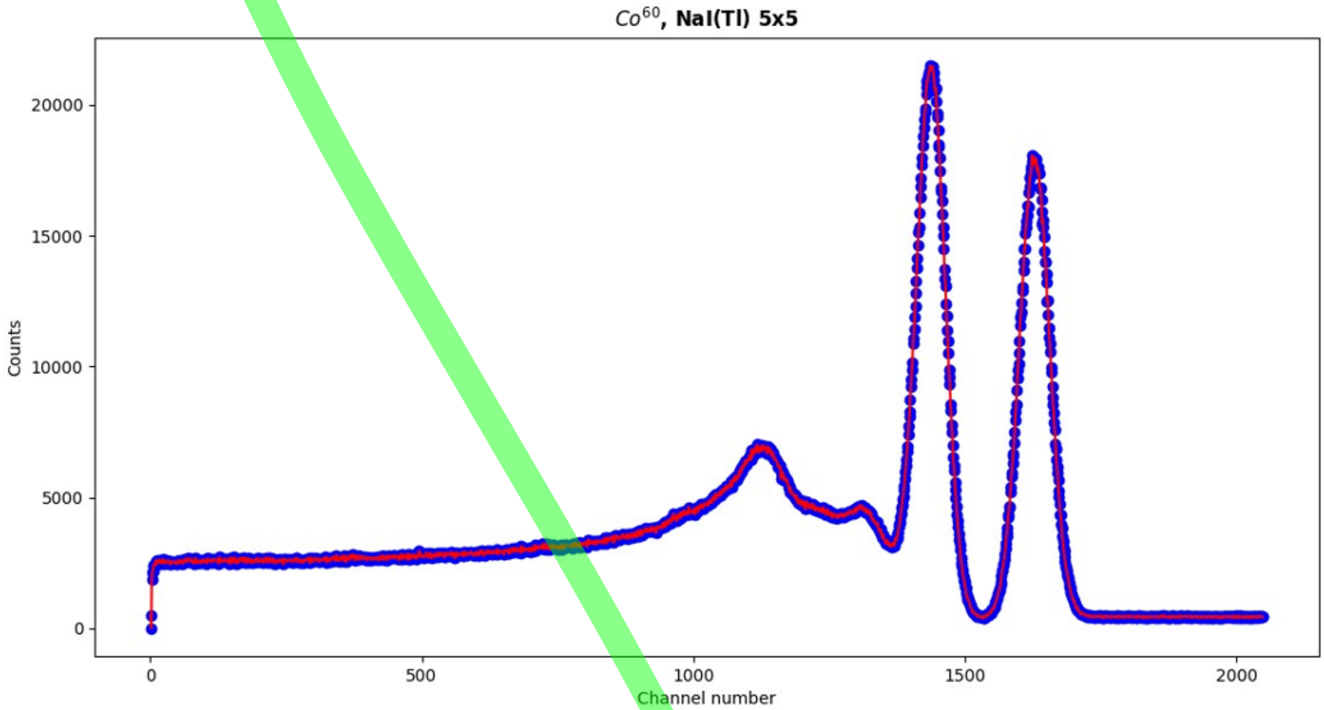
B. Graph 2


Co60, NaI(Tl) 3x3
Counts
Channel number
0
2000
4000
6000
8000
10000
12000
0
500
1000
1500
2000

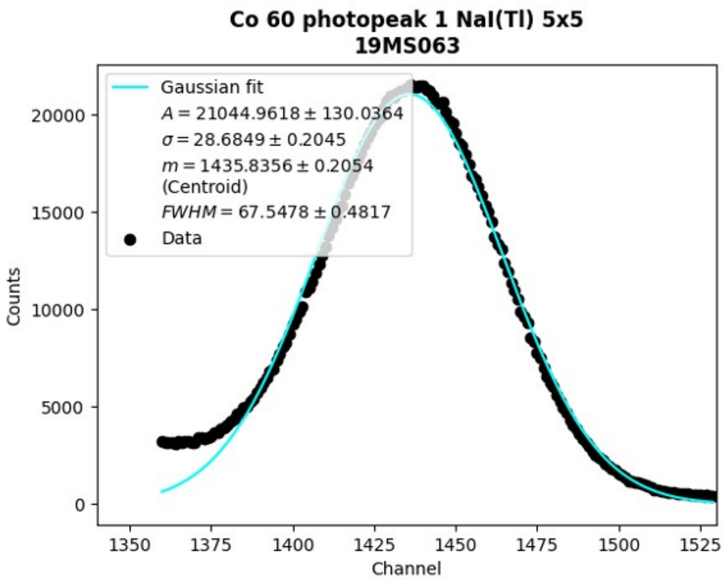

Co 60 photopeak 1 NaI(Tl) 3x3
19MS063
Gaussian fit
A = 11802.7671 ± 64.7655
σ = 28.5532 ± 0.1808
m = 1435.5456 ± 0.1823
(Centroid)
FWHM = 67.2377 ± 0.4257
Data
Counts
Channel
1300
1350
1400
1450
1500


Co 60 photopeak 2 NaI(Tl) 3x3
19MS063
Gaussian fit
A = 9859.7323 ± 15.4063
σ = 28.1992 ± 0.0509
m = 1627.778 ± 0.051
(Centroid)
FWHM = 66.4041 ± 0.1198
Data
Counts
Channel
1500
1550
1600
1650
1700

