EXPERIMENTS WITH GAMMA RAY SPECTROMETER

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PREFACE

This is the second revised experimental manual for a product which is manufactured and fully supported in all respects. Nucleonix Systems supplied, instrumentation for studies in Physics, provides an experimental manual of this nature, to enable university faculty, to utilize the equipment both for teaching and research labs.

Considerable efforts have been put in preparing the manuscript for this experimental manual. Editors have gone through this and reviewed the manuscript thoroughly and made corrections. However if there are any errors or omissions, you are requested to write to us.

There may be still scope to add a few experiments to this manual. We welcome feedback on new additions to this, from professors and others from scientific community. We may include such additional experiments in future editions, if found suitable.

This manual on '**Experiments with Gamma Ray Spectrometer**' has been written to include the important information such as basic definitions on related radiation units and fundamentals of Nuclear & Radiation Physics, working principle and a list of experiments on Gamma Ray Spectrometry which illustrate some of the important fundamentals of Gamma ray interactions & its characteristics.

There is also condensed information provided on various **Gamma Ray Spectrometer** models offerred along with accessories, which will help in having better understanding while going through this experimental manual. Of course, for more detailed information one can go through respective instrument user manuals, for operation and commands description.

Additionally, basic calculation procedure on **activity** and **dose rate** as on a given date by knowing the activity on the date of manufacture of source are also given in this manual.

In this edition two more experiments have been added, which include -

5.11. Measurement of Half value thickness and evaluation of Mass Absorption Coefficient.

5.12. Back scattering of Gamma Rays

We are sure that this experiments booklet will be useful for the experimental labs at PG level in the following departments which includes, Nuclear Physics, Radiation Physics, Medical Physics, Nuclear Sciences & Engineering, Engineering Physics etc.

We also thank all our staff at NUCLEONIX SYSTEMS who have helped us in preparing this manuscript for releasing to Press.

Finally, Editors will be happy if this manual has served the purpose for which it is written. Efforts will go on continuously to improve on this in the next edition. Suggestions and feedback are welcome from all concerned with this subject.

J. Narender Reddy

Dr. M.S.R. Murty

Editors

EQUIPMENT & ACCESSORIES REQUIRED FOR DOING THE EXPERIMENTS :

(Equipment / Accessories mentioned below are manufactured and or supplied by NUCLEONIX SYSTEMS)

	EQUIPMENT / SYSTEM	TYPE
1.	Gamma Ray Spectrometer (or) MINIM Gamma Ray Spectrometer	GR612 GR611M
2.	Scintillation Detectors	SD151/152/152W
3.	Sliding bench with scintillation detector stand & source stand	
4.	Gamma Reference Standard Set	GS290
5.	Aluminium Absorber Disc Set	AA270
6.	Copper Absorber Set	CL275

EXPERIMENTS WITH GAMMA RAY SPECTROMETER

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1.0 INTRODUCTION

GAMMA- RAY INTERACTIONS

Of the various ways gamma rays can interact in matter, only three interaction mechanisms have any real significance in gamma-ray spectroscopy: photoelectric absorption, Compton scattering, and pair production. As detailed in the following sections (i, ii & iii), photoelectric absorption predominates for low-energy gamma rays (up to several hundred keV), pair production predominates for high-energy gamma rays (above 5-10 MeV), and Compton scattering is the most probable process over the range of energies between these extremes. The atomic number of the interaction medium has a strong influence on the relative probabilities of these three interactions, as can be seen from the formulae and plots given. The most striking of these variations involves the cross section for photoelectric absorption, which varies approximately as $Z^{4.5}$. As we shall see from the following discussion, because photoelectric absorption is the preferred mode of interaction, there is a premium on choosing detectors for gamma-ray spectroscopy from materials that incorporate elements with high atomic number.

(i) PHOTOELECTRIC ABSORPTION

Photoelectric absorption is an interaction in which the incident gamma-ray photon disappears. In its place, a photoelectron is produced from one of the electron shells of the absorber atom with a kinetic energy given by the incident photon energy ($h\nu$) minus the binding energy of the electron in its original shell (E_b). This process is shown in Fig.1. For typical gamma-ray energies, the photoelectron is most likely to emerge from the K shell, for which typical binding energies range from a few keV for low-Z materials to tens of keV for materials with higher atomic number. Conservation of momentum requires that the atom recoils in this process, but its recoil energy is very small and usually can be neglected.

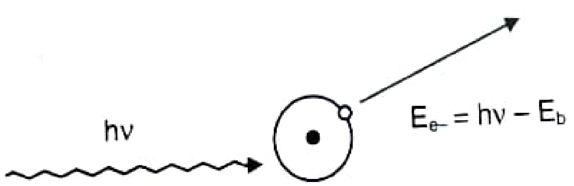

Fig. 1: Process of photoelectric absorption

The vacancy that is created in the electron shell as a result of the photoelectron emission is quickly filled by electron rearrangement. In the process, the binding energy is liberated either in the form of a characteristic X-ray or Auger electron. In iodine, a characteristic X-ray is emitted in about 88% of the cases. The auger electrons have extremely short range because of their low energy. The characteristic X-rays may travel some distance (typically a millimeter or less) before being reabsorbed through photoelectric interactions with less tightly bound electron shells of the absorber atoms. Although escape of these X-rays can at times be significant, for now, we assume that they are also fully absorbed in keeping with our simplified model.

Thus, the effect of photoelectric absorption is the liberation of a photoelectron, which carries off most of the gamma-ray energy, together with one or more low-energy electrons corresponding to absorption of the original binding energy of the photoelectron. If nothing escapes from the detector, then the sum of the kinetic energies of the electrons that are created must equal the original energy of the gamma-ray photon.

Photoelectric absorption is therefore an ideal process if one is interested in measuring the energy of the original gamma ray. The total electron kinetic energy equals the incident gamma-ray energy and will always be the same if mono-energetic gamma rays are involved. Under these conditions, the differential distribution of electron kinetic energy for a series of photoelectric absorption events would be a simple delta function as shown Fig.2. The single peak appears at a total electron energy corresponding to the energy of the incident gamma rays.

Fig. 2 : Photopeak corresponding to photoelectron absorption events

(ii) COMPTON SCATTERING

The result of a Compton scattering interaction is the creation of a recoil electron and scattered gamma-ray photon, with the division of energy between the two dependent on the scattering angle. A sketch of the interaction is given in figures 3a & 3b.

Fig. 3: Process of Compton scattering

The energy of the scattered gamma ray hv' in terms of its scattering angle θ is given by

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

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

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

Two extreme cases can be identified:

- A grazing angle scattering or one in which $\theta \cong 0$. In this case, Eqs. (1) and (2) predict that $h\nu' \cong h\nu$ and $E_{e-} \cong 0$. In this extreme, the recoil Compton electron has very little energy and the scattered gamma ray has nearly the same energy as the incident gamma ray.
- A head-on collision in which $\theta = \pi$ In this extreme, the incident gamma ray is backscattered toward its direction of origin, whereas the electron recoils along the direction of incidence. This extreme represents the maximum energy that can be transferred to an electron in a single Compton interaction. Equations (1) and (2) yield for this case.

$$hv' \Big|_{\theta = \pi} = \frac{hv}{1 + 2hv/ m_0c^2} \tag{3}$$

$$E_{e-} \Big|_{\theta = \pi} = hv \left(\frac{2hv/ m_0c^2}{1 + 2hv/ m_0c^2} \right) \tag{4}$$

In normal circumstances, all scattering angles will occur in the detector. Therefore, a continuum of energies can be transferred to the electron, ranging from zero up to the maximum predicted by Eq. (4). Fig. 4. shows the shape of the distribution of Compton recoil electrons predicted by the Klein-Nishina cross section for several different values of the incident gamma-ray energy. For any one specific gamma-ray energy, the electron energy distribution has the general shape shown in the sketch below.

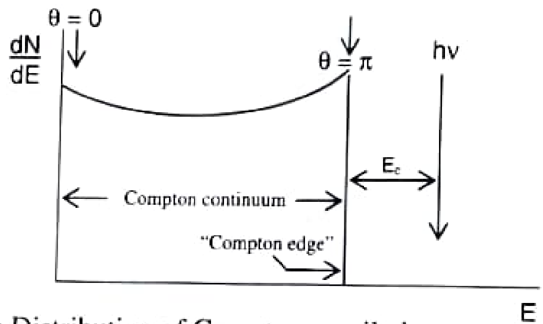

Fig. 4 : Distribution of Compton recoil electrons

The gap between the maximum Compton recoil electron energy and the incident gamma-ray energy is given by

$$E_c = hv - E_{e-} \Big|_{\theta = \pi} = \frac{hv}{1 + 2hv / m_0c^2} \tag{5}$$

In the limit that the incident gamma-ray energy is large, or $hv >> m_0c^2/2$, this energy difference tends toward a constant value given by

$$Ec \cong \frac{m_0c^2}{2} = 0.256 \text{ MeV} \tag{6}$$

The preceding analysis is based on the assumption that Compton scattering involves electrons that are initially free or unbound. In actual detector materials, the binding energy of the electron prior to the scattering process can have a measurable effect on the shape of the Compton continuum. These effects will be particularly noticeable for low incident gamma-ray energy. They involve a rounding-off of the rise in the continuum near its upper extreme and the introduction of a finite slope to the abrupt drop of the Compton edge. These effects are often masked by the finite energy resolution of the detector but can be evident in the spectra from detectors with high inherent resolution. The finite momentum of orbital electrons also causes gamma-ray photons that are scattered at a fixed angle from a mono-energetic source to have a narrow distribution in their energy (the "Doppler spread"), as contrasted with a single energy predicted by Eq. (1)

(iii) PAIR PRODUCTION

The third significant gamma-ray interaction is pair production. The process occurs in the intense electric field near the protons 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. Because energy of $2m_0c^2$ is required to create the electron-positron pair, minimum gamma-ray energy of 1.02 MeV is required to make the process energetically possible. If the incident gamma-ray energy exceeds this value, the excess energy appears in the form of kinetic energy shared by the electron-positron pair. Therefore, the process consists of converting the incident gamma-ray photon into electron and positron kinetic energies, which total

$$E_{e-} + E_{e+} = h\nu - 2m_0c^2 \tag{7}$$

For typical energies, both the electron and positron travel a few millimeters at most before losing all their kinetic energy to the absorbing medium. A plot of the total (electron + positron) charged particle kinetic energy created by the incident gamma ray is again a simple delta function, but it is now located $2m_0c^2$ below the incident gamma-ray energy, as illustrated in Fig. 5. In our simple model, this amount of energy will be deposited each time a pair production interaction occurs within the detector.

This energy corresponds to the position of the double escape peak in actual gamma-ray pulse height spectra.

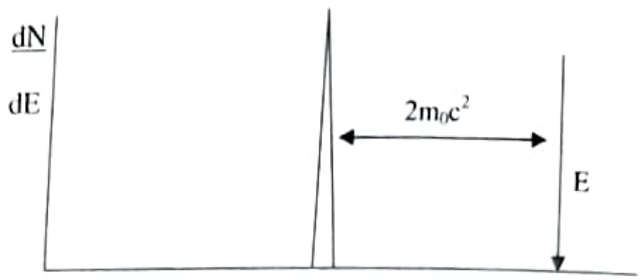

Fig. 5: Peak corresponding to the total kinetic energy of the pair (electron+ positron) created during pair production process

The pair production process is complicated by the fact that the positron is not a stable particle. Once its kinetic energy becomes very low (comparable to the thermal energy of normal electrons in the absorbing material), the positron will annihilate or combine with a normal electron in the absorbing medium. At this point both disappear, and they are replaced by two annihilation photons of energy m_0c^2 (0.511 MeV) each. The time required for the positron to slow down and annihilate is small, so that the annihilation radiation appears in virtual coincidence with the original pair production interaction.

2.0 BRIEF DESCRIPTION & SPECIFICATIONS OF GAMMA RAY SPECTROMETER (INTEGRAL MODEL) WITH ACCESSORIES INCLUDING BLOCK DIAGRAM DESCRIPTION

2.0A INTEGRAL MODEL (GR612)

Gamma Ray Spectrometer GR612, developed & manufactured by Nucleonix Systems is a low cost integral model specially designed to serve the requirements of P.G. Colleges & Universities both for Teaching & Research labs. Considerable cost saving is achieved because of optimal design & Integral construction, without any degradation in performance. It is designed around microcontroller which is used basically to derive timer, counter functions & also to set required HV for the detector, along with support peripheral chips. Also all the required data storage & calculations are done using microcontroller in embedded coding.

Fig. 6 : Gamma Ray Spectrometer GR612 Front view

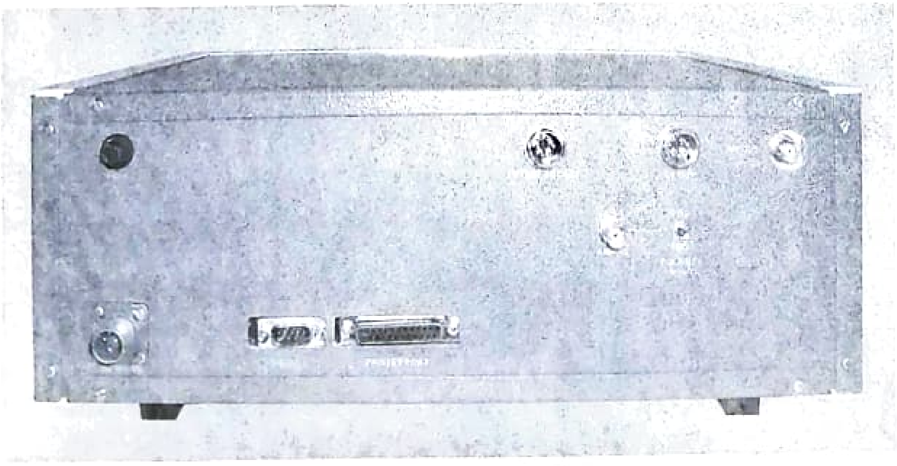

Fig. 7 : Gamma Ray Spectrometer GR612 Rear view

2.0A. 1 IMPORTANT SPECIFICATIONS:

- **LOW VOLTAGE SUPPLY** : +15V, -15V, +24V & 5V are generated in LV PCB, to power up all the circuits.

