Study of Gamma ray spectroscopy using SCA and MCA

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Different radioactive gamma sources emit gamma rays having different energy. In this experiment, we analyze the spectrum of gamma rays from different sources using a Single channel analyzer (SCA) and a Multi-channel analyzer (MCA). Using the known energies of one or more sources we can calibrate the MCA and then find the photopeak energy of any unknown sample. We also calculated the mass absorption coefficient of Aluminium blocks using MCA.

I. OBJECTIVES

- To study the energy resolution characteristics of a scintillation spectrometer as a function of applied high voltage and to determine the best operating voltage using SCA.
- To study the gamma-ray spectrum of Cs-137 over a range of (LLD-ULD) using SCA.
- To determine the resolution of MCA using Cs-137 and Co-60 sources and to find the photopeaks for the respective spectrum and calibrate the spectrum in terms of energy (keV/Channel).
- Study of multiple spectrum and calculation of FWHM and resolution for a given scintillation detector and hence verify the energy linearity curve.
- Study of unknown sample spectrum and finding its properties.
- To measure experimentally the mass absorption coefficient in Aluminium for 662 keV gamma rays.

II. THEORY

Gamma rays are generated from radioactive nuclei and have high energy. These are basically high-energy photons.
Gamma rays can interact with matter in 3 different ways:

- Photoelectric absorption
- Compton scattering
- Pair production

These interactions happen at different energy levels, as photoelectric absorption happens at low energy (up to several hundred keVs) while pair production happens at high energy (above 5-10 MeVs) and Compton scattering can occur for all energies.
The gamma-ray interaction is highly dependent on the atomic number of the interaction medium.

A. Photoelectric absorption

In photoelectric absorption, the incident gamma ray is absorbed by an electron completely. The kinetic energy of the released electron is now equal to, the energy of the gamma ray - binding energy of the electron.

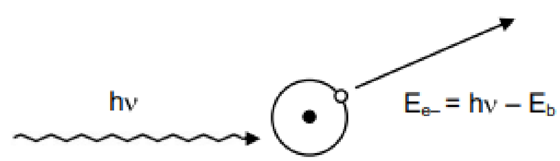

FIG. 1. Photoelectric absorption

$$E_{e^-} = h\nu - E_b \tag{1}$$

Generally, photoelectrons are more likely to emerge from K-shell since the binding energy for this shell ranges from a few to tens of keV depending upon its atomic number. Photoelectric absorption is the process of emitting the electron which carries most of the gamma-ray energy, with some low-energy electrons corresponding to the absorption of the original binding energy of the photoelectron. If nothing leaves the system the KE of electrons must be equal to that of the gamma-ray photon. Therefore for an ideal process, the above condition must be satisfied.

FIG. 2. Photopeak corresponding to photoelectric absorption

B. Compton scattering

In the Compton scattering interaction, a photon is not absorbed but instead scatters elastically with the electron. Energy and momentum of the photons and electrons after the scattering are exactly like if this is a collision between particles, and, as first measured by Compton, this was one of the early convincing pieces of evidence that light could behave as “a particle”.

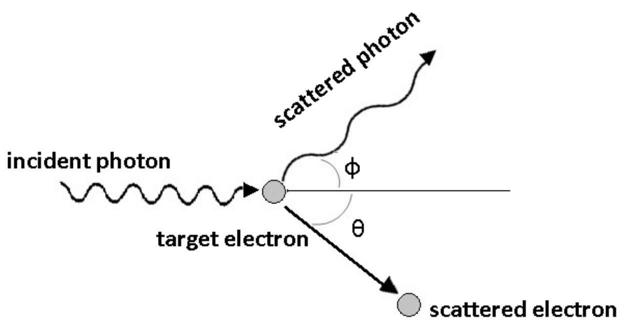

FIG. 3. Compton scattering

The energy of scattered gamma ray $h\nu'$ in terms of angle θ is given by:

$$h\nu' = \frac{h\nu}{1 + (h\nu/m_0c^2)(1 - cos\theta)} \tag{2}$$

where m_0c^2 is the rest mass energy of electron (0.511MeV).
The kinetic energy of recoil is therefore

$$E_{e^-=h\nu-h\nu'} = h\nu\frac{(h\nu/m_0c^2)(1 - cos\theta)}{1 + (h\nu/m_0c^2)(1 - cos\theta)} \tag{3}$$