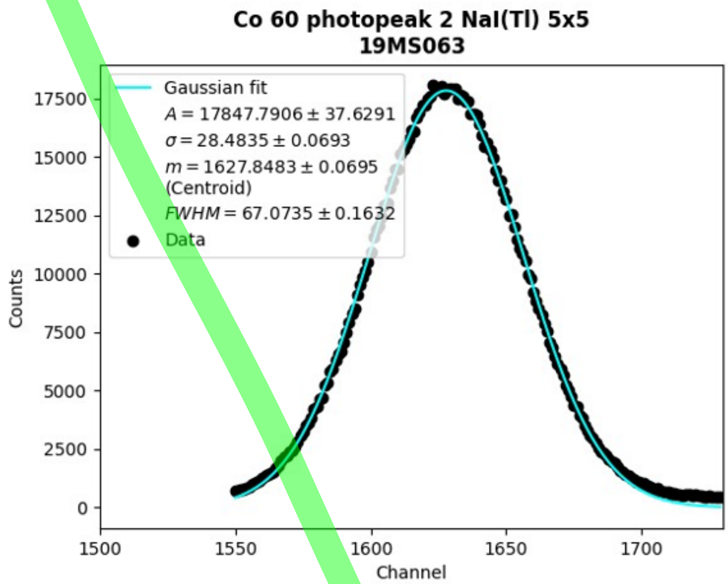
B. Graph 3



Co^{60}, NaI(Tl) 5x5
Counts
Channel number

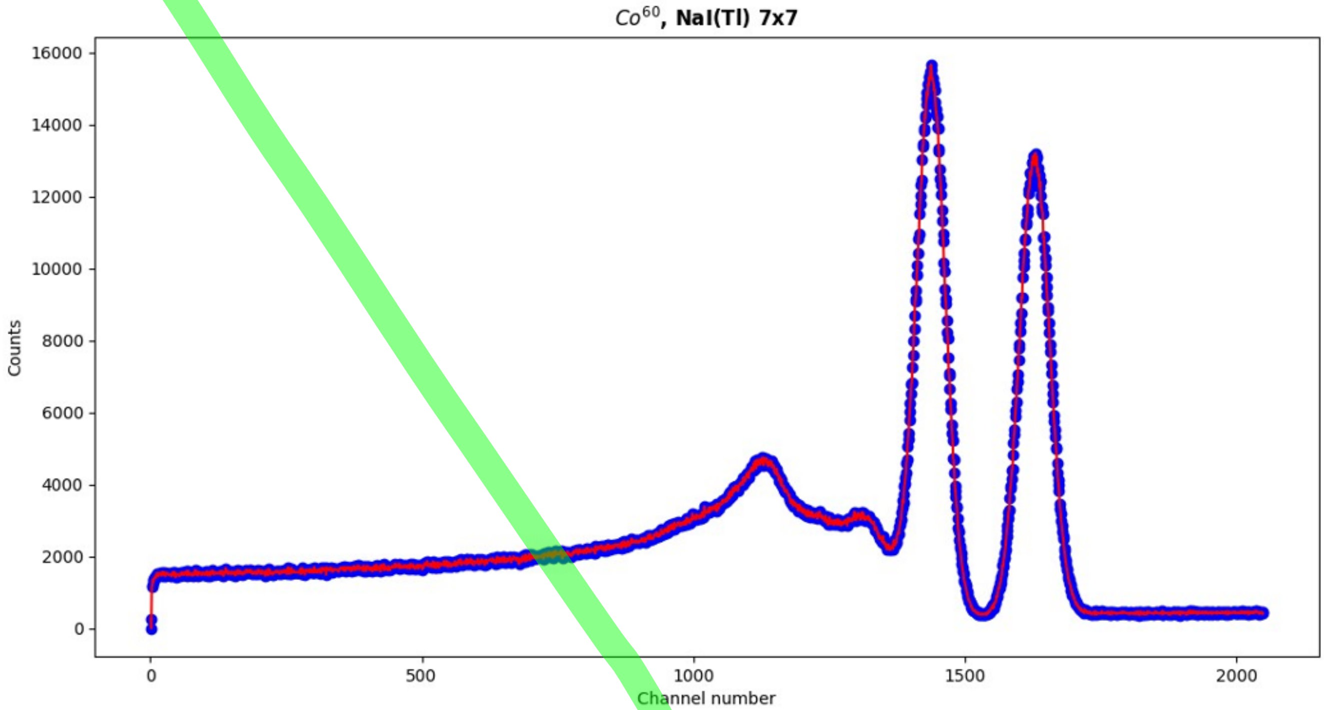


Co 60 photopeak 1 NaI(Tl) 5x5
19MS063
Gaussian fit
$A = 21044.9618 \pm 130.0364$
$\sigma = 28.6849 \pm 0.2045$
$m = 1435.8356 \pm 0.2054$
(Centroid)
$FWHM = 67.5478 \pm 0.4817$
Data
Counts
Channel