- **HIGH VOLTAGE SUPPLY** : (0 to 1500V) @ 1mA HV is adjustable by a ten turn helipot & dial.

a. HV Output	:	Positive polarities
b. Ripple & noise	:	Less than 25mV
c. Regulation	:	Better than 0.5%

- **LINEAR AMPLIFIER**

a. Input Polarity	:	Positive or Negative
b. Total Gain (Typical)	:	600 (Approx.)
c. Output (Bipolar)	:	0V to 8V (usable recommended Linear range)
d. Max. Output	:	12V (Saturation Level)

- **SINGLE CHANNEL ANALYSER**

a. Input	:	Unipolar or Bipolar with a +ve leading edge 0 to 10V
b. Output Pulse Polarity	:	Positive
Pulse Amplitude	:	+5V
Pulse Width	:	0.5 micro sec
c. LLD output pulse amplitude	:	+5V
Output pulse width	:	0.5 micro sec
Base line variable by	:	10 turn helipot / Dial
Base line variation	:	0 to 10V by helical potentiometer

d. Window width continuously variable by helical potentiometer / Dial

Window	:	0 - 1V in WINDOW mode
ULD range	:	0 - 10V in NORMAL mode

e. LLD, ULD & MODE switch, controls have been provided on front panel o **COUNTER TIMER**

a. Display	:	20x2 LCD Dot-matrix display has been provided to indicate data counts & elapsed time.
b. Preset time	:	0-9999 seconds
c. Command Buttons	:	START, STOP, PROG, STORE, INC & DEC command buttons have been provided on the front panel key board.
d. Modes of Data Acquisition	:	a. Counts for a preset time b. CPS c. CPM
e Preset Time Selection	:	Programmable through switch control buttons
f. Data storage	:	Up to 1000 readings
g. Programmability	:	Includes selection of preset time storing / Recalling of data, starting and stopping of Acquisition, label assignment for data counts such as BG (background), ST (standard) and SP (sample).
h. Printing option	:	This module has built in parallel port for Data Printing.
i. Serial port	:	This module additionally has built-in RS232C Serial port for downloading the data into PC.

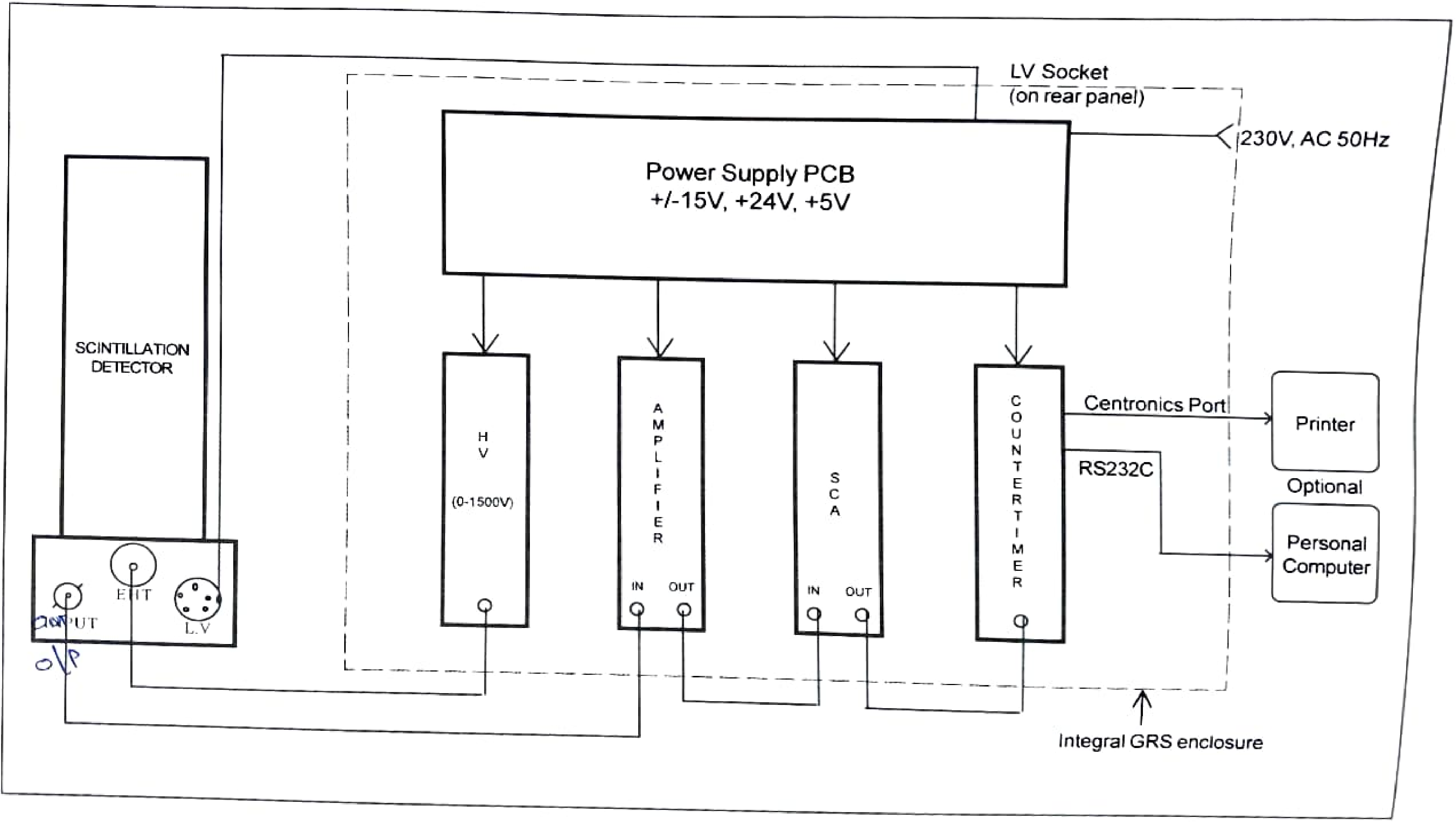

Fig. 8 : Block diagram of Gamma Ray Spectrometer (*Integral Model*)
Type : GR612

2.0A.2 BLOCK DIAGRAM DESCRIPTION

GAMMA RAY SPECTROMETER (INTEGRAL MODEL)

Refer to the block diagram Fig. 8, given in the previous page. It consists of Scintillation detector SD 151 or its equivalent, Low Voltage circuit, High Voltage circuit, Linear Amplifier circuit, Single Channel Analyzer circuit & Controller with peripheral IC circuits. All these circuits are integrated into a single mother board and housed in the main electronic unit. The scintillation detector is coupled to the main electronic unit. This total assembly of scintillation detector and the main electronic unit is called as Gamma Ray Spectrometer. This unit is essentially designed for teaching lab/ research lab experiments for universities in the departments such as Nuclear Physics, Radiation Physics, Radiological Physics, Medical Physics, Applied Physics, Radio Chemistry, Nuclear Sciences and Nuclear Engineering.

SCINTILLATION DETECTOR: It consists of a Sodium Iodide crystal optically coupled to a photomultiplier. It has got three connectors, UHF, circular I/O or Minihex & BNC connector. The high voltage (operating voltage) required for the detector is fed from the HV circuit and is connected to the UHF connector. Minihex / 5 pin I/O connector is used to feed in the low voltages to pre-amplifier from rear panel of GRS. The output of the detector is given to the linear amplifier input through a BNC cable. Scintillation detector of NUCLEONIX make or its equivalent can be connected to NUCLEONIX Gamma Ray Spectrometer electronic unit.

LOW VOLTAGE CIRCUIT: Low Voltage Circuit receives secondary voltage outputs from the transformer and generates +15V, -15V, +24V, +5V which are used by various circuits. All these supply voltages are generated using 3 Terminal regulator ICs.

HIGH VOLTAGE CIRCUIT: It will generate 0 to 1500V. It has got HV out (UHF connector) and the ten turn dial / helipot for changing the EHT continuously from 0 to 1500V. It can deliver up to a maximum current of 1mA. Line & Load regulation is better than 0.001%. HV indication is provided on a 20x2 Dot Matrix Display. It is designed using a DC to DC converter type of circuit.

Output from the HV CIRCUIT is fed to Scintillation Detector through a UHF cable for biasing of the detector.

Typically detector bias to scintillation detector can be from 600V to 900V.

LINEAR AMPLIFIER: The Linear amplifier is basically a pulse shaping amplifier which amplifies scintillation detector output and gives either unipolar or bipolar output. Both coarse and fine gain controls have been provided. Also, there is provision for selecting input polarity. Shaping time also is adjustable between 0.1 to 10□sec. It gives a gain of 600 (approx).

SINGLE CHANNEL ANALYSER: Single Channel Analyzer (SCA) receives the input from Pulse Amplifier output. SCA essentially scans the input pulses for differential pulse height analysis and gives out TTL output pulses for the windowed pulses. Output from SCA is fed to Controller circuit for counting purpose.

COUNTER TIMER: Controller circuit can count the events for a preset time. Elapsed time and counts are indicated on the 20x2 LCD displays. Input can accept input pulses of POS or NEG polarity of unipolar / bipolar or TTL pulse.

Integral GRS Front Panel has keypad buttons for operation and is designed around a microcontroller. It can acquire data in three modes of operation namely

a. Preset Scaler b. CPS c. CPM.

Readings up to 1000 can be stored and recalled back onto the display. Further, unit has built-in printer port for direct data printing and serial port for downloading of readings to PC.

ACCESSORIES FOR GRS: Accessories required for GRS are mentioned in the later pages, which are identical for both the models GR612 and GR611M.

2.0B MODULAR SYSTEM [TYPE: GR611M]

The Gamma Ray Spectrometer (Micro controller based) Type GR 611M consists of a MINIM based modular counting unit and a Scintillation Detector Type: SD 150/151/160W. The Spectrometer can also be used for Gamma Counting applications. This MINIM based system has added advantage of savings in cost and also conserves bench space because of its optimal design.

This system is configured around MINI BIN and Power Supply Type: MB 403 with the following Modules:

High Voltage Unit Type: HV 502

Linear Amplifier Type: LA 520

Single Channel Analyzer Type: SC 530

and Counter Timer Type: CT 541A (Micro controller based), having unique built-in user programmable features for data acquisition & data outputting.

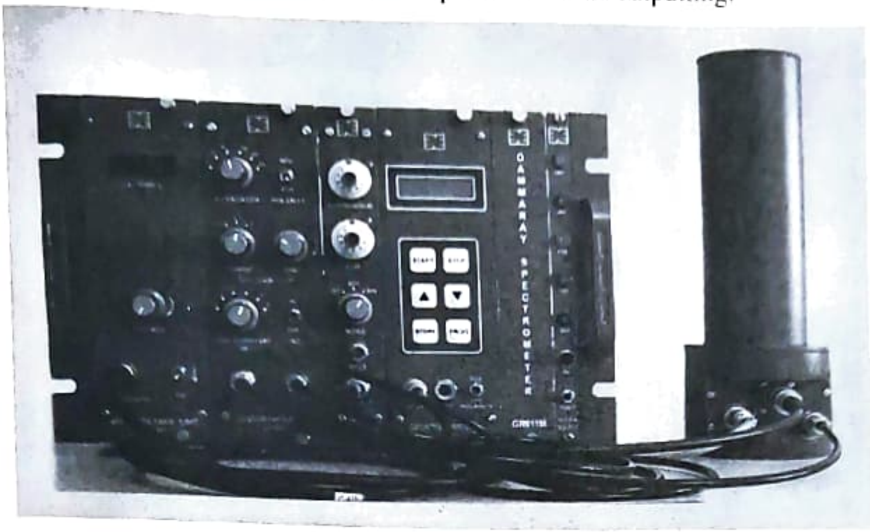

Fig. 9 : Gamma Ray Spectrometer GR611M (Modular Minim based)

2.0B.1 SPCIFICATIONS OF CONSTITUENT UNITS OF GR611M

NIM INSTRUMENTATION BIN:

Interchangeability	:	Mechanical Tolerances are in accordance with TID 20893 (Rev).
Panel dimensions	:	Standard rack 8 ¾ inches high and 11 ¾ inches wide (without flanges).
Depth	:	12 ¾ including heat sinks
Module connectors	:	8 NIM connectors per bin at the panel as specified by TID 20893 (Rev) or 24 pin of Amphenol connectors (for use in INDIA).
Installed wiring	:	All connectors of MINI BIN are wired in parallel for +12V, -12V, +24V and -24V, high quality GND and power return GND.
Construction	:	Bin is constructed with two side aluminum flanges with casted handles, top and bottom S.S. Rod spot welded mesh supported with two aluminum bars at top and bottom, module guides with S.S. rods and connector plate at the back. All these parts are anodized / painted completely. The channels are milled; spot welded S.S. rod guides provide precisely smooth and easy movement of modules into the bin.

MINIBIN enclosure dimension: 14" wide X 10" height x 11.5" depth without accounting handles and heat sinks.