The two extreme cases arise when θ=0, incident and emitted gamma have nearly the same energy.
When $\theta = \pi$ the incident gamma is backscattered towards its direction of origin.
The energy distribution for any one specific gamma-ray energy is the difference between maximum Compton recoil electron energy and incident energy is:

$$E_c = \frac{h\nu}{1 + 2h\nu/m_0c^2} \tag{4}$$

In the limit of $h\nu >> m_0c^2/2$;

$$E_c = 0.256MeV$$

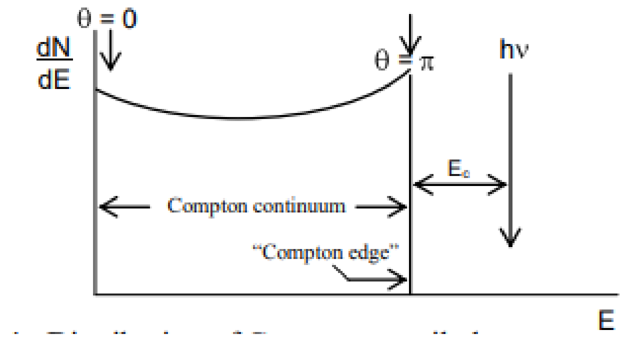

FIG. 4. Distribution of Compton recoil electrons

C. Pair production

The process occurs in the intense electric field near the photons in the nuclei of the absorbing material and corresponds to the creation of an electron-positron pair at the point of complete disappearance of the incident gamma-ray photon.

$$E_{e^-} + E_{e^+} = h\nu – 2m_oc^2 \tag{5}$$

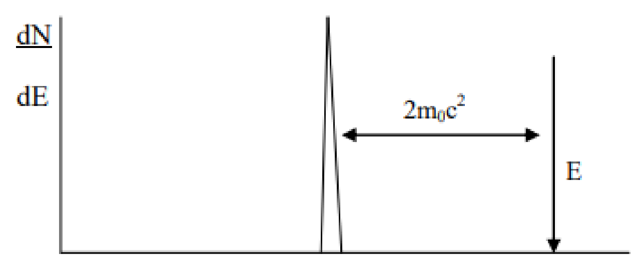

FIG. 5. Peak corresponding to the total kinetic energy of the pair (electron+ positron) created during the pair production process