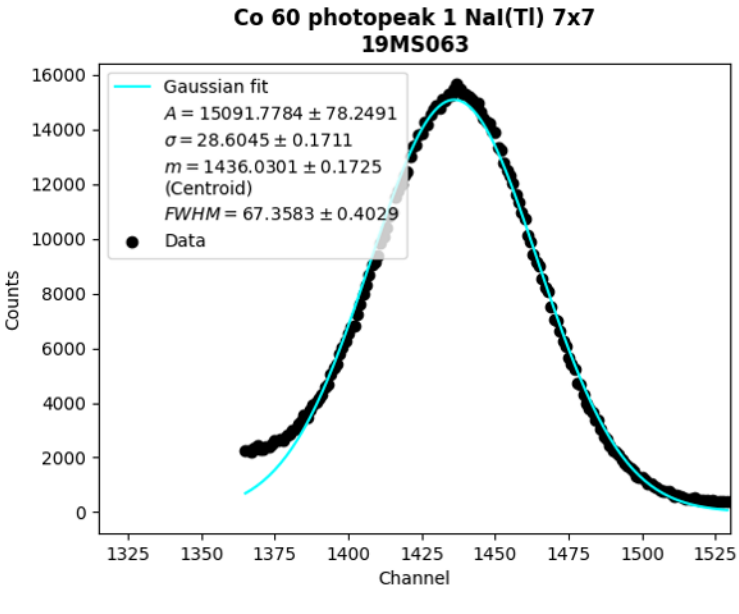


Co 60 photopeak 2 NaI(Tl) 5x5
19MS063
Gaussian fit
$A = 17847.7906 \pm 37.6291$
$\sigma = 28.4835 \pm 0.0693$
$m = 1627.8483 \pm 0.0695$
(Centroid)
$FWHM = 67.0735 \pm 0.1632$
Data
Counts
Channel

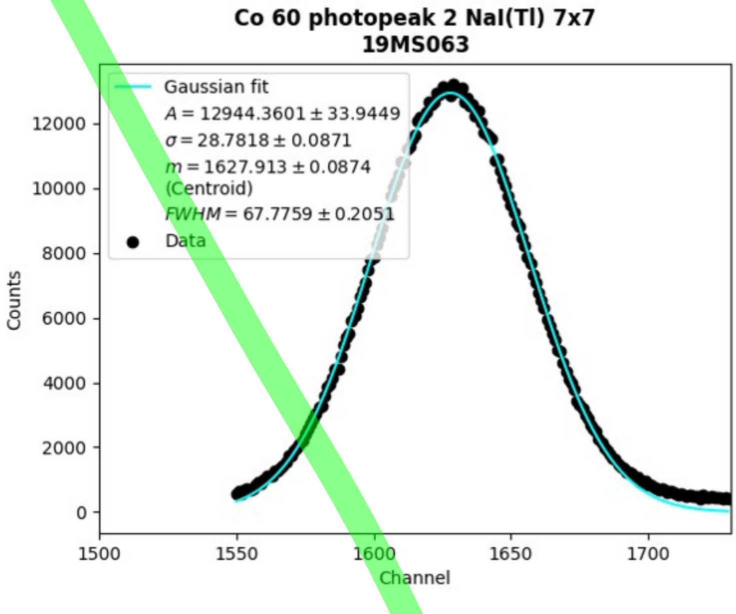
B. Graph 4



Co^{60}, NaI(Tl) 7x7
Counts
Channel number

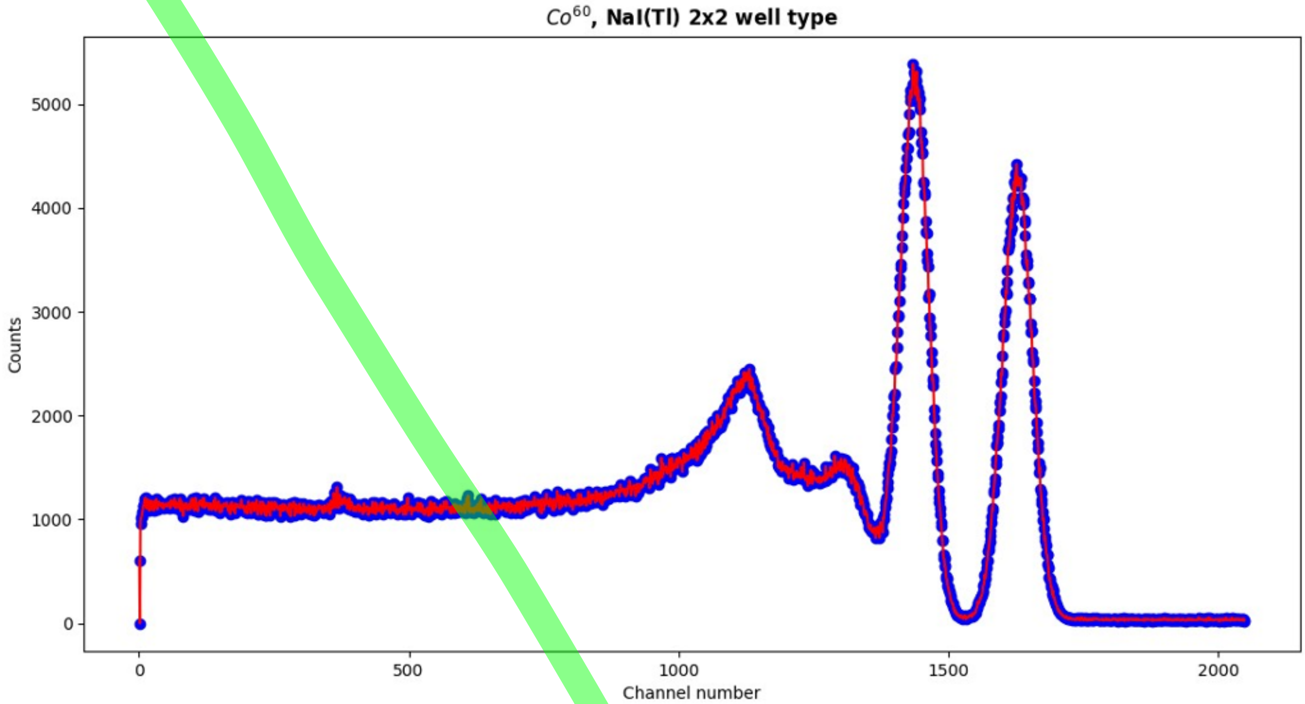


Co 60 photopeak 1 NaI(Tl) 7x7
19MS063
Gaussian fit
$A = 15091.7784 \pm 78.2491$
$\sigma = 28.6045 \pm 0.1711$
$m = 1436.0301 \pm 0.1725$
(Centroid)
$FWHM = 67.3583 \pm 0.4029$
Data
Counts
Channel