POWER SUPPLY [TYPE: PS401]

Input voltage	:	220V +/- 10% AC
Frequency	:	50Hz
Stability	:	For +/- 12V & +/- 24V, +/- 0.3% over any 24 Hours period at constant ambient temperature. Over the combined range of no load to full load and specified mains variation after 60 min.
Temperature range	:	0 to 50° C ambient
Temperature coefficient	:	0.02% per °C over 0 to 50° C ambient.
Noise and ripple	:	for +/- 12V & +/- 24V, 3mV rms
Voltage adjustments	:	+/- 2% minimum range. Reset ability +/- 0.5% of supply voltage.
Recovery time	:	+/- 12V & +/- 24V outputs will recover within +/- 0.1% of steady state values within 100 µsec following any change in specified line Voltage or between 10 to 100% full load.
Circuit protection	:	a) Input of the supply is protected by two fuses b) Output of the power supply is short circuit and overload protected by means of fold back electronic circuit. c) Recovery is automatic when overload or short circuit is removed. d) Continuous short circuit will not damage the power supply Unit.

HIGH VOLTAGE UNIT [TYPE: HV 502]

- Output voltage variable continuously from 0 to 2000 volts.
- Output current (maximum) 1mA.
- Load and Line Regulations: better than 0.005% of full scale
- Indefinite overload and short circuit protections and self-recovery.
- Output ripple less than 20 mV
- Dimensions: Two bit Module.
- HV is adjustable by ten turn helipot with knob.

LINEAR AMPLIFIER [TYPE: LA 520]

o Input Polarity	:	Positive or Negative
o Total Gain (Typical)	:	800 (approx.)
o Output (Unipolar)	:	0V to 8V (usable recommended linear range)
o Max. Output (Unipolar)	:	12V (Saturation Level)

4. SINGLE CHANNEL ANALYSER [TYPE: SC 530]

o Input	:	Unipolar or Bipolar with a +Ve leading edge 0-10V
o Pulse Pair Resolution (approx.)	:	0.6 μsec
o Output Pulse Polarity	:	Positive
Pulse Amplitude	:	+5V
Pulse Width	:	0.5 μsec
o LLD output pulse amplitude	:	+5V
Output pulse width	:	0.5 μsec
LLD/Base line variable by	:	10 turn helipot / Dial
o Window width	:	Continuously variable by helical potentiometer /Dial
Window	:	0-1V in WINDOW mode
ULD range	:	0-10V in NORMAL mode
o Dimensions of module	:	1 Bit

COUNTER TIMER [TYPE: CT 541A]

o Input	:	100 mV to 10V, unipolar or positive bipolar semi Gaussian / Gaussian pulse
o Pulse width	:	0.5 msec (min)
o Polarity	:	Positive or Negative
o Input Impedance	:	10 K Ω
o Input counts capacity	:	999999 counts
o Pulse height Discriminator	:	100 mV – 10 V by a preset provided on front panel
o Display	:	8x2 LCD dot-matrix display has been provided to indicate data counts & Elapsed time
o Preset time	:	0-9999 seconds

○ Command Buttons	:	START, STOP, PROG, STORE, INC & DEC command buttons have been provided on the front panel key board
○ Modes of Data Acquisition	:	(a) Counts for a preset time (b) CPS (c) CPM
○ Preset Time Selection	:	Programmable through switch control buttons
○ Data storage	:	Up to 1000 readings
○ Programmability	:	includes selection of preset time storing / recalling of data, starting and stopping of acquisition, label assignment for data counts such as BG (background), ST (standard) and SM (sample).
○ Printing option	:	This module has built in parallel port for Data transfer
○ Serial port	:	This module additionally has built-in RS232C serial port for downloading the data into PC.
○ Extension keypad (Optional)	:	From rear panel I/O connector one can have extension keypad with same command buttons as mentioned above.

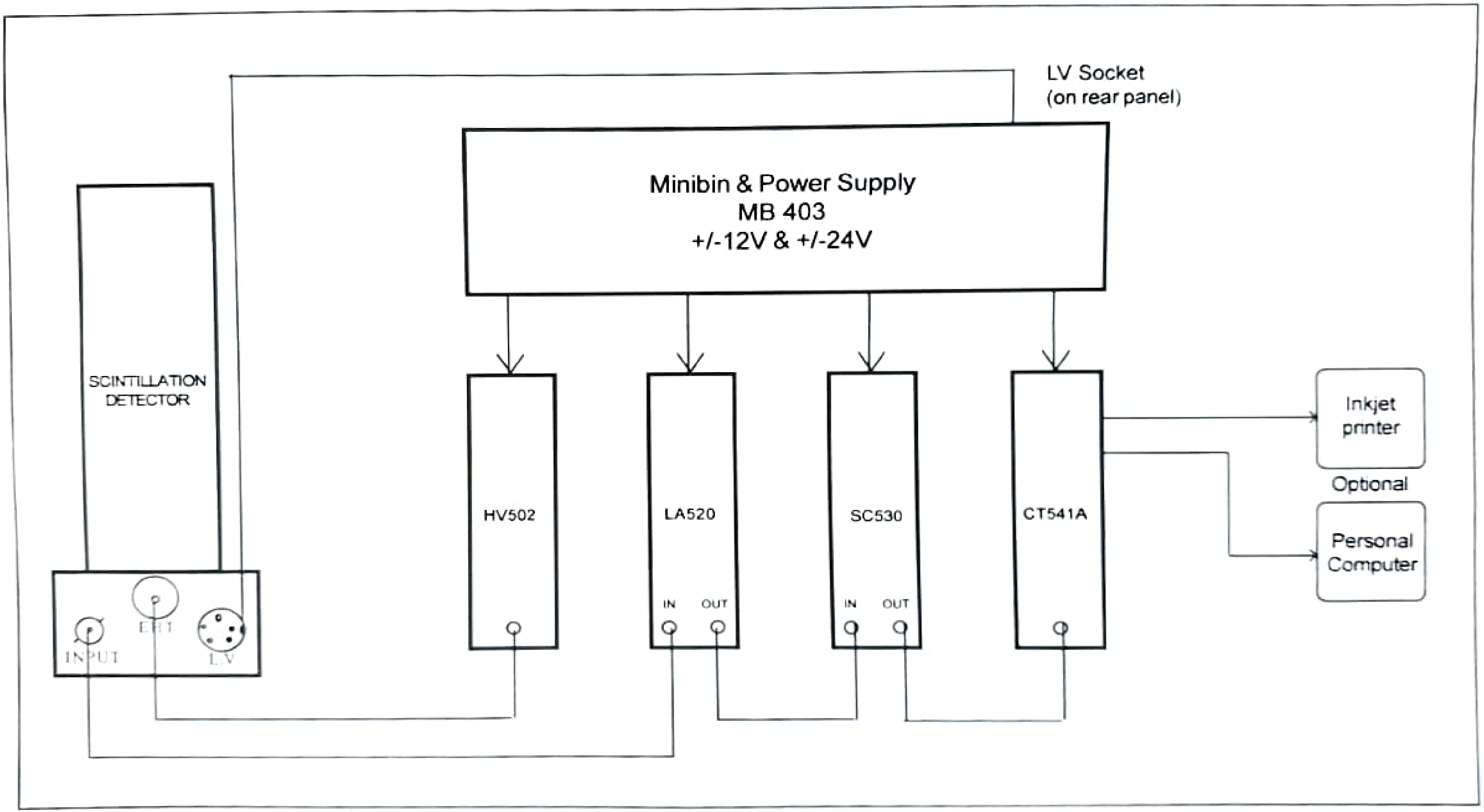

Fig. 10 : Block diagram of MINIM based Gamma Ray Spectrometer

2.0B. 2 BLOCK DIAGRAM DESCRIPTION (GR611M)

Refer to the block diagram, given in Fig.10. It consists of Scintillation Detector SD 151 or its equivalent, High Voltage unit HV 502, Linear Amplifier LA 520, Single Channel Analyzer SC 530 & Counter Timer CT 541A. All these modules are housed inside Minibin and Power Supply Type: MB403. Minibin and Power Supply provides low voltage supplies +/- 12V & +/- 24V to these modules. The Scintillation Detector is coupled to the main electronics unit. The assembly of scintillation detector and main electronic unit is called as Gamma Ray Spectrometer. This unit is essentially used for studying the Gamma Ray Spectra of Gamma isotopes.

SCINTILLATION DETECTOR

It consists of a Sodium Iodide crystal optically coupled to a photomultiplier. It has got three connectors, UHF, circular I/O or Minihex & BNC connector. The high voltage (operating voltage) required for the detector is fed from the HV module and is connected to the UHF connector. Minihex / 5 pin I/O connector is used to feed in the low voltages to pre-amplifier from Minibin power supply. The output of the detector is given to the linear amplifier input through a BNC cable. Scintillation detector of NUCLEONIX make or its equivalent can be connected to NUCLEONIX Gamma Ray Spectrometer electronic unit.

HIGH VOLTAGE UNIT (HV 502)

It is basically a two-bit module which generates 0 to 2000 V. It has got HV out (UHF connector) and the ten turn dial / helipot for changing the EHT continuously from 0 to 2000 V. It can deliver up to a maximum current of 1mA. Line & Load regulation is better than 0.001%. HV indication is provided on a three and half DPM.

Output from the HV 502 is fed to Scintillation Detector through a UHF cable for biasing of the detector.

Typically detector bias can be from 600V to 800V.

LINEAR AMPLIFIER (LA520)

Linear Amplifier LA 520 uses solid-state/Integrated circuits extensively in its design. Featuring excellent non-overload characteristics, a high gain, low equivalent input noise and flexibility of pulse shaping, LA 520 is ideally suited for use with Nuclear Counting Systems such as Gamma Ray Spectrometers and other similar units.

SINGLE CHANNEL ANALYSER (SC530)

Single Channel Analyzer receives the input from Linear Amplifier LA 520 output. SC 530 essentially scans the input pulses for differential pulse height analysis and gives out TTL output pulses for the windowed pulses. Output from SC 530 is fed to Counter Timer CT 541A for counting purpose. SC530 can be operated in three modes.

COUNTER TIMER (CT541A)

Counter timer CT 541A is a two-bit module. It can count the events for a preset time. Elapsed time and counts are indicated on the 8x2 LCD displays. Input can accept input pulses of POS or NEG polarity of unipolar / bipolar or TTL pulse.

Counter timer CT 541A has keypad buttons for operation and is designed around a microcontroller. It can acquire data in three modes of operation namely

a. Preset Scaler b. CPS c. CPM.

Readings up to 1000 can be stored and recalled back onto the display. Further unit has built-in printer port for direct data printing and serial port for downloading of readings to PC.

3.0 ACCESSORIES FOR GRS (611M OR GR612)

- **SCINTILLATION DETECTOR :** Scintillation detector with flat type NaI crystal of 1"x1" or 1.5"x1.5" " or 2" x 2" flat or well type detector of 1.5" x1 .5" or 2" X 2" of NUCLEONIX make or its equivalent is compatible to GR611M. The output of these units (taken from preamplifier) is POSITIVE for all Nucleonix make Scintillation detectors.

  Hence the input polarity of the amplifier in GR611M is to be selected for POSITIVE. Scintillation detector preamplifier required LV supply of -12V is drawn from the GRS rear panel. So, also the HV bias supply for the PMT of the detector assembly is also drawn from GRS rear panel. Preamplifier of the scintillation detector is a charge integrating type of preamplifier.

- **TO PRINTER (Optional):** There is a centronics port built-in which facilitates data printing on to a dot matrix printer.

(a) SCINTILLATION DETECTORS

Nucleonix Systems offers wide range of NaI Scintillation Detectors of different sizes both with flat & well type crystals, to meet the requirements of wide range of users for Gamma ray spectrometry measurements.
Scintillation detectors offered include 1"x1", 2"x2" & 3"x3" NaI integral assemblies with built-in pre-amplifiers. These detector assemblies give excellent stability, superior performance & good resolution in the range of 8.0 to 9.5% for Cs-137. Scintillation detectors of other sizes can also be offered against user specific requirements.

1" X 1" 2" X 2"
Fig. 11.

(b) GAMMA REFERENCE STANDARD SET [TYPE GS 290

Gamma Reference Standard Set Type: GS290 consists of a set of FIVE Gamma sources evaporated & sealed on 25mm dia x 5mm plastic disc covering SIX photo peak energies in the range of 2 to 5 micro curie. A reference chart for this is given below. The accuracy of these sources is in the range of +/-10%. All these disc sources are enclosed in a box made of acrylic sheet and supplied.

Fig. 12.

Gamma Isotope	Energy MeV	Nominal Activity	Half life
Co-57	0.123	2-5 μCi	273 Days
Ba-133	0.36 (Main)	2-5 μCi	7.5 years
Cs-137	0.662	2-5 μCi	30 years
Co-60	1.17; 1.33	2-5 μCi	5.3 years
Na-22	0.511; 1.280	2-5 μCi	2.6 years

4.0 SYSTEM INTERCONNECTIONS & DEFAULT SETTINGS

(a) FOR INTEGRAL MODEL (GR612)

(i) Interconnection table

Sl.No.	Type of Cable	Signal from	Signal to
01.	UHF to UHF high voltage cable (1.5 meter length)	EHT output from UHF socket on rear panel of GRS	Scintillation detector UHF socket
02.	LV cable with two end Circular I/O to Circular I/O connector.	LV signal on R.P of Instrument	LV signal to Scintillation detector Circular I/O Connector.
03.	Signal Cable (BNC to BNC) 1 or 1.5 meter long	Scintillation Detector (O/P BNC)	AMP Input BNC receptacle on R.P of Instrument
04.	A.C mains cord	230V, AC, 50Hz, Power socket	Instrument socket on R.P

OPTIONAL CONNECTIONS

05.	25 pin D-25 pin D cable	Rear panel GRS	To printer
06.	9 pin D-connector	Rear panel GRS	To PC Serial Port

(ii) Default control positions are set as given below:

Coarse gain : 2.0

Fine gain (dial) : 1.5

High voltage setting : set it to operating voltage as mentioned on the Detector

Polarity : 'POS'

- Now take amplifier output through a 'T' connector to oscilloscope parallelly, apart from connecting to the input of the SCA (single channel analyzer) BNC socket.
- Place Cs-137 standard reference source on the scintillation detector & observe in the oscilloscope photopeak of Cs-137 amplitude (with 1 volt / Div. sensitivity) and adjust amplifier gain such that photo-peak amplitude is set to ≅ 3 V. This will ensure that, we will be able to scan energies in the range of 100 keV to 2 MeV within 0 to 8 V of amplifier linear range.
- Now the system is ready for experiments.