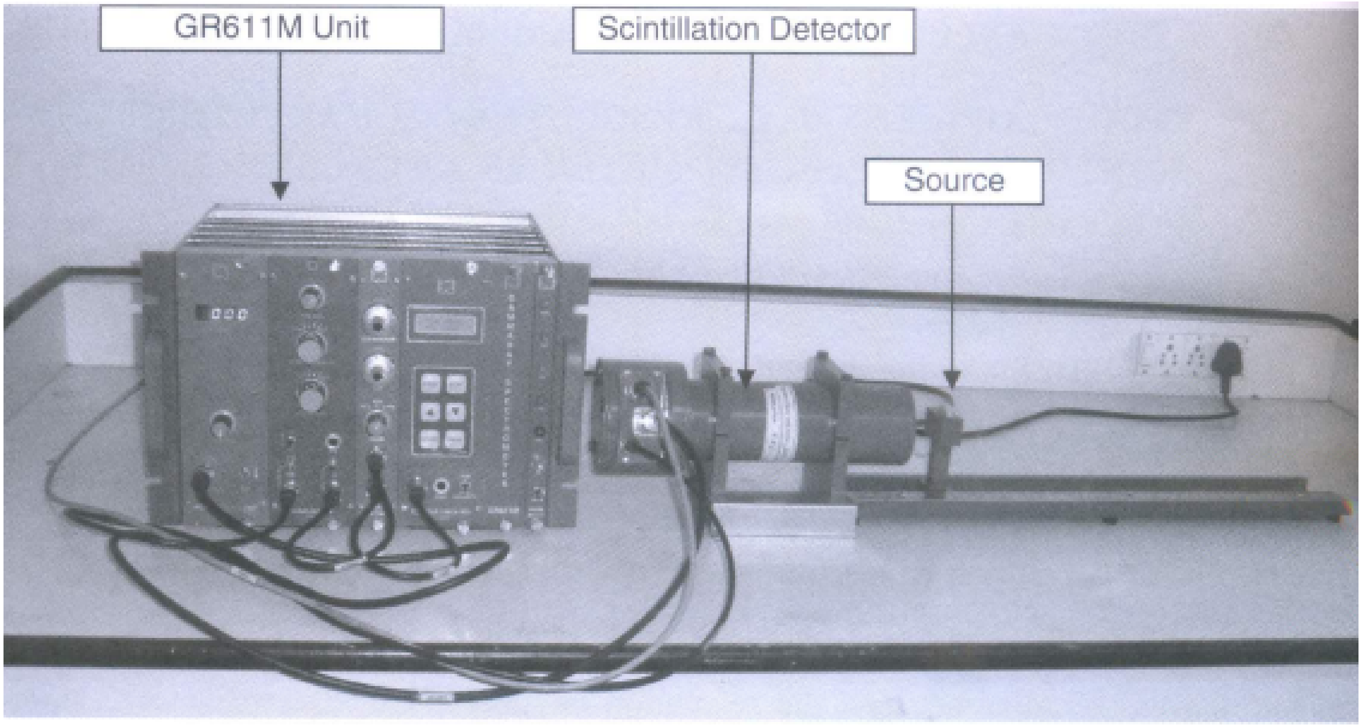

FIG. 6. Experimental setup

III. EXPERIMENTAL SETUP

Components required :

- Scintillation detector
- High voltage unit
- Single channel analyser(produces an output logic pulse on the condition that the peak amplitude of its input signal falls within the pulse height window that is established with two preset threshold levels)
- Multi channel analyzer (analyzes a stream of voltage pulses and sorts them into a histogram, or "spectrum" of the number of events, versus pulse height, which may often relate to energy or time of arrival)
- PC
- Gamma-ray sources:
  - Cs-137
  - Co-60
  - Ba-133
  - Na-22(Unknown)
- Aluminium plates

The experimental setup is shown in FIG.6.

IV. OBSERVATIONS AND CALCULATIONS -

A. Single Channel Analyzer (SCA)

Table 1: Baseline voltage vs Count for different operating voltages using Cs-137

Operating voltage = 500 V	
Baseline voltage (V)	Counts
2.4	1497
2.5	1062
2.6	1022
2.7	993
2.8	1069
2.9	1676
3	5068
3.1	10791
3.2	7543
3.3	3330
3.4	699
3.5	212

Operating voltage = 551 V	
Baseline voltage (V)	Counts
2.4	1979
2.5	1998
2.6	2211
2.7	2796
2.8	4087
2.9	8527
3	4371
3.1	3185
3.2	2313
3.3	1990
3.4	1978
3.5	2056

Operating voltage = 602 V	
Baseline voltage (V)	Counts
2.4	1769
2.5	1813
2.6	2307
2.7	3146
2.8	4987
2.9	10542
3	5135
3.1	3672
3.2	3167
3.3	2998
3.4	2859
3.5	2453

Operating voltage = 651 V	
Baseline voltage (V)	Counts
2.4	562
2.5	551
2.6	770
2.7	2517
2.8	6321
2.9	10186
3	8465
3.1	3295
3.2	675
3.3	189
3.4	135
3.5	109

Operating voltage = 700 V	
Baseline voltage (V)	Counts
2.4	755
2.5	744
2.6	895
2.7	1925
2.8	4936
2.9	9153
3	8822
3.1	4038
3.2	921
3.3	437
3.4	255
3.5	145