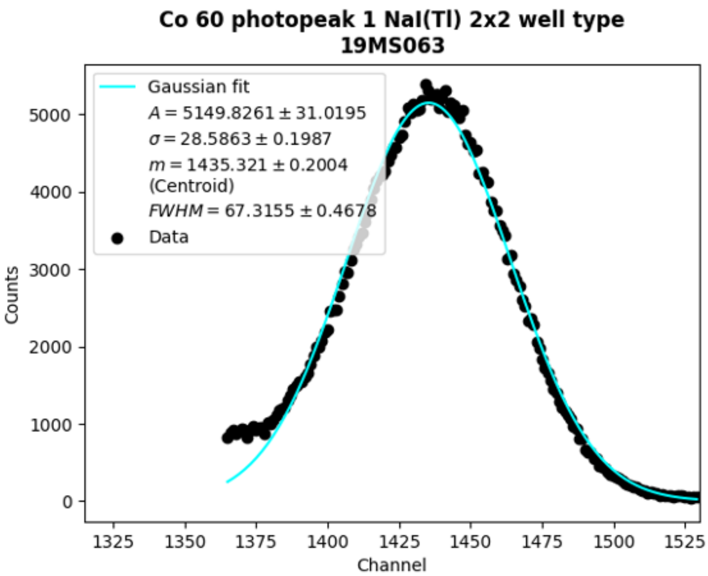


Co 60 photopeak 2 NaI(Tl) 7x7
19MS063
Gaussian fit
$A = 12944.3601 \pm 33.9449$
$\sigma = 28.7818 \pm 0.0871$
$m = 1627.913 \pm 0.0874$
(Centroid)
$FWHM = 67.7759 \pm 0.2051$
Data
Counts
Channel