4.0 SYSTEM INTERCONNECTIONS & DEFAULT SETTINGS

(a) FOR INTEGRAL MODEL (GR612)

(i) Interconnection table

Sl.No.	Type of Cable	Signal from	Signal to
01.	UHF to UHF high voltage cable (1.5 meter length)	EHT output from UHF socket on rear panel of GRS	Scintillation detector UHF socket
02.	LV cable with two end Circular I/O to Circular I/O connector.	LV signal on R.P of Instrument	LV signal to Scintillation detector Circular I/O Connector.
03.	Signal Cable (BNC to BNC) 1 or 1.5 meter long	Scintillation Detector (O/P BNC)	AMP Input BNC receptacle on R.P of Instrument
04.	A.C mains cord	230V, AC, 50Hz, Power socket	Instrument socket on R.P

OPTIONAL CONNECTIONS

05.	25 pin D-25 pin D cable	Rear panel GRS	To printer
06.	9 pin D-connector	Rear panel GRS	To PC Serial Port

(ii) Default control positions are set as given below:

Coarse gain : 2.0

Fine gain (dial) : 1.5

High voltage setting : set it to operating voltage as mentioned on the Detector

Polarity : 'POS'

- Now take amplifier output through a 'T' connector to oscilloscope parallelly, apart from connecting to the input of the SCA (single channel analyzer) BNC socket.
- Place Cs-137 standard reference source on the scintillation detector & observe in the oscilloscope photopeak of Cs-137 amplitude (with 1 volt / Div. sensitivity) and adjust amplifier gain such that photo-peak amplitude is set to ≅ 3 V. This will ensure that, we will be able to scan energies in the range of 100 keV to 2 MeV within 0 to 8 V of amplifier linear range.
- Now the system is ready for experiments.

Typical oscilloscope output for Cs-137 & Co-60 peaks are shown below:

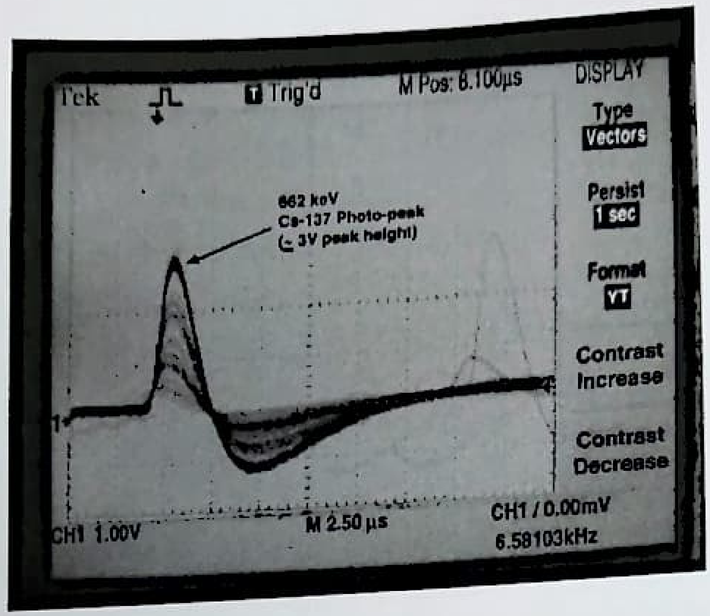

Fig.13 : Amplifier output of GR611M/612 as seen in 60 MHz oscilloscope Tek Make, with Cs-137 source placed on scintillation detector. Approximately 3 V photopeak height can be noticed.

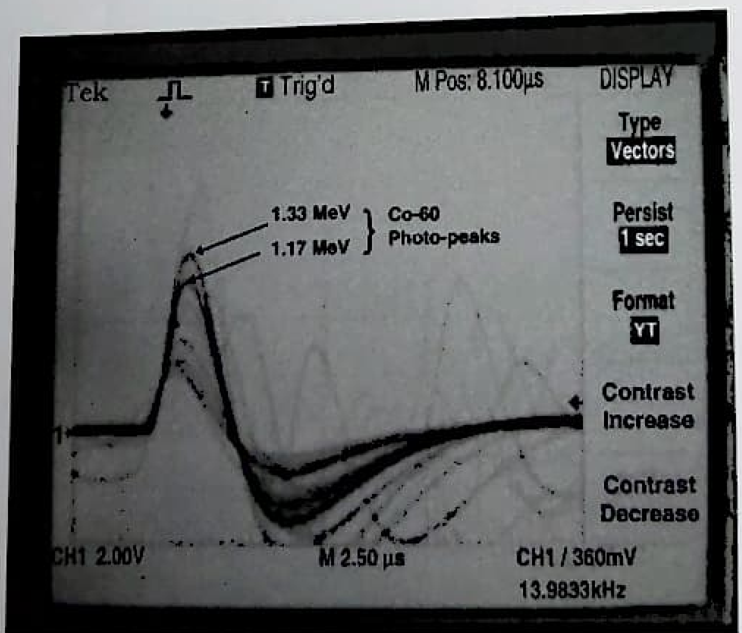

Fig.14 : Co-60 Photopeaks of 1.17 & 1.33 MeV as seen on oscilloscope, after amplification in GR611M/612. Second peak (1.33 MeV) height can be noticed to be of 6.0 V in amplitude approximately.

(b) FOR MODULAR SYSTEM

(i) Interconnection table

Sl.No.	Type of Cable	Signal from	Signal to
01.	UHF to UHF EHT cable	EHT output UHF socket on HV 502	Scintillation detector UHF socket
02.	LV cable with two end male mini-hex connectors or one end circular I/O & other Minihex/I/O circular con.	Mini-hex / 9 pin of D or circular I/O from rear panel of Minibin	Scintillation detector Mini-hex socket/Circular I/O connector
03.	Signal Cable (BNC to BNC) 1 or 1.5 meter long	Scintillation Detector (O/P BNC)	I/P BNC receptacle on LA520
04.	Signal Cable (BNC to BNC) 0.3 or 0.5 meter long	OUTPUT BNC receptacle on LA520	I/P BNC on SC530
05.	Signal Cable (BNC to BNC) 0.3 or 0.5 meter long)	OUPUT BNC receptacle on SC530	I/P BNC on CT541

OPTIONAL CONNECTIONS

06.	25 pin D-25 pin D cable	CT541A rear panel	Inkjet printer
07.	3/5 pin circular I/O connector to 9/25 pin D-connector	CT541A rear panel	PC Serial Port

(ii) Default control positions for a modular system

HV module (HV501/502): Set the HV to **operating voltage** of the scintillation detector by adjusting the HV knob

Now place Cs-137 source on the scintillation detector & adjust Atten, Gain (coarse & fine) such that Cs-137 photopeak is approx. 3V in amplitude as indicated in Fig.13. (One can observe this in the oscilloscope by connecting amplifier output through a T-connector to oscilloscope & other connection to SCA input). Typical settings to achieve this are indicated below. However, for a given detector, these settings vary.

Linear Amplifier:

Attenuation: 1

Coarse Gain: 2.0

Fine Gain: Adjustable

Shaping : 0.5

- Now keep SCA & Counter Timer controls as given below.

Single Channel Analyser:

Mode: Window

LLD (baseline): 0.0

ULD (window): 1.0

Counter Timer :

Pol : POS

Program it for desired preset time mode of operation (refer to CT541A Manual)

Now the system is ready for student experiments. Some of the following points may please be noted before proceeding further.

- All the experimental procedures explained in detail later are generic in nature & are applicable to both GR611M / GR612 models.
- Placing the scintillation detector inside **lead castle** is optional & not essential for most of these experiments. Hence, even if Lead Castle is not purchased with the system, it is also O.K.
- However a good oscilloscope (50/60 MHz) may be essential to setup the spectrometer and for visualization of the photopeaks as given by amplifier.

5.0 LIST OF EXPERIMENTS USING GAMMA RAY SPECTROMETER

5.1 STUDY OF ENERGY RESOLUTION CHARACTERISTICS OF A SCINTILLATION SPECTROMETER AS A FUNCTION OF APPLIED HIGH VOLTAGE

PURPOSE : To Study the dependence of Energy Resolution on the Applied High Voltage and to determine the best Operating Voltage for the Scintillation Detector.

THEORY: Resolution of a scintillation spectrometer is specified in percentage and defined as the 'full-width at half maximum of the photopeak spectrum. Usually, a Cs-137 source is selected as the reference and the resolution is specified with respect to its monoenergetic gammas of energy 662 keV. Finite resolution for the spectrometer is a result of the various statistical processes involved in the detection. Thus the energy expenditure in the scintillator results in the number of photons liberated which fluctuates. Likewise, the number of photons reaching the cathode, the number of photoelectrons liberated and the multiplication at the dynodes are all fluctuating quantities. Assuming Gaussian statistics to hold for all fluctuating quantities, the resultant characteristics distribution can be worked out and the full width of the distribution is the uncertainty in the determination of the total number under the distribution. The total number of electrons collected at the anode of the photomultiplier is proportional to the energy expended in the scintillator. Thus the fractional spread (or resolution) decreases with increasing energy. The over-all multiplications (gain) in the photomultiplier being dependent on the inter-dynode potential, the resolution is expected to vary with the inter-dynode potential (or the applied high voltage). The resolution should, however, be independent of gain of the linear amplifier.

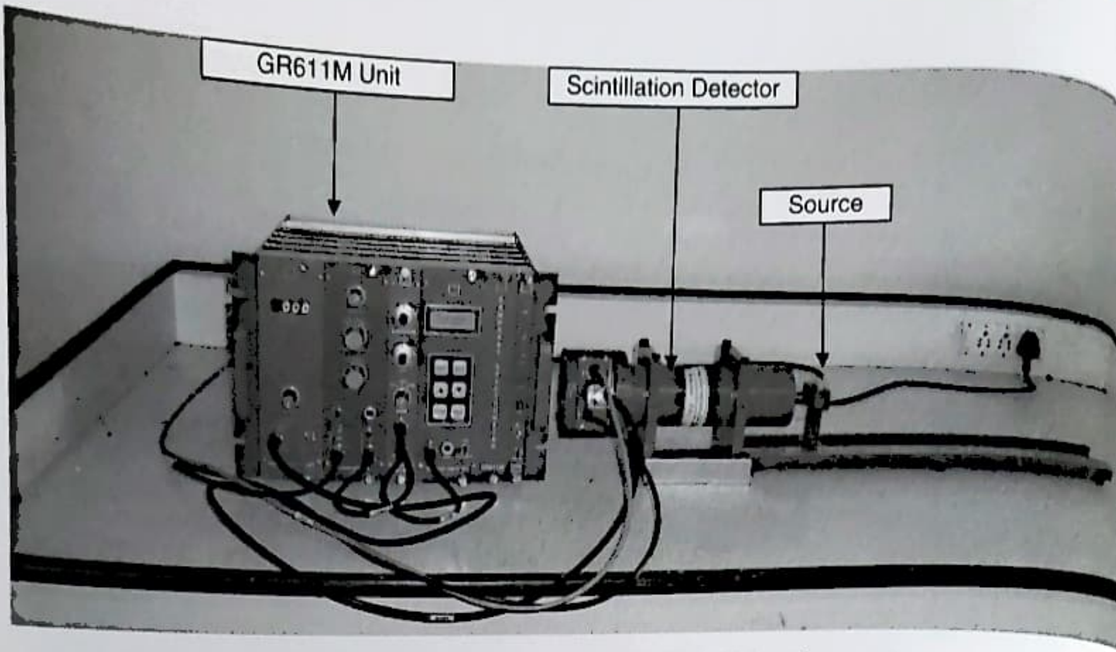

Fig. 15 : Experimental setup with GR611M unit

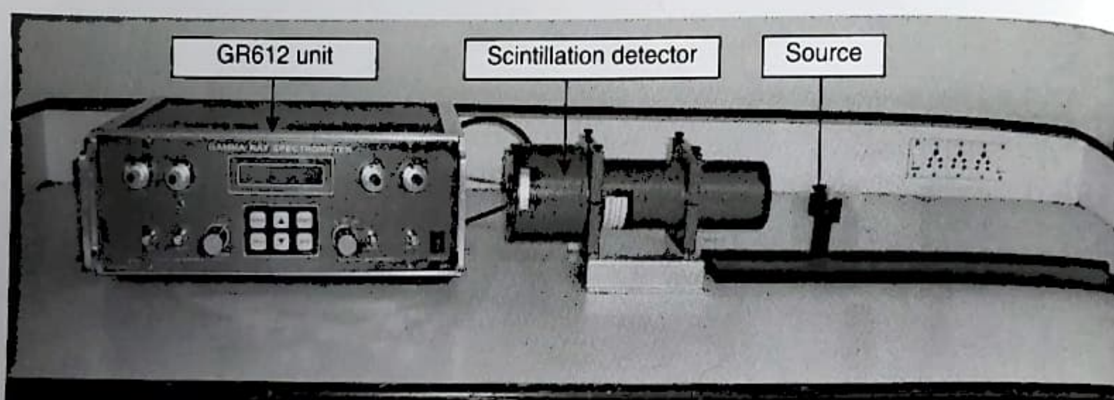

Fig. 16 : Experimental setup with GR612 unit

PROCEDURE:

- Make system interconnections & default settings for either GR611M or 612 model.
- Place a Cs-137 radioactive standard source at a distance of 4 to 5 cm from the face of the scintillation detector.
- Set controls on the instrument to default settings as described in the earlier section.
- Set HV on the instrument to **650 Volts.** .
- Now adjust amplifier gain such that the photopeak pertaining to 662 keV energy of Cs-137 is approx. 3.0V (amplitude). [Described in previous section also refer to Fig. 13. in the previous pages]

- This we do usually with the idea of using the GRS and to study the gamma energies in the range of 100 keV to 2.0 MeV over which NaI scintillation detectors are used and to cover within 8V /10V linear range of the amplifier .
- Now set the single channel analyzer MODE switch controls in GRS to WINDOW (WIN) position, LLD/Base line dial to 0.0V and ULD/window dial to 1.0 turns (equal to 100mV window)
- Operate the GRS in preset time mode and select the preset time so as to get at least 5000 counts in the peak channel. Normally a preset time of 30/60 sec. is selected.
- Take reading with LLD (Base line) starting from 2.4V in steps of 0.1(100mV) till you cross Cs-137 photo-peak i.e., may be up to 3.5/4.0V.
- Tabulate the readings and plot a graph of **count rate** Vs **LLD / Base line** on a graph sheet or in EXCEL in PC as shown in the Fig. 17.
- Now extrapolate Cs-137 photo-peak to mark peak channel No (LLD point) which is at 2.9 (LLD setting) (it can also be noticed from the data of Table-1). To simplify the experiment for the student we are taking LLD in steps of 0.1 only. To get more precise peak position, one can take additionally data counts at 2.85V and also at 2.95V to ascertain correct peak location if needed.