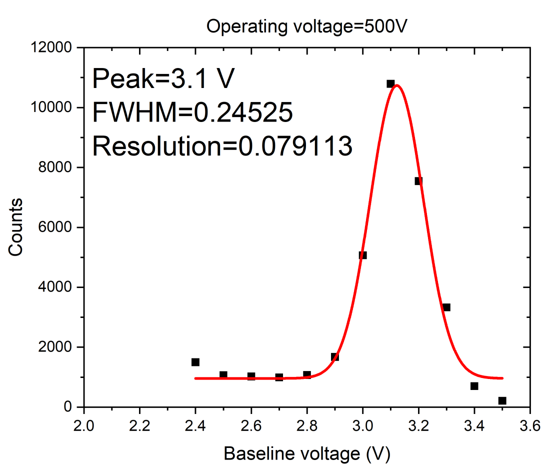

FIG. 7. Plot of baseline voltage vs counts at operating voltage=500V

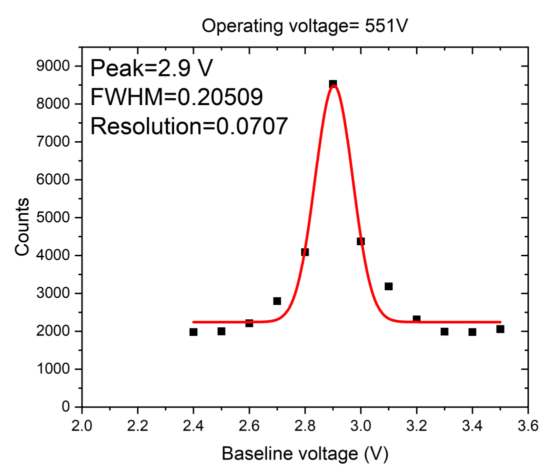

FIG. 8. Plot of baseline voltage vs counts at operating voltage=551V

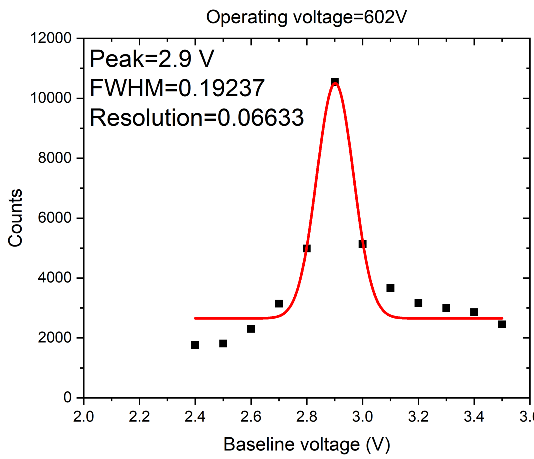

FIG. 9. Plot of baseline voltage vs counts at operating voltage=602V

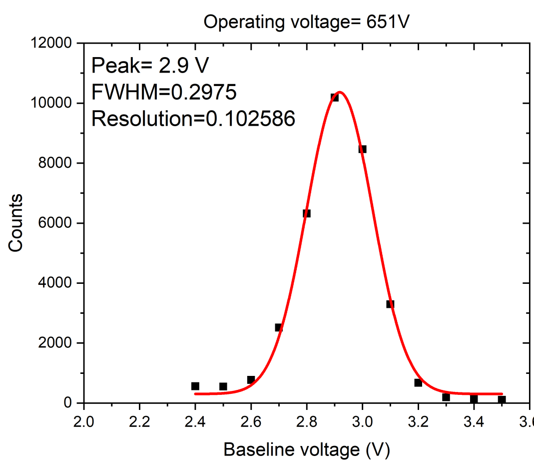

FIG. 10. Plot of baseline voltage vs counts at operating voltage=651V

From FIG.(12), we can see that the resolution is minimum around 600 V.
Error:

$$\frac{\delta V_o}{V_o} = \frac{1}{600} = 0.00167$$

$$\delta V_o = 1$$

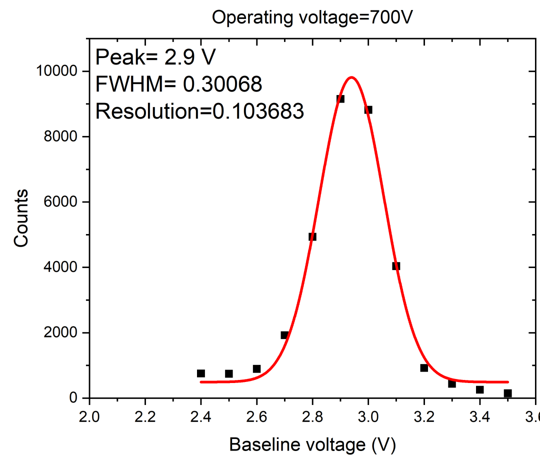

FIG. 11. Plot of baseline voltage vs counts at operating voltage=700V

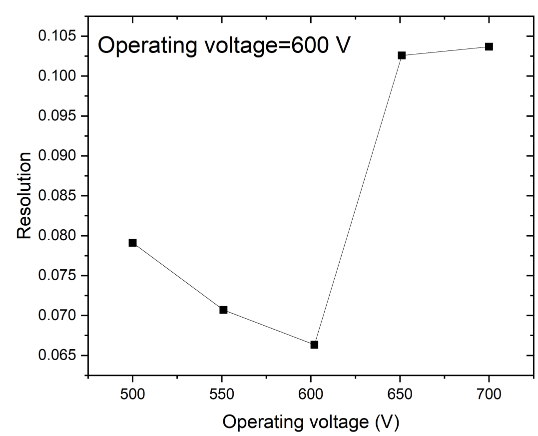

FIG. 12. Plot of operating voltage vs resolution

So, the operating voltage $(V_o) = (600 \pm 1)$ V.