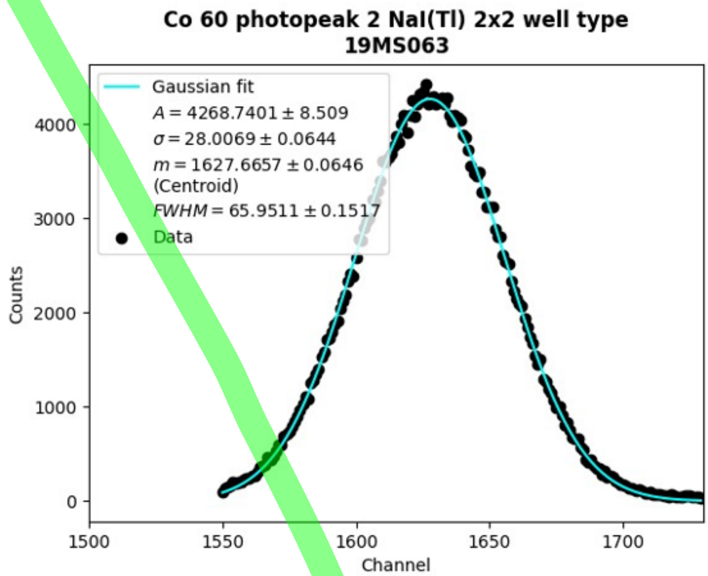
B. Graph 5



Co60, NaI(Tl) 2x2 well type
Counts
Channel number

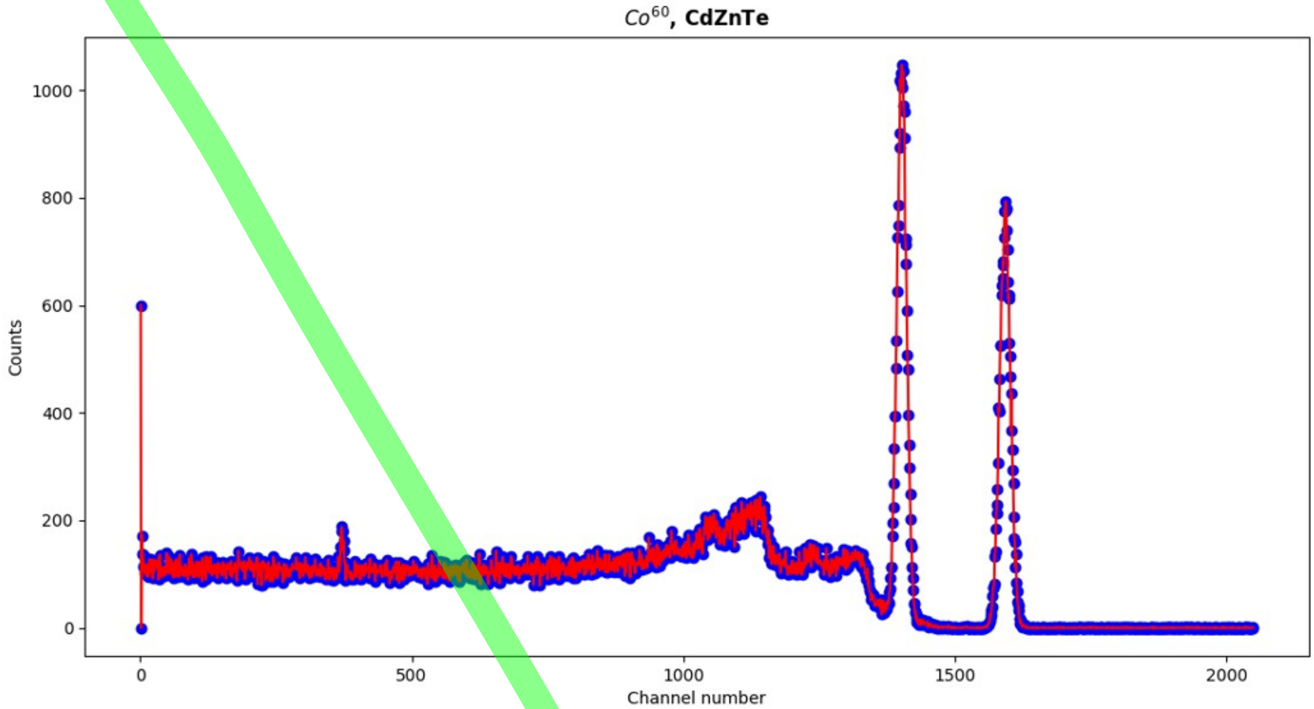


Co 60 photopeak 1 NaI(Tl) 2x2 well type
19MS063
Gaussian fit
A = 5149.8261 ± 31.0195
σ = 28.5863 ± 0.1987
m = 1435.321 ± 0.2004
(Centroid)
FWHM = 67.3155 ± 0.4678
Data
Counts
Channel

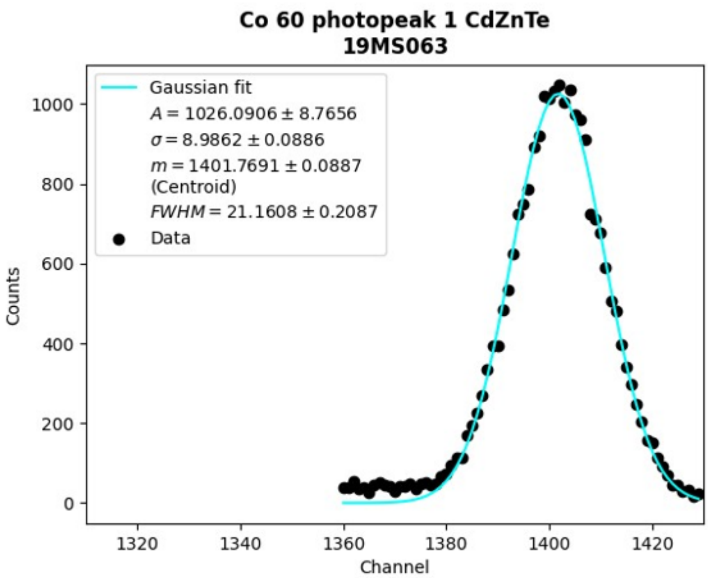


Co 60 photopeak 2 NaI(Tl) 2x2 well type
19MS063
Gaussian fit
A = 4268.7401 ± 8.509
σ = 28.0069 ± 0.0644
m = 1627.6657 ± 0.0646
(Centroid)
FWHM = 65.9511 ± 0.1517
Data
Counts
Channel