Repeat the experiment with different voltages viz.,650,700,750,800 and 850 Volts. Adjust the gain of the linear amplifier so as to get the CS-137 photo peak around 3.0 volts for each applied voltage. Tabulate the data. Calculate the resolution in each case. Plot the resolution as a function of applied voltage.

It can be observed that the resolution varies with the applied voltage, and best resolution is obtained for a particular applied voltage. That particular voltage is to be fixed as the operating voltage for the scintillation detector being used.

DATA, ANALYSIS & COMPUTATIONS

OPERATING VOLTAGE: 650V

Table -1

Base Line (V)	Counts
3.4	65
3.3	73
3.2	108
3.1	785
3	4702
2.9	7208
2.8	4369
2.7	1669
2.6	723
2.5	460
2.4	415

Table - 2
Operating Voltage : 650V
FWHM = 0.24V
Max. Height at 2.9V
Resolution : 0.24/2.9 = 8.3%

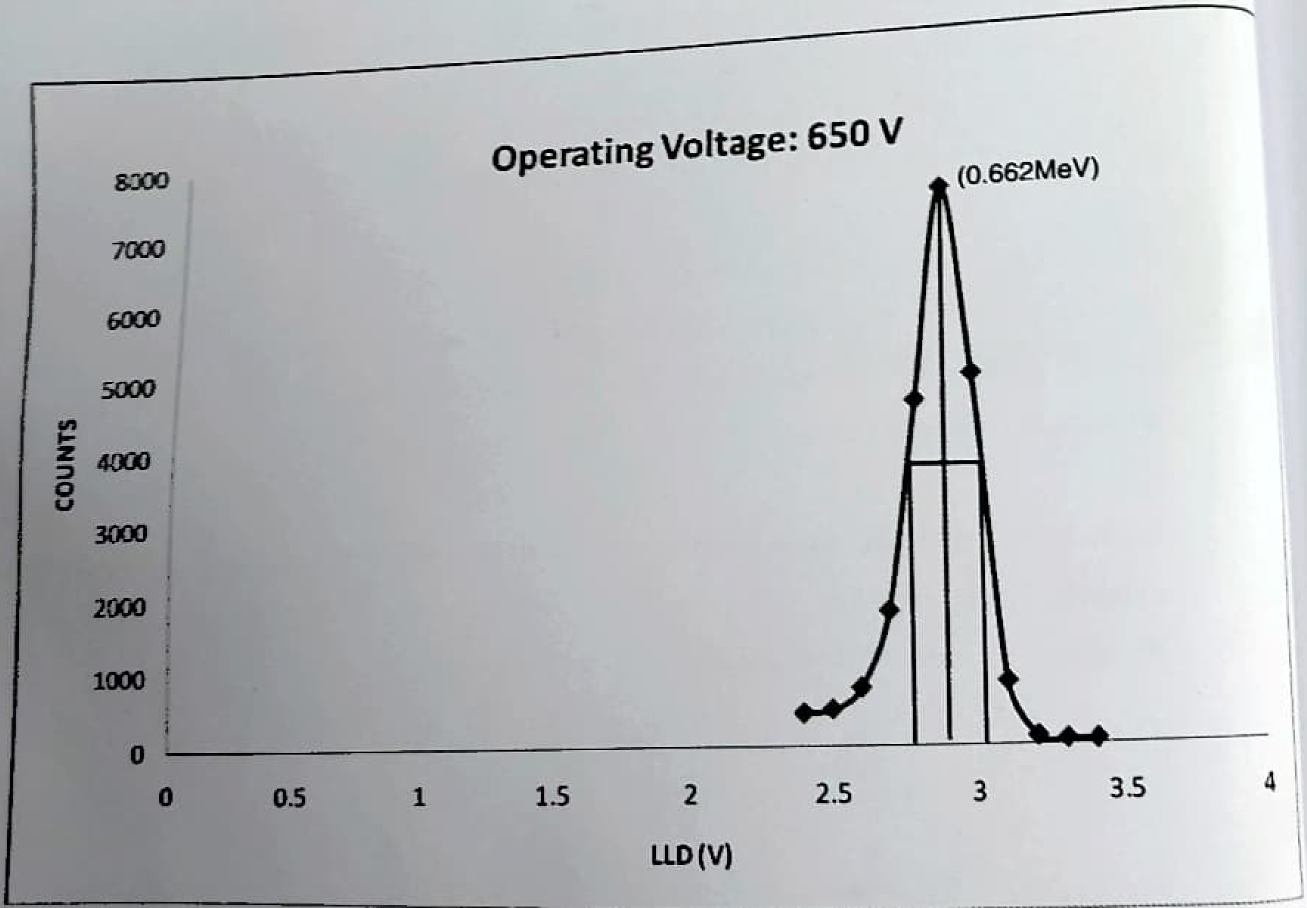

Fig. 17 : Cs-137 photopeak spectrum at 650V

OPERATING VOLTAGE: 750 V:

Table -5	
Base Line (V)	Counts
3.4	51
3.3	71
3.2	85
3.1	189
3	1729
2.9	6708
2.8	7356
2.7	2581
2.6	1237
2.5	638
2.4	467
2.3	424

Table - 6
Operating Voltage : 750V
FWHM = 0.22V
Max. Height at 2.85V
Resolution : 0.22/2.85 = 7.7%

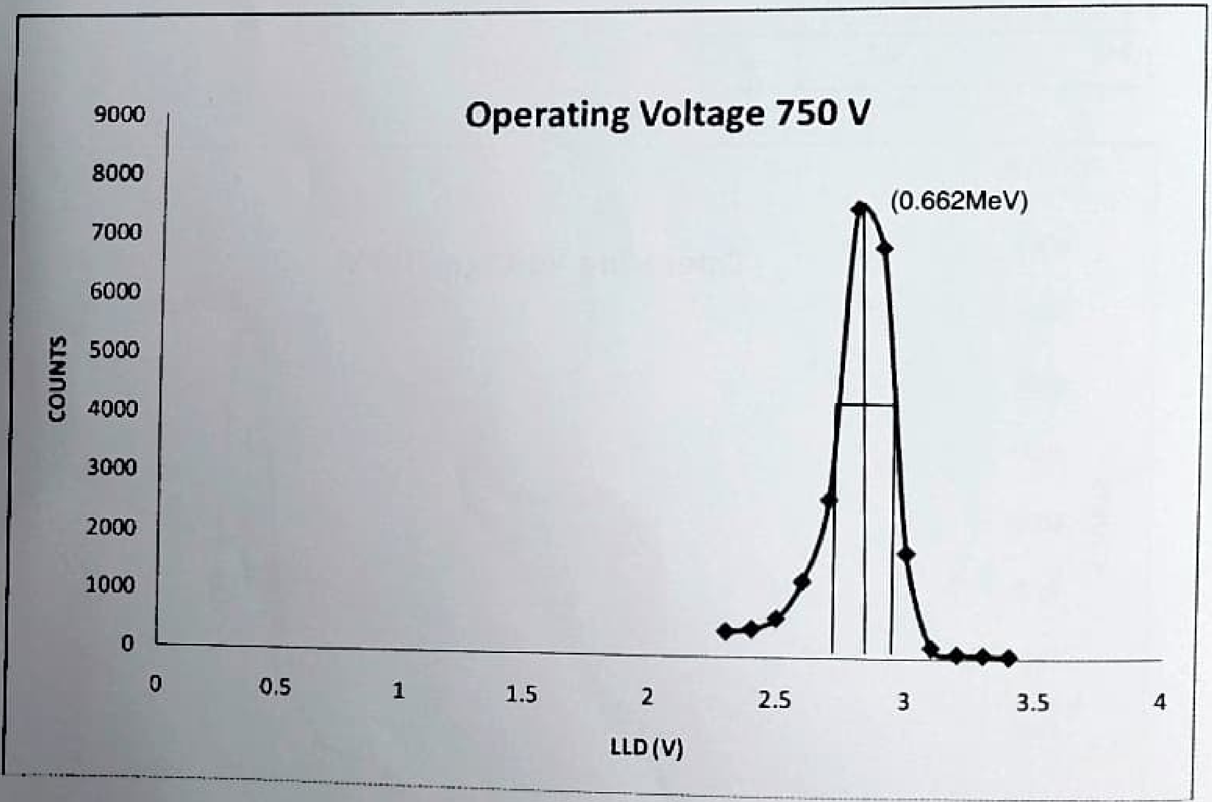

Fig. 19 : Cs-137 photopeak spectrum at 750V

OPERATING VOLTAGE: 800 V:

Table -7	
Base Line (V)	Counts
3.4	55
3.3	63
3.2	79
3.1	115
3	394
2.9	1305
2.8	5036
2.7	5118
2.6	1868
2.5	803
2.4	481
2.3	450

Table - 8
Operating Voltage : 800V
FWHM = 0.22V
Max. Height at 2.75V
Resolution : 0.22/2.75 = 8%

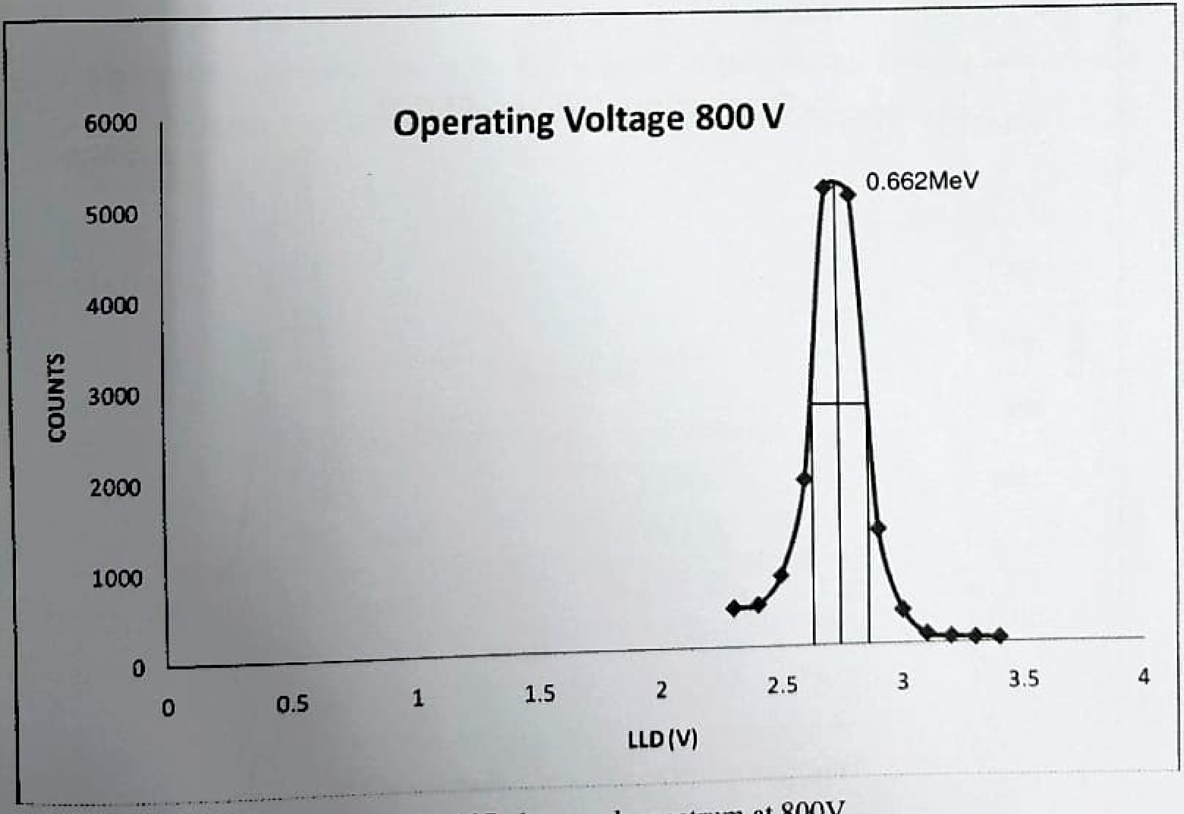

Fig.20 : Cs-137 photopeak spectrum at 800V

OPERATING VOLTAGE: 850 V:

Table -9	
Base Line (V)	Counts
3.4	61
3.3	59
3.2	144
3.1	1998
3	5442
2.9	5833
2.8	2479
2.7	930
2.6	422
2.5	348
2.4	376

Table - 10
Operating Voltage : 850V
FWHM = 0.25V
Max. Height at 2.95V
Resolution : 0.22/2.95 = 8.5%

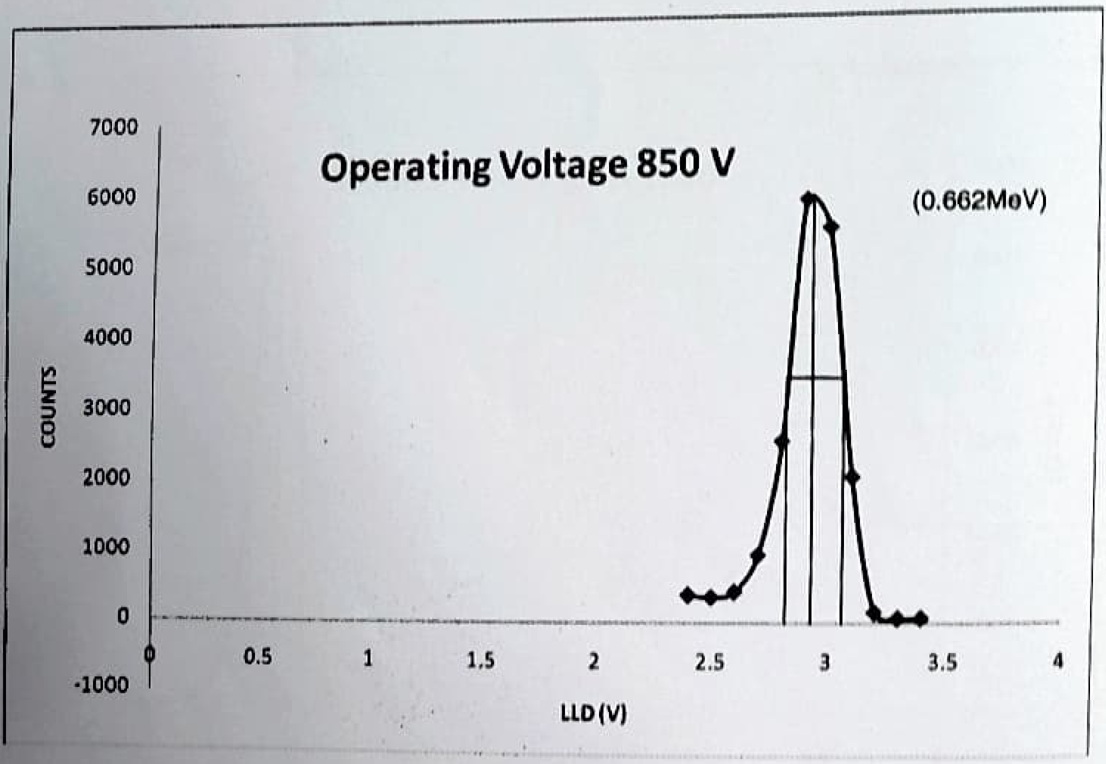

Fig. 21 : Cs-137 photopeak spectrum at 850V

- **FWHM:** Full width at half maximum is the channel width of the Cs-137 photopeak spectrum at half the peak height. In the graph of photopeak spectrum, one can draw a horizontal line at half peak height and see the width. Also from the data of Table-1, one can see that half the peak height will be (7208/2) = 3604. The LLD values corresponding to the counts 3604 are 2.78 and 3.02.

Hence, FWHM = (3.02-2.78) V

= 0.24

- **Resolution (%):** Resolution of a NaI scintillation detector is defined as the ratio of FWHM divided by peak channel LLD value.

$$\text{Resolution} = \left(\frac{0.24}{2.9}\right)$$

$$\text{In percentage} = 0.24/2.9 \text{ X } 100 = 8.28\%$$

- Both resolution & FWHM are important for NaI scintillation detectors and are universally specified with a Cs-137 standard source by the manufacturer of the detector when they supply. Typically resolution for these detectors range from 7.5 % to 9.5%.

SUMMARY:

Table - 11	
Applied Voltage (volts)	Resolution
650	8.3 %
700	8.1 %
750	7.7 %
800	8 %
850	8.5 %

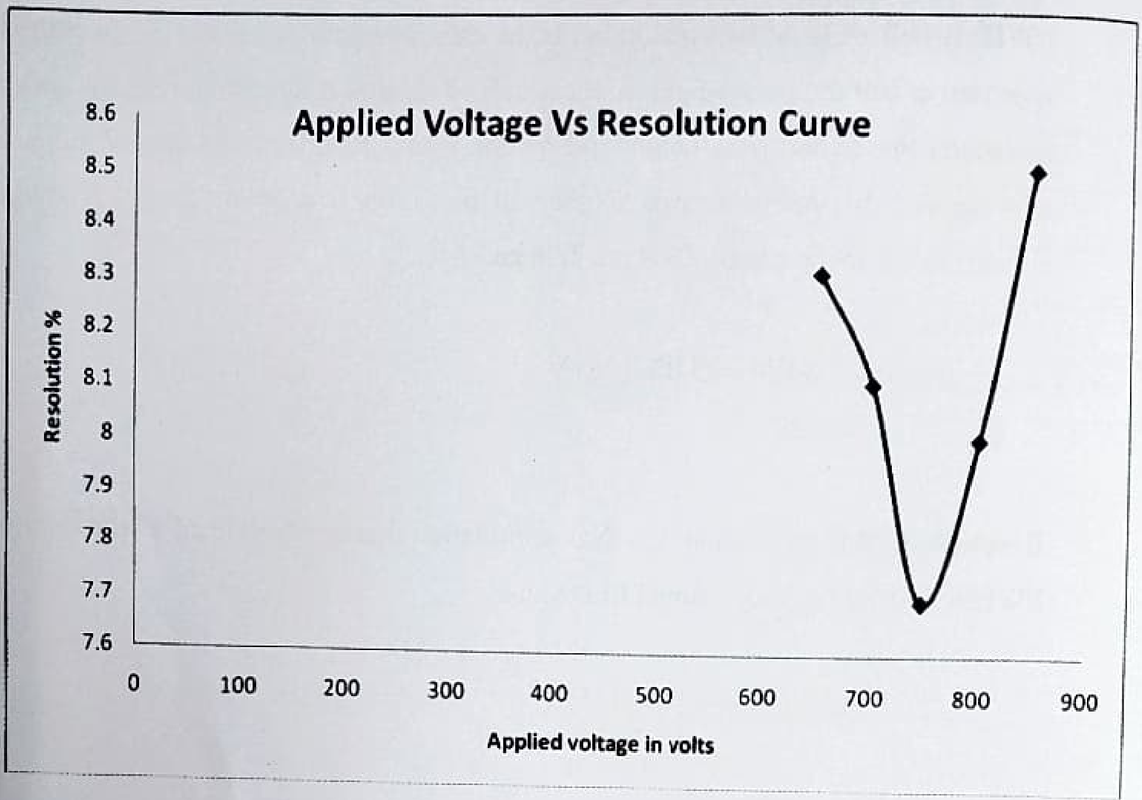

Fig.22 : Applied voltage Vs. resolution characteristics.

CONCLUSION :

From the above observations, it can be concluded that optimum (best) resolution is obtained at 750 V, and hence the same voltage of 750 V is to be used as the best operating voltage for this detector under study.

EXPERIMENT – 2

5.2 STUDY OF Cs-137 SPECTRUM AND CALCULATION OF FWHM & RESOLUTION FOR A GIVEN SCINTILLATION DETECTOR

PURPOSE:

Resolution is an important parameter which determines the quality of any scintillation detector. The purpose of this experiment is to calculate FWHM (Full Width at Half Maximum of the Photopeak) and resolution for a given scintillation detector.

PROCEDURE:

The experimental setup is same as that was shown in Fig. 15/16.

- o Make system interconnections & default settings for either GR611M or 612 model.
- o Place a Cs-137 radioactive standard source at a distance of 4 to 5 cm from the face of the scintillation detector.
- o Set HV on the instrument to **operating voltage (750 V)**, specified by the manufacturer of scintillation detector.
- o Now adjust amplifier gain such that the photo-peak pertaining to 662 keV energy of Cs-137 is approx. 3.0 V (amplitude). [Described in previous section also refer to Fig.13. in the previous pages]
- o This we do usually with the idea of using the GRS to study the gamma energies in the range of 100 keV to 2.0 MeV over which NaI scintillation detectors are used and to cover within 8 V /10 V linear range of the amplifier.
- o Now set the single channel analyzer MODE switch controls in GRS to WINDOW (WIN) position, LLD/Base line dial to 0.0 V and ULD/window dial to 1.0 turns (equal to 100mV window)
- o Operate the GRS in preset time mode with preset time set to 60 sec.
- o Take readings with LLD (Base line) starting from 0.4V in steps of 0.1(100 mV) till you cross Cs-137 photopeak i.e., may be up to 3.5/4.0 V.
- o Tabulate the readings & plot the graph of **count rate** Vs **LLD / Base line** on a graph sheet or in EXCEL in PC as shown in the Fig. 23.

Data Analysis & Computations:

For Cs 137 (0.662 MeV)

Table – 12

LLD	Counts	LLD	Counts
0.4	25741	2.0	5930
0.5	20183	2.1	4806
0.6	17148	2.2	4428
0.7	16452	2.3	4628
0.8	17991	2.4	4112
0.9	17632	2.5	4325
1.0	16145	2.6	7269
1.1	14856	2.7	28527
1.2	13651	2.8	70999
1.3	28421	2.9	55856
1.4	12724	3.0	17579
1.5	12186	3.1	4786
1.6	11980	3.2	1911
1.7	12354	3.3	1226
1.8	11277	3.4	1006
1.9	8163	3.5	906

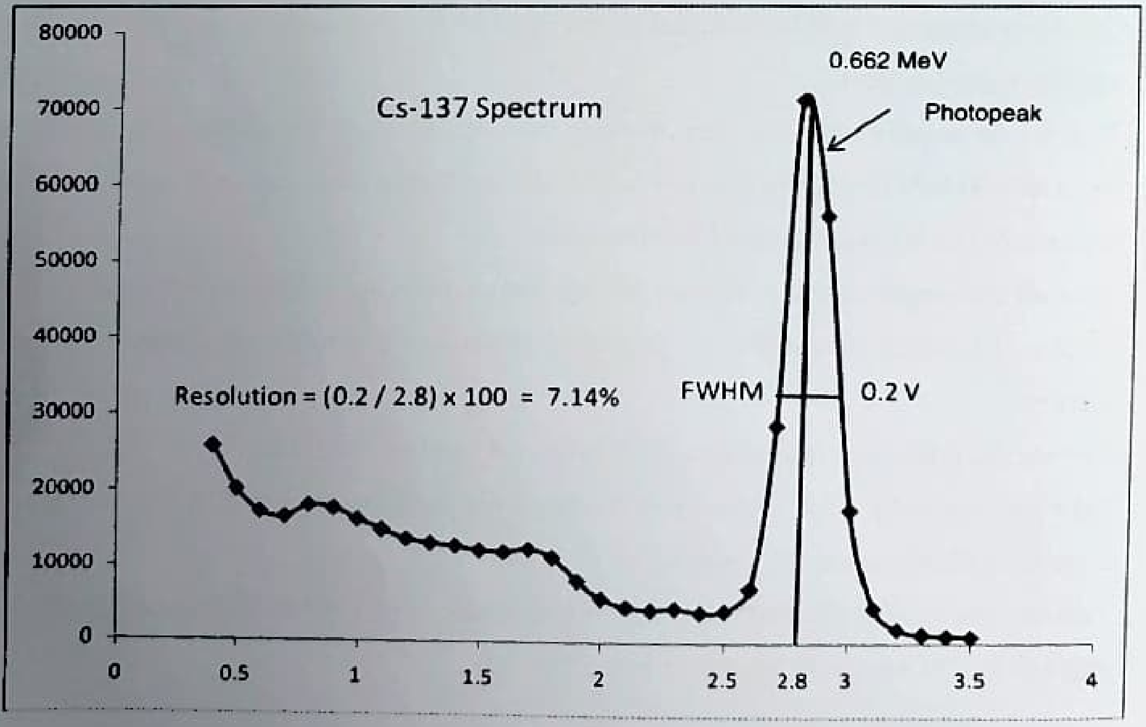

Fig.23 : Cs-137 Energy spectrum

- **FWHM:** Full width at half maximum is the channel width of the Cs-137 spectrum at half the peak height. From the graph one can draw a horizontal line at half peak height & see the width. Also from the tabulated data one can see that half the peak height will be (70, 999 / 2) = 35,499. To obtain exact baseline for these data counts one can repeat the data recording at LLD setting of 2.75V & 2.95 V which may yield data counts very close to half the peak height. Assuming these to be FWHM baseline (LLD) / channels we have

$$\text{FWHM} = (2.95 - 2.75)\ \text{V}$$
$$= 0.20$$

- **Resolution (%):** Resolution of a NaI scintillation detector is defined as the ratio of FWHM divided by peak channel LLD value.

$$\text{Resolution} = 0.20 / 2.8$$
$$\text{In percentage} = 0.20 / 2.8 \times 100 = 7.14\ \%$$

- Both resolution & FWHM are important for NaI scintillation detectors and are universally specified with a Cs-137 standard source by the manufacturer of the detector when they supply. Typically resolution for these detectors range from 7.5 % to 9.5%. Resolution is also specified sometimes in keV. This is calculated and illustrated in Experiment-3.