Table 2: Baseline voltage vs Count over a range using Cs-137
Please refer to the next page.

LLD (V)	Counts
0.4	3290
0.5	3741
0.6	4028
0.7	4063
0.8	4403
0.9	5111
1	5226
1.1	4431
1.2	3652
1.3	3310
1.4	3273
1.5	3029
1.6	3001
1.7	2970
1.8	2990
1.9	2913
2	2980
2.1	2924
2.2	2400
2.3	1717
2.4	1240
2.5	933
2.6	828
2.7	804
2.8	1265
2.9	3745
3	9372
3.1	14678
3.2	12491
3.3	5358
3.4	1353
3.5	330
3.6	178

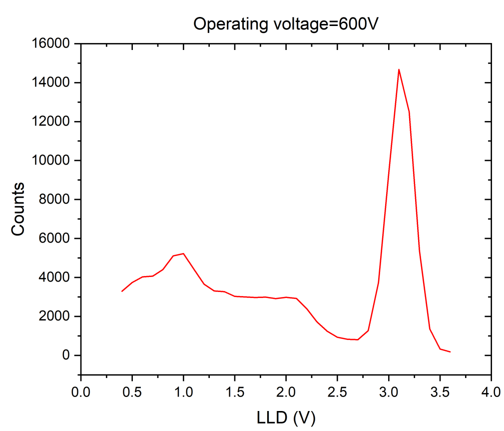

FIG. 13. Gamma ray spectrum for Cs-137 using SCA

B. Multi Channel Analyzer

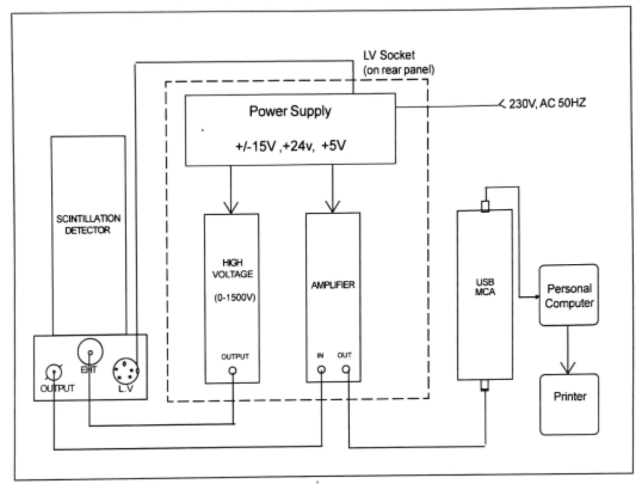

FIG. 14. Operation of MCA

1. *Calibration using Cs-137*

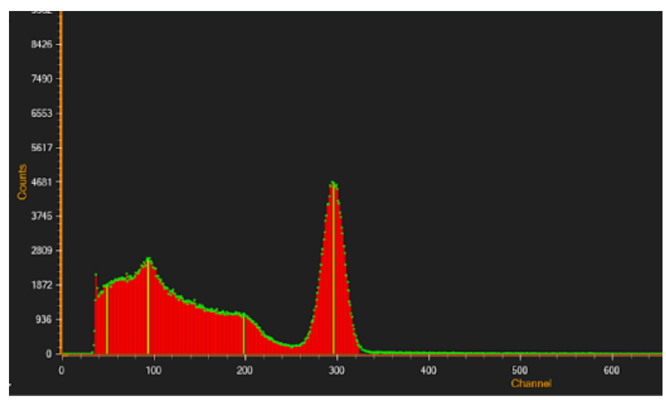

FIG. 15. Gamma-ray Spectrum of Cs-137 using MCA

From the ROI report, we got the following values:

- Photopeak energy = 662 keV
- Peak Channel number = 299.2451
- FWHM = 27.26237

So,
Resolution $= \frac{FWHM}{Peakchannelnumber} \times 100 = 9.11\%$

2. *Multi-peak Calibration using Co-60*

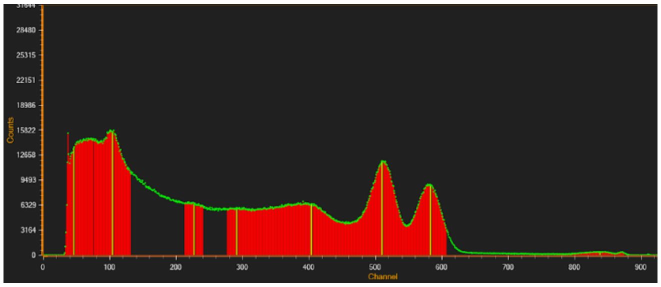

FIG. 16. Gamma-ray Spectrum of Co-60 using MCA

From the ROI report, we got the following values:

- Photopeak energy = 1170 keV & 1330 keV
- Peak Channel number = 511.3022 & 580.6375
- FWHM = 15 & 15

So,
$$\text{Resolution}(1) = \frac{FWHM}{Peakchannelnumber} \times 100 = 2.93\%$$
$$\text{Resolution}(2) = \frac{FWHM}{Peakchannelnumber} \times 100 = 2.58\%$$

Peak channel difference = 69.3353 channels
Peak energy difference = (1330-1170) keV = 160 keV

Thus, 1 channel corresponds to energy = 160/69.3353 = 2.307 keV

3. *Gamma ray Spectrum for a mixed source*

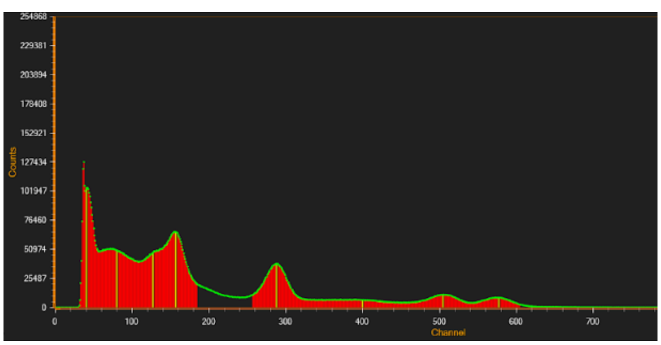

FIG. 17. Gamma-ray Spectrum of mixed source using MCA

According to ROI report, for the spectrum, we get 4 peak channels at 158.7645, 284.0424, 504.8062, and 578.6011 channels. These peak channels correspond to the energy (as calculated in the previous subsection) 366.27 keV, 655.286 keV, 1164.588 keV, and 1334.833 keV respectively.

4. *Energy linearity curve*

Source	Peak energy (keV)	Peak channel
Ba-133	366.27	158.7645
Cs-137	655.286	284.0424
Co-60	1164.588	504.8062
Co-60	1334.833	578.6011

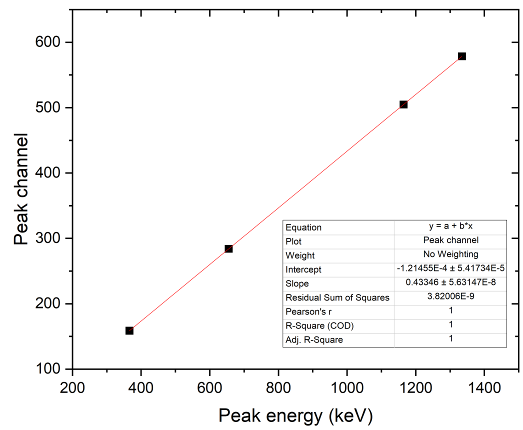

FIG. 18. Energy-channel linearity curve

5. *Gamma ray spectrum of Na-22*

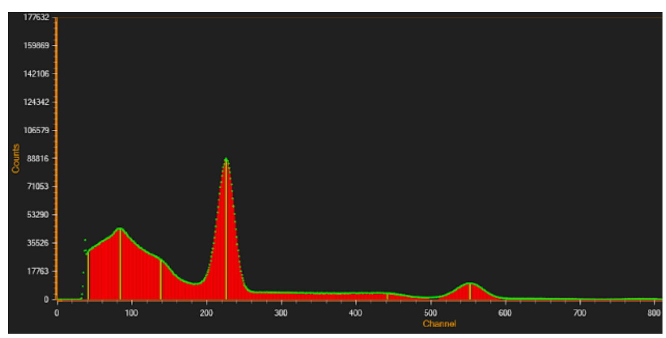

FIG. 19. Gamma ray spectrum of Na-22 using MCA

From the ROI report, we got the following values:

- Photopeak channel= 222.129
- FWHM = 28.28634
- Resolution = 12.4 %

FIG. 20. Photopeak energy corresponding to photopeak channel for Na-22

Photopeak energy corresponding to the obtained photopeak channel (from FIG.18) = 512.303 keV.
Relative error:

$$\frac{\delta E}{E} = \frac{512.303 - 511}{511} = 0.0025$$

$$\delta E = 1.303$$

6. *Mass absorption coefficient of Aluminium*

Aluminium absorber, t=150 s		**Background=1498**
Thickness (cm)	Gross counts	Net counts
7.2	13184	11686
6.55	14052	12554
5.9	15506	14008
5.25	17035	15537
4.6	18829	17331
3.95	20856	19358
3.3	23063	21565
2.65	24670	23172
2	27567	26069
1.35	30158	28660
0.65	33476	31978
0	37170	35672

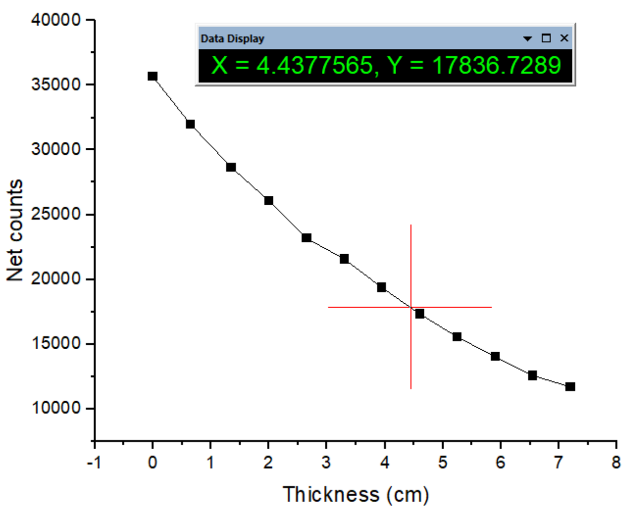

FIG. 21. Plot of thickness of Al absorber vs counts

From FIG.21,

- The half value corresponds to thickness (HVL) = 4.4377 cm
- Density thickness = $4.4377 \times 2.7 = 11.9818 g/cm^2$
- The mass absorption coefficient,

$$m = 0.693/HVL = 0.156 cm^2/gm$$

Error:

$$\frac{\delta m}{m} = \frac{\delta HVL}{HVL} = 0.146$$

$$\delta m = 0.023 cm^2/gm$$

V. RESULTS AND CONCLUSIONS

- Using SCA, we adjusted different operating voltages and found the resolution of the scintillation detector. The best resolution is observed for operating voltage (600 ± 1)V.
- Using SCA for operating voltage (600V) we observed counts for a range of LLD values(0.4-3.5V) and plotted the spectrum. The prominent peak is the gamma photo peak, while the other peaks were due to backscattering and Compton.
- For the MCA part, we used ANUSPECT software to observe the spectrum of Cs-137. The spectrum had a photopeak at 299.2451 channel. The resolution was found to be 9.11%. Effects like Compton and backscattering are also present in the spectrum.
- Using Co-60, we observed two peaks in the spectrum. The resolution, in this case, was found to be 2.93% and 2.58% for the two peaks.
- For the calibration study we used 3 radioactive samples at the same time, Cs-137, Ba-133, and Co-60 from which we got a linearity curve.
- The unknown source has an energy peak at (512.303 ± 1.303) KeV, which was identified by calibration done in the previous part so the unknown source is found to be Na-22.
- We can observe that the counts decrease as the thickness of the absorber increases. The mass absorption coefficient for Al was found to be $(0.156 \pm 0.023) cm^2/gm$ from the curve.

VI. SOURCES OF ERRORS AND PRECAUTIONS

- Source should be kept near the detector to get a good spectrum.

- The errors could be due to the presence of other radioactive sources present in the lab.
- Systemic errors.

VII. REFERENCES

- NISER Lab Manual
- `http://www.physics.rutgers.edu/~eandrei/389/gamma.pdf`