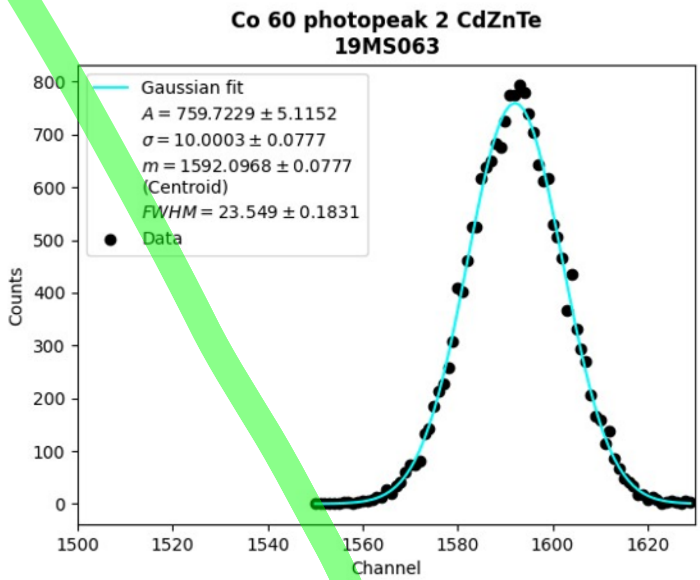
B. Graph 6



Co^{60}, CdZnTe
Counts
Channel number

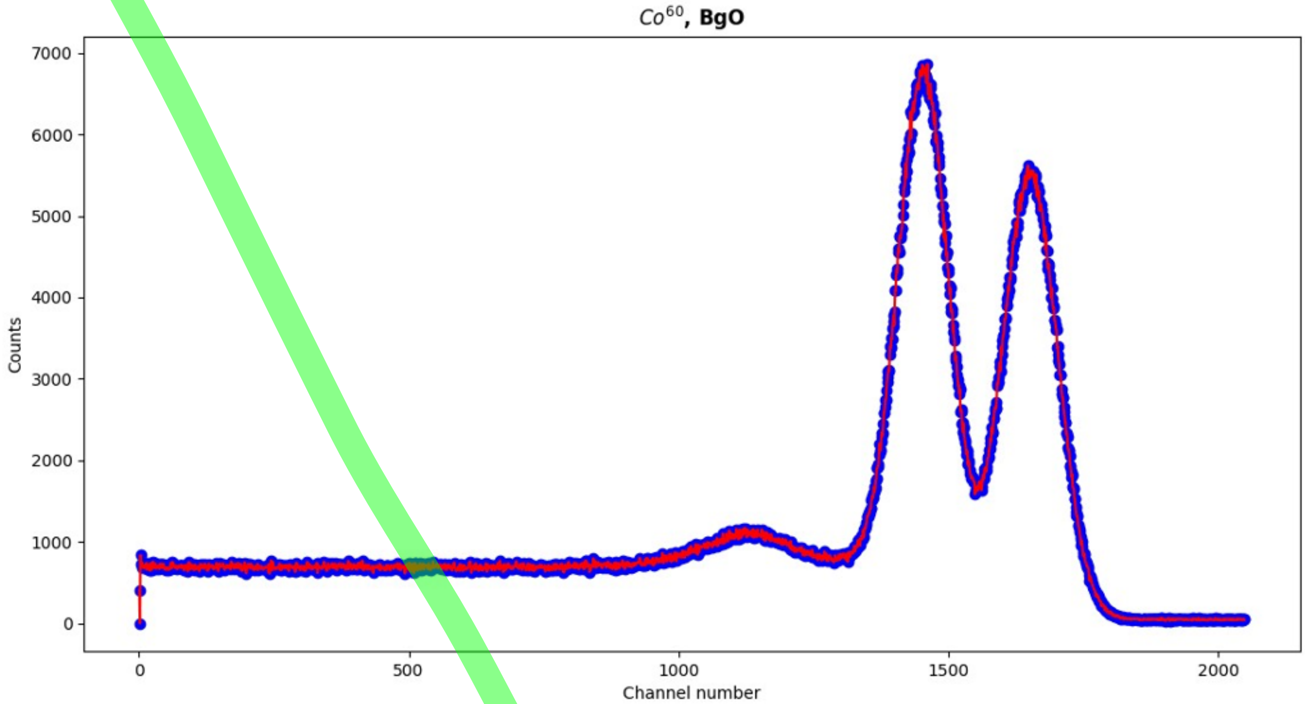


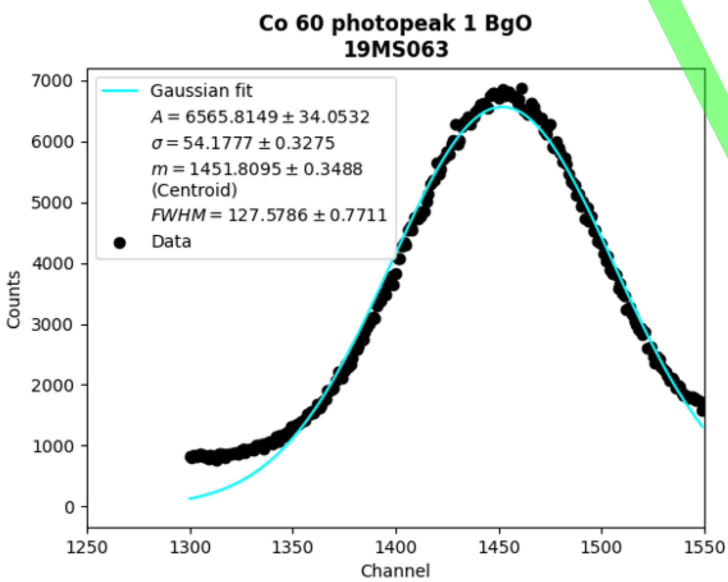
Co 60 photopeak 1 CdZnTe
19MS063
Gaussian fit
$A = 1026.0906 \pm 8.7656$
$\sigma = 8.9862 \pm 0.0886$
$m = 1401.7691 \pm 0.0887$
(Centroid)
$FWHM = 21.1608 \pm 0.2087$
Data
Counts
Channel

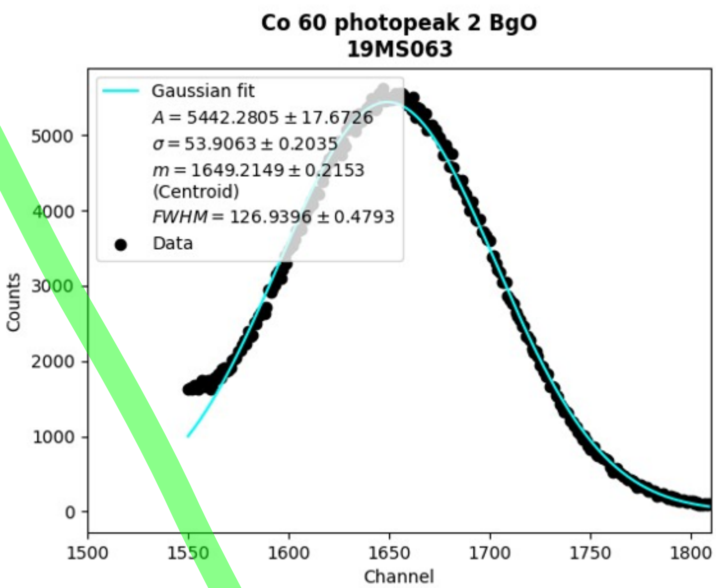


Co 60 photopeak 2 CdZnTe
19MS063
Gaussian fit
$A = 759.7229 \pm 5.1152$
$\sigma = 10.0003 \pm 0.0777$
$m = 1592.0968 \pm 0.0777$
(Centroid)
$FWHM = 23.549 \pm 0.1831$
Data
Counts
Channel