EXPERIMENT – 3

5.3 STUDY OF Co-60 SPECTRUM AND CALCULATION OF RESOLUTION OF DETECTOR IN TERMS OF ENERGY

PURPOSE: Some times the resolution of a scintillation detector is expressed in terms of energy. The purpose of this experiment is to calculate the resolution of a scintillation detector in terms of energy (keV / channel) with the help of Co-60 Spectrum.

PROCEDURE:

Note: If Experiment-2 was performed and this is a continuation of that, then same settings are to be retained and only Cs-137 source is to be replaced by Co-60 source. If one is doing afresh this experiment then proceed as follows.

- The experimental setup is same as that was shown in Fig. 15/16.
- Make system interconnections & default settings for either GR611M or 612 model.
- Place a Co-60 radioactive standard source on the scintillation detector preferably 2 to 3 cm away from the face of the detector.
- Set controls on the instrument to default settings for HV & amplifier gain, as was done for recording Cs-137 spectrum (i.e., Cs-137 source if placed will have its photopeak approx. 3.0V in amplitude)
- Set HV on the instrument to **operating voltage (750V)**, specified by the manufacturer of scintillation detector.
- Now adjust amplifier gain such that the photopeak pertaining to 662 keV energy of Cs-137 is approx. 3.0V amplitude (Described in previous section and also refer to Fig.13. in the previous pages).
- This we do usually with the idea of using the GRS to study the gamma energies in the range of 100 keV to 2.0 MeV over which NaI scintillation detectors are used and to cover within 8V /10V linear range of the amplifier.
- Now set the single channel analyzer controls in GRS as below: MODE switch, to WINDOW (WIN) position, LLD/Base line dial to 0.0V and ULD / window dial to: 1.0 turns (equal to 100mV window)
- Operate the GRS in preset time mode with preset time set to 60 sec.
- Take reading with LLD (Base line) starting from 0.1 V in steps of 0.1(100mV window) till you cross Co-60 photo-peaks i.e., may be up to 6.3 V.

- Tabulate the readings and plot graph of count rate Vs LLD on a graph sheet or in EXCEL in PC as shown in the Fig.24.
- Note down the LLD values (in volts) corresponding to the two energy peaks 1.17 MeV & 1.33 MeV, which are 4.8 V and 5.45 V respectively. It can also be noticed from the tabulated data also.
- Now assuming zero energy intercept at origin, now compute peak channel difference & energy difference from the table and calculate per channel (1 Ch. = 100 mV) keV.

DATA ANALYSIS & COMPUTATIONS:

<u>For CO-60 (1.17 & 1.33 MeV)</u>

Table – 13

LLD	Counts	LLD	Counts	LLD	Counts	LLD	Counts
0.10	22604	1.70	16630	3.30	16756	4.90	33536
0.20	22723	1.80	16477	3.40	17526	5.00	13460
0.30	22574	1.90	16209	3.50	18050	5.10	6147
0.40	22460	2.00	16011	3.60	18393	5.20	8332
0.50	21790	2.10	15753	3.70	18524	5.30	18284
0.60	21695	2.20	15952	3.80	18366	5.40	31564
0.70	21556	2.30	15433	3.90	16607	5.45	33860
0.80	21793	2.40	15684	4.00	15180	5.50	31835
0.90	25159	2.50	15359	4.10	13682	5.60	17578
1.00	26933	2.60	15511	4.20	13456	5.70	6361
1.10	24386	2.70	15545	4.30	13390	5.80	2818
1.20	21665	2.80	15549	4.40	13074	5.90	2395
1.30	20188	2.90	15851	4.50	12161	6.00	2409
1.40	18745	3.00	16303	4.60	13936	6.10	2241
1.50	17744	3.10	16210	4.70	29977	6.20	2387
1.60	17335	3.20	16592	4.80	42864	6.30	2382

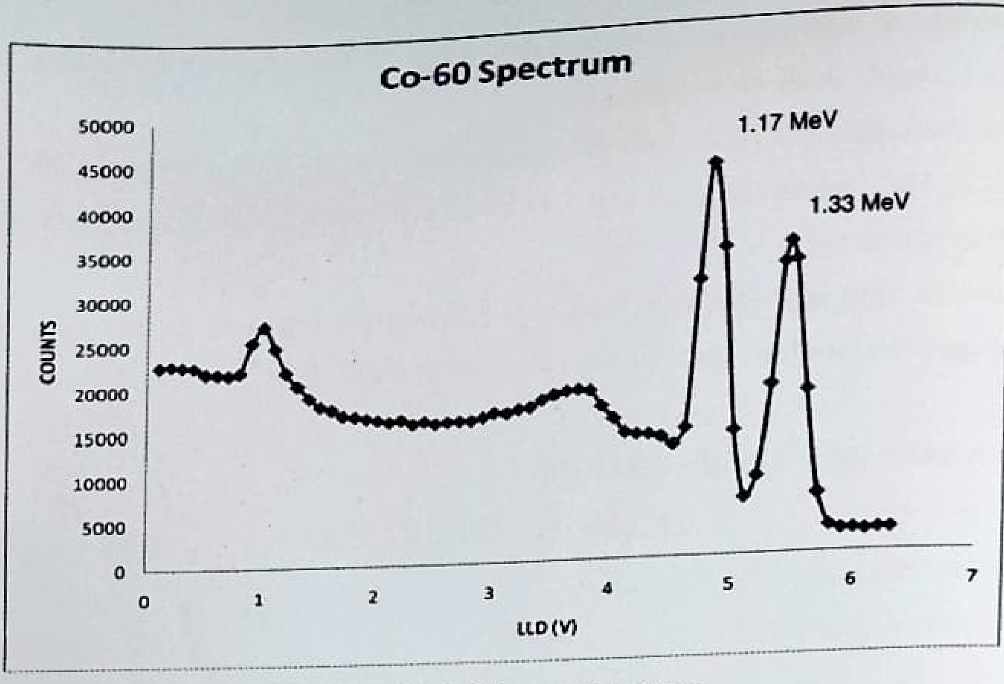

Fig. 24 : Cobalt-60 energy spectrum

- **Calculation of per channel keV :** Co-60 photopeak energies are known to be 1.17 MeV & 1.33 MeV. From the data recorded we know that peak channels are

Base line	Co-60 Energy
4.8 V	1.17 MeV
5.45 V	1.33 MeV

Difference in baseline = 5.45-4.8 = 0.65 V

Difference in energy = 1.33-1.17 = 0.16 MeV = 160 keV

0.65 V ---- 160 keV　　　　say 0.1 V = 1 channel

0.1V ---- 160/6.5 = 24.6 keV　　　　so, 1 channel = 24.6 keV

- **Calculation of detector resolution in terms of keV :** From the above data, resolution for Cs-137 can be calculated by taking the ratio of FWHM in keV and peak channel in keV. (It is important that amplifier & HV settings for Experiments 2 & 3 are kept same, for this result to be correct)

It is known from the Experiment-2 that FWHM = 0.20V = 2 channels = 2x24.6 keV = 49.2 keV

Peak channel corresponds to 662 keV.

Hence, Resolution = $\dfrac{\text{FWHM}}{\text{Peak energy}} = \dfrac{49.2 \text{ keV}}{662 \text{ keV}} = 0.0743$

Resolution in % = 0.0743 x 100 = 7.43%

EXPERIMENT – 4

5.4 ENERGY CALIBRATION OF GAMMA RAY SPECTROMETER (STUDY OF LINEARITY)

PURPOSE: To study the different energy gamma sources.

PROCEDURE:

- The experimental setup is same as that was shown in Fig. 15/16.
- Make interconnections & default settings and proceed with the recording of Cs-137 spectrum by following the steps as detailed in Experiment-2. Record data only in the peak portion of Cs-137 by taking about $\pm$ 6 channels on either side of peak.
- Replace this with other energy radioactive standards one by one from **Gamma standards reference** set which contains sources as tabulated below

Table-14

Gamma Isotope	Energy MeV	Nominal Activity	Half life
Ba-133	0.36 (Main)	2-5 μCi	7.5 years
Cs-137	0.662	2-5 μCi	30 years
Co-60	1.17, 1.33	2-5 μCi	5.3 years
Na-22	0.511, 1.28	2-5 μCi	2.6 years

- For each of the energies, by knowing the photopeak energy, one can know the LLD/Baseline setting approx and hence one can take readings so as to cover readings on either side of the peak. (There is no need to scan and take readings completely for base lines from 0.0 to 10.0)
- Tabulate complete data (Tables 15 to 19), and plot photopeak spectra for each of the energies (Fig. 25 to 29).
- Plot LLD / Base line Vs peak energy data (Table-20) on a graph sheet or in EXCEL as shown in Fig.30.
- This shall be a straight line, which indicates that the spectrometer is linear. This is an important parameter of the spectrometer.

DATA ANALYSIS & COMPUTATIONS:

For CS-137 (0.662 MeV)

Table-15	
Base Line (V)	Counts
3.4	161
3.3	213
3.2	533
3.1	6761
3	18860
2.9	21173
2.8	7083
2.7	1565
2.6	1129
2.5	1126
2.4	1150

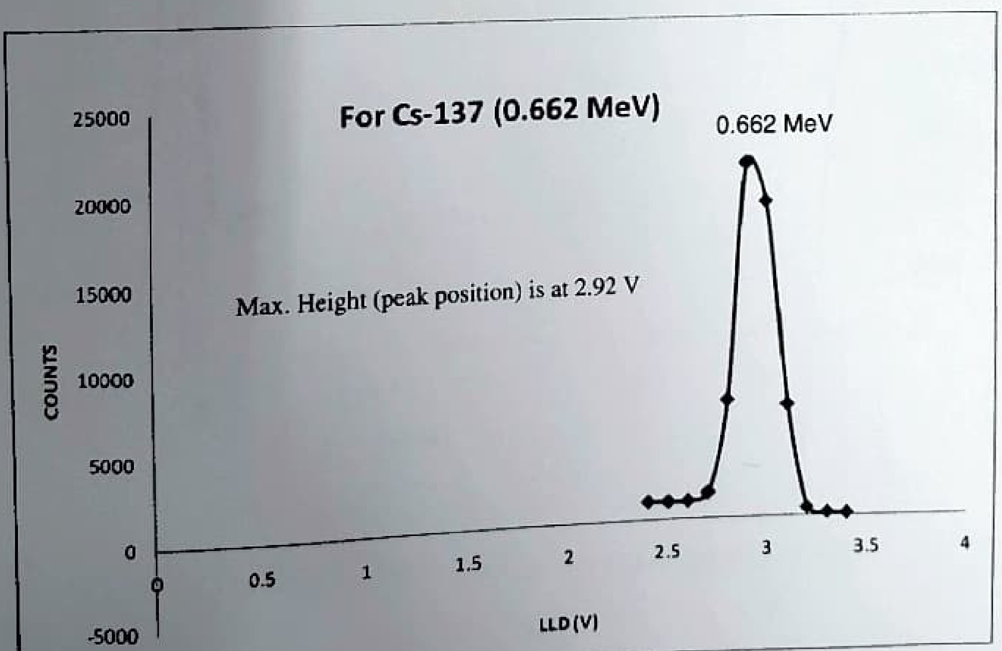

Fig.25 : Photopeak spectrum for 0.662 MeV of Cs-137

For Co-60 (1.17 & 1.33 MeV)

Table-16			
Base Line (V)	Counts	Base Line (V)	Counts
6.4	530	5.4	2865
6.3	557	5.3	8232
6.2	775	5.2	13664
6.1	1748	5.1	13502
6.0	5639	5.0	7478
5.9	11031	4.9	4106
5.8	10506	4.8	3806
5.7	6210	4.7	4140
5.6	2692	4.6	4214
5.5	1768	4.5	4256