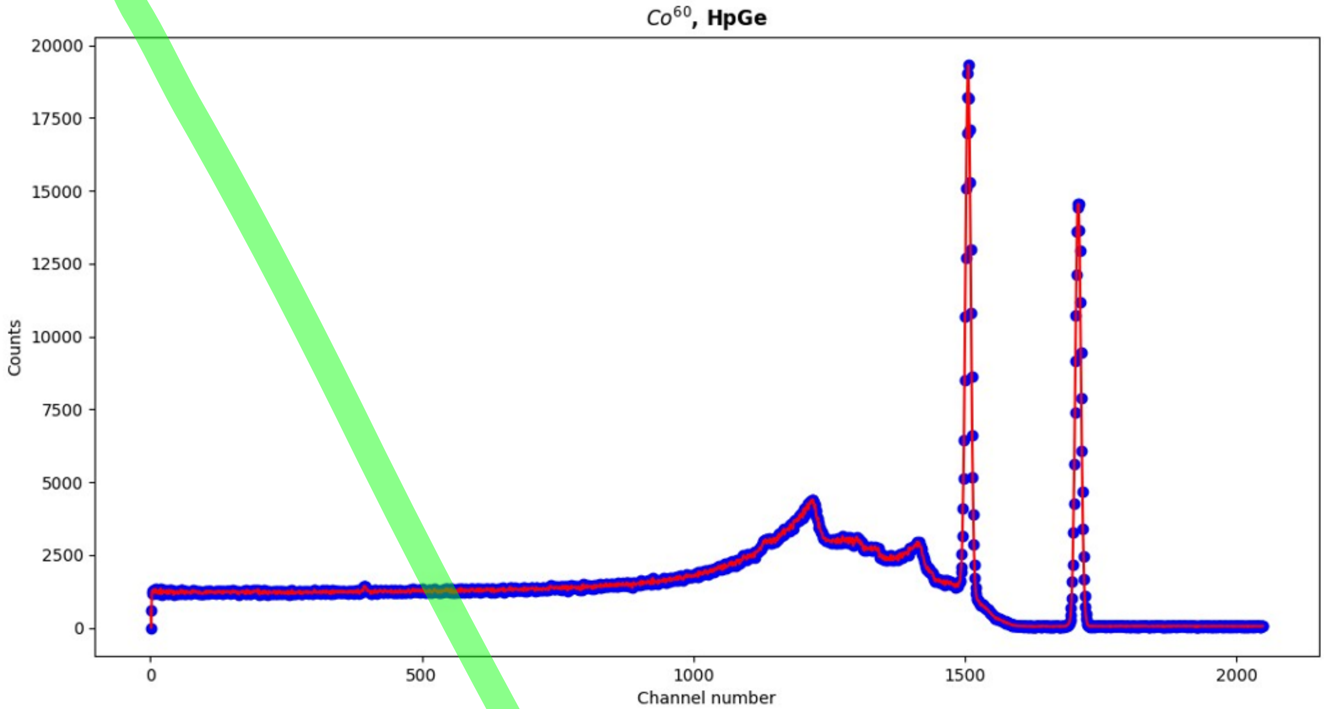
B. Graph 7

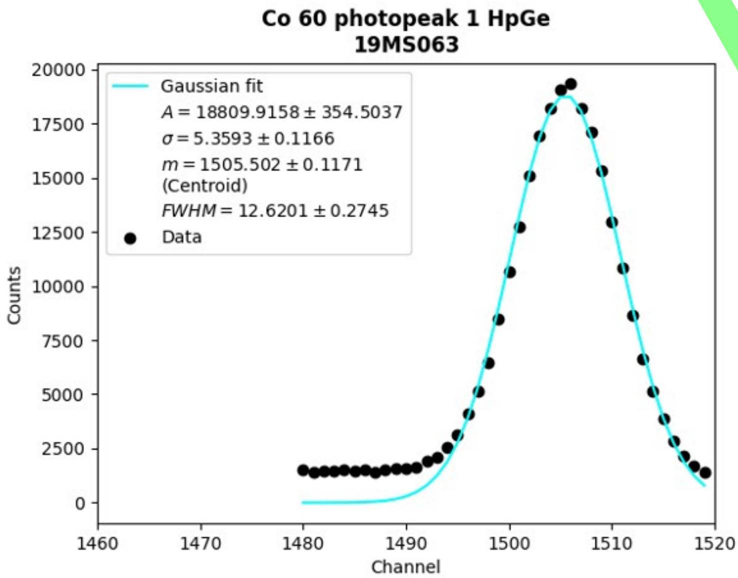

Co^{60}, BgO
Counts
Channel number
0
1000
2000
3000
4000
5000
6000
7000
500
1500
2000

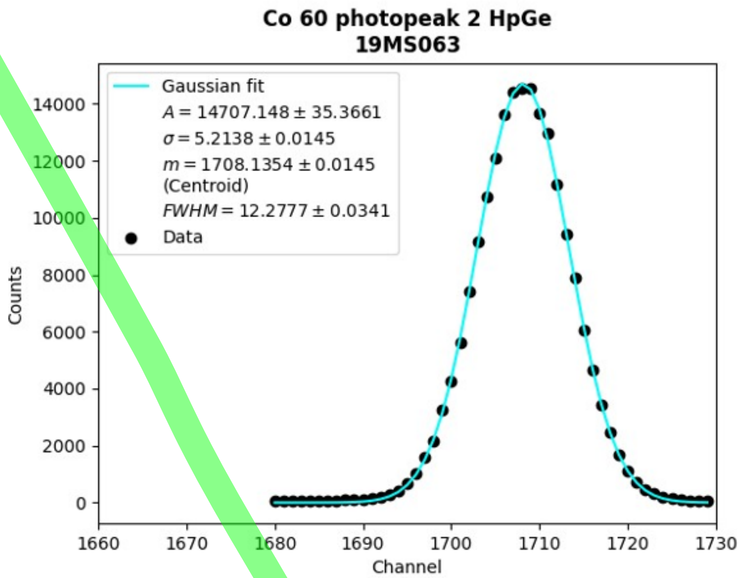

Co 60 photopeak 1 BgO
19MS063
Gaussian fit
$A = 6565.8149 \pm 34.0532$
$\sigma = 54.1777 \pm 0.3275$
$m = 1451.8095 \pm 0.3488$
(Centroid)
$FWHM = 127.5786 \pm 0.7711$
Data
Counts
Channel
1250
1300
1350
1400
1450
1500
1550


Co 60 photopeak 2 BgO
19MS063
Gaussian fit
$A = 5442.2805 \pm 17.6726$
$\sigma = 53.9063 \pm 0.2035$
$m = 1649.2149 \pm 0.2153$
(Centroid)
$FWHM = 126.9396 \pm 0.4793$
Data
Counts
Channel
1500
1550
1600
1650
1700
1750
1800

B. Graph 8







*

* Note : Data can be found at

B. Table 1

Photopeak efficiency of various detectors at 1.17 MeV and 1.33 MeV

Sl no.	Detector type	HV supply (kV)	Amp. Gain		Area under			Photopeak efficiency	
			Course	Fine	Whole curve	1.17 MeV peak	1.33 MeV peak	1.17 MeV peak	1.33 MeV peak
1	NaI(Tl) 2 x 2	0.9	70	0	2439835.5625	359917.1666667	299591.8333333	0.1475	0.1228
2	NaI(Tl) 3 x 3	1.2	50	50	4875318.33333	846795.6666667	699688.8333333	0.1737	0.1435
3	NaI(Tl) 5 x 5	1.5	50	50	7731585.60417	1516734	1284946.583333	0.1962	0.1662
4	NaI(Tl) 7 x 7	2	50	50	5301651.91667	1089821	944263.5	0.2056	0.1781
5	NaI(Tl) 2 x 2 well type	0.9	50	50	2443635.75	369696.6666667	300213.9166667	0.1513	0.1229
6	CdZnTe	0.7	150	0	207837.416667	23864	19042.66666667	0.1148	0.0916
7	BgO*	1.2	130	50	2586156.0625	874016.75	711070.4166667	0.338	0.275
8	HpGe	1.1	230	0	3118067.25	269342.0833333	193635.3333333	0.0864	0.0621

B. Table 2

Energy resolution of various detectors at 1.17 MeV and 1.33 MeV

Sl no.	Detector type	HV supply (kV)	Amp. Gain		1.17 MeV peak		1.33 MeV peak		Energy resolution	
			Course	Fine	FWHM	Centroid	FWHM	Centroid	1.17 MeV peak	1.33 MeV peak
1	NaI(Tl) 2 x 2	0.9	70	0	78.6671	1674.3908	77.0351	1898.7818	0.047	0.0406
2	NaI(Tl) 3 x 3	1.2	50	50	67.2377	1435.5456	66.4041	1627.778	0.0468	0.0408
3	NaI(Tl) 5 x 5	1.5	50	50	67.5478	1435.8356	67.0735	1627.8483	0.047	0.0412
4	NaI(Tl) 7 x 7	2	50	50	67.3593	1436.0301	67.7759	1627.913	0.0469	0.0416
5	NaI(Tl) 2 x 2 well type	0.9	50	50	67.3155	1435.321	65.9511	1627.6657	0.0469	0.0405
6	CdZnTe	0.7	150	0	21.1608	1401.7691	23.549	1592.0968	0.0151	0.0148
7	BgO*	1.2	130	50	127.5786	1451.8095	126.9396	1649.2149	0.0879	0.077
8	HpGe	1.1	230	0	12.6201	1505.502	12.2777	1708.1354	0.0084	0.0072

B. Table 3

Photopeak efficiency and energy resolution of various detectors at 1.17 MeV and 1.33 MeV

Detector type	HV supply (kV)	Amp. Gain		Energy resolution		Photopeak efficiency	
		Course	Fine	1.17 MeV peak	1.33 MeV peak	1.17 MeV peak	1.33 MeV peak
NaI(Tl) 2 x 2	0.9	70	0	0.047	0.0406	0.1475	0.1228
NaI(Tl) 3 x 3	1.2	50	50	0.0468	0.0408	0.1737	0.1435
NaI(Tl) 5 x 5	1.5	50	50	0.047	0.0412	0.1962	0.1662
NaI(Tl) 7 x 7	2	50	50	0.0469	0.0416	0.2056	0.1781
NaI(Tl) 2 x 2 well type	0.9	50	50	0.0469	0.0405	0.1513	0.1229
CdZnTe	0.7	150	0	0.0151	0.0151	0.1148	0.0916
BgO*	1.2	130	50	0.0879	0.077	0.338	0.275
HpGe	1.1	230	0	0.0084	0.0072	0.0864	0.0621

*

* Note : For BgO detector, we could only take readings for 400s since RADLAB constantly hanged for this particular detector.

Conclusions

In **PART A**, we successfully calibrated the **MCA** with known energies of **Co**^{60} peaks and found out the unknown energies of the peaks for other sources which indeed matched quite well with the theoretical values. For **Ba^{133}** RADLAB could resolve only 3 peaks which had matching energies with the theoretical values.

In **PART B** of the experiment, we notice that for **NaI(Tl)** detectors the **photopeak efficiency** increases with the size of the detector so **NaI(Tl) 7x7** is the most energy efficient and has similar resolution to other **NaI(Tl)** detectors. In terms of **energy efficiency**, **BgO** detector turns out to be the best but not preferably good in terms of **resolution**. **HpGe** detectors followed by **CdZnTe** detectors are **best for resolution** but have low **energy efficiency**.

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* All the graphs are plotted and fitted using MATPLOTLIB
Data collected for the experiment can be found at