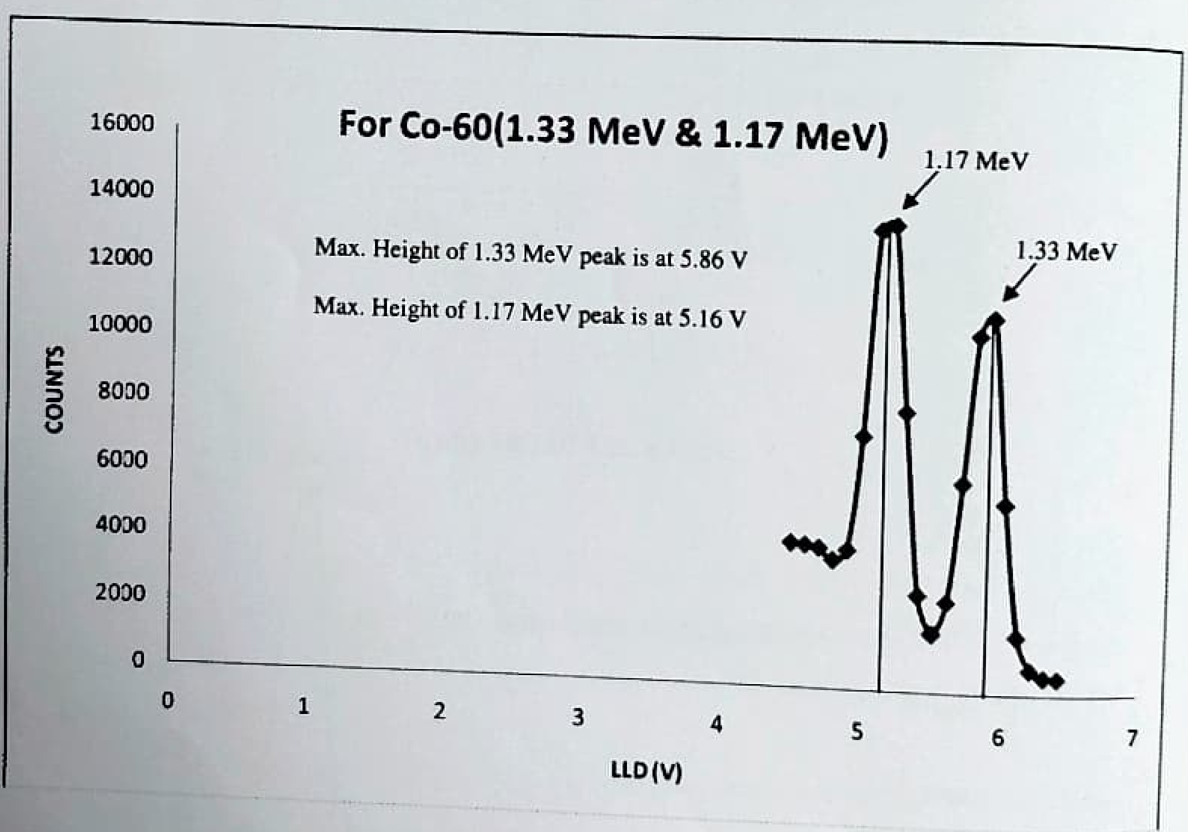

Fig.26 : Photopeak spectrum for 1.17& 1.33 MeV of Co-60

For Na-22 (0.511 MeV)

Table-17	
Base Line (V)	Counts
2.70	1032
2.60	996
2.50	985
2.40	2701
2.30	21620
2.25	26500
2.20	20412
2.10	4084
2.00	2561
1.90	2412

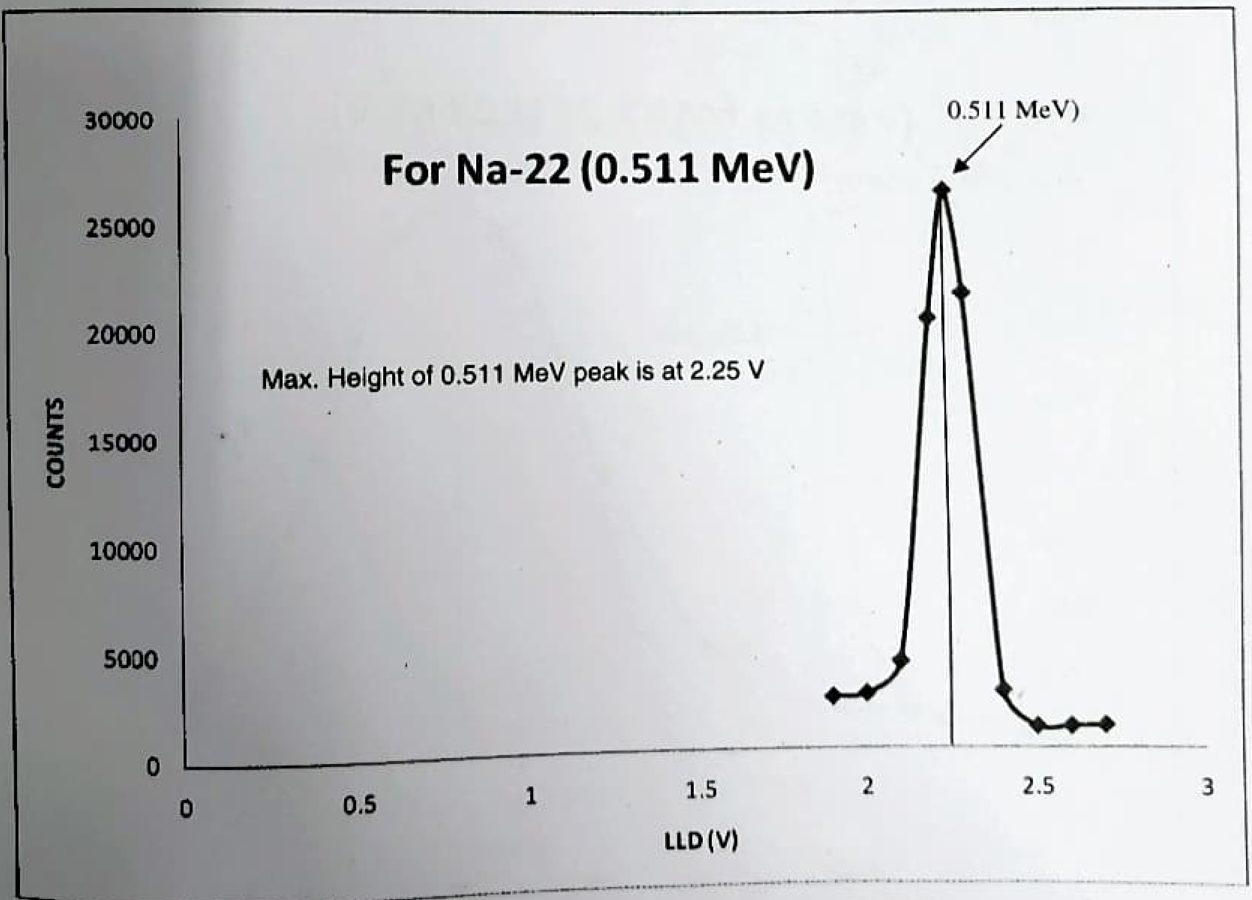

Fig.27 : Photopeak spectrum for 0.511 MeV of Na-22

For Na-22 (1.28 MeV)

Table-18	
Base Line (V)	Counts
6.0	134
5.9	486
5.8	1789
5.7	3650
5.6	3689
5.5	1944
5.4	713
5.3	314
5.2	266

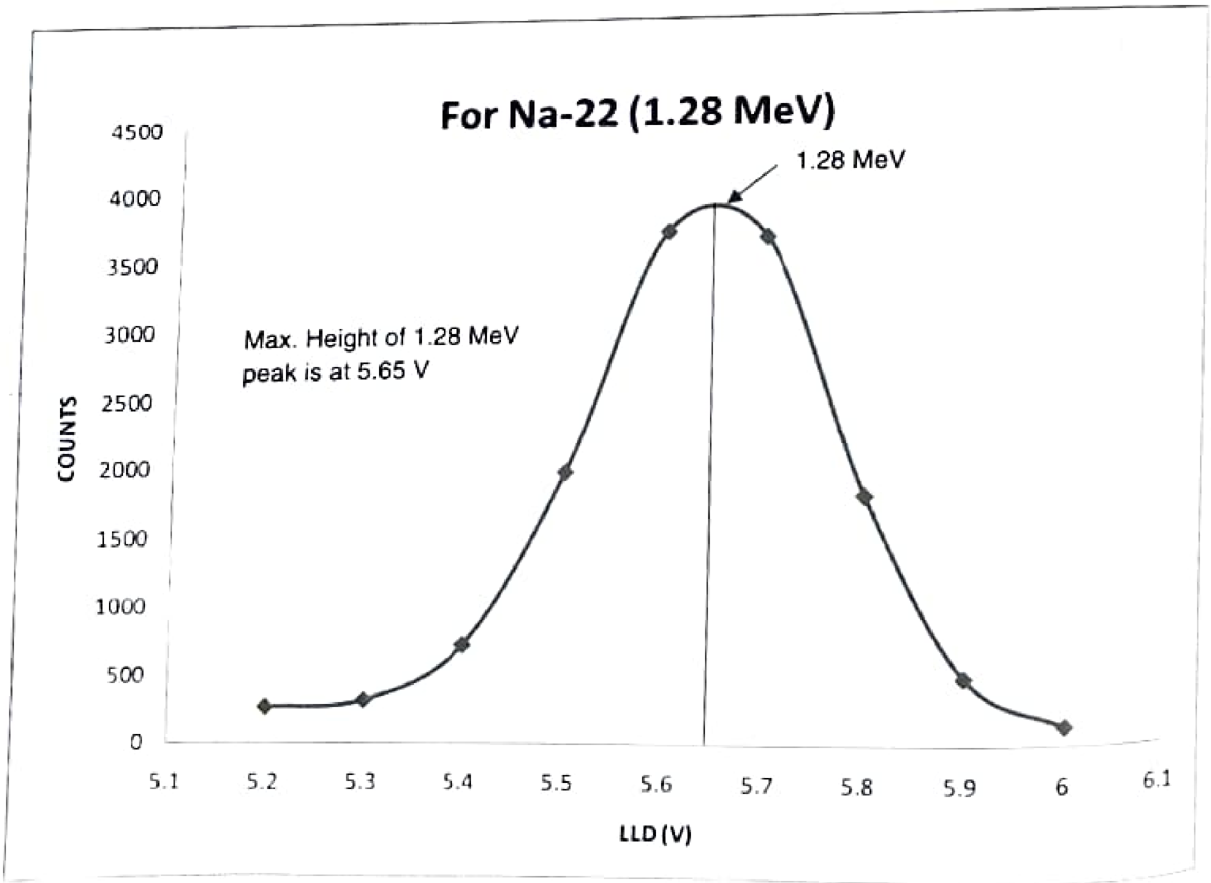

Fig.28 : Photopeak spectrum for 1.28 MeV of Na-22

For Ba-133 (0.36 MeV)

Table-19	
Base Line (V)	Counts
2.2	492
2.1	988
2.0	1758
1.9	1846
1.8	4087
1.7	8500
1.6	33653
1.5	13414
1.4	6459
1.3	6966

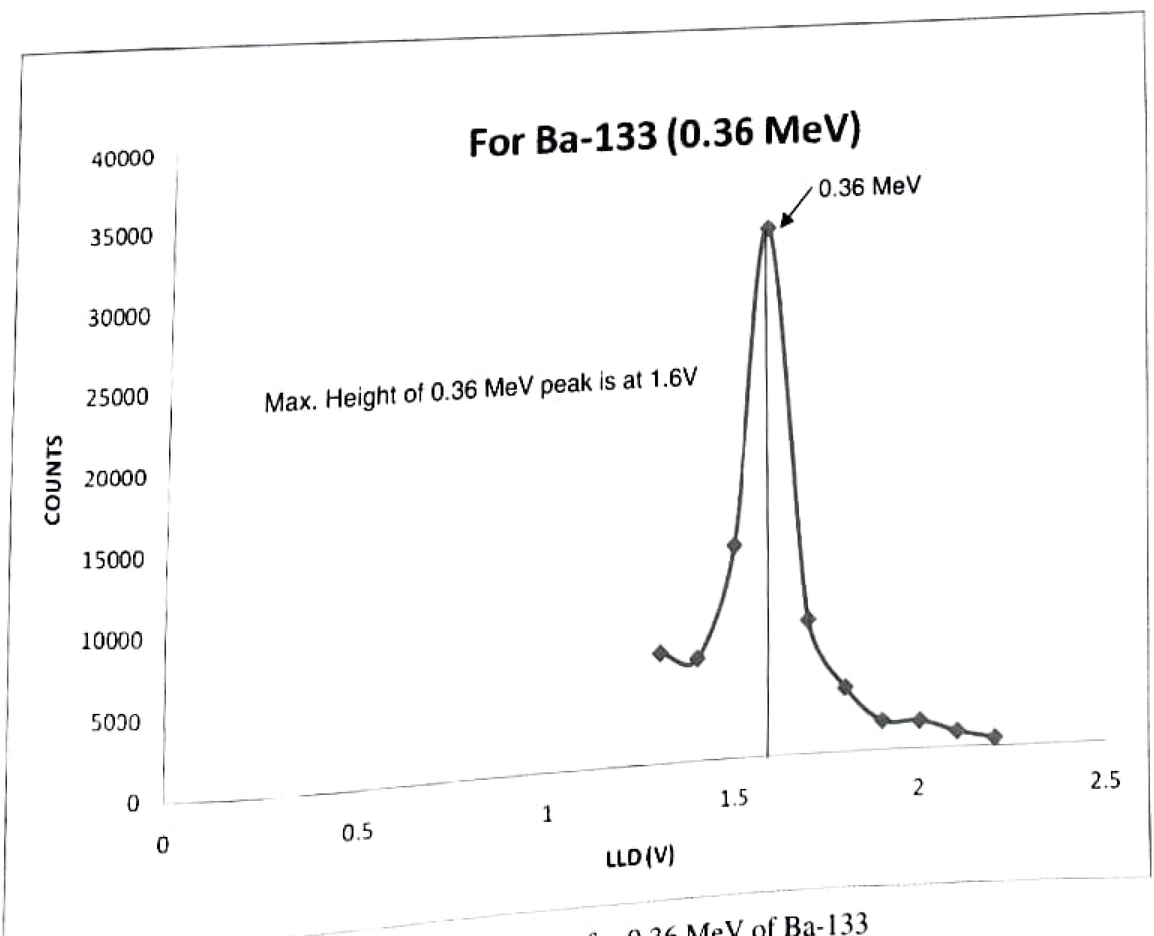

Fig.29 : Photopeak spectrum for 0.36 MeV of Ba-133

SUMMAY :

Table-20		
Source	Energy (MeV)	Base line voltage (Volts)
Ba-133	0.36	1.60
Na-22	0.511	2.25
Cs-137	0.662	2.92
Co-60	1.17	5.16
Na-22	1.28	5.65
Co-60	1.33	5.86

A plot is drawn between energy and base line voltage as shown below. The obtained graph is a straight line, which indicates at the Gamma Ray Spectrometer is linear over the entire energy range. This is a very important parameter of the spectrometer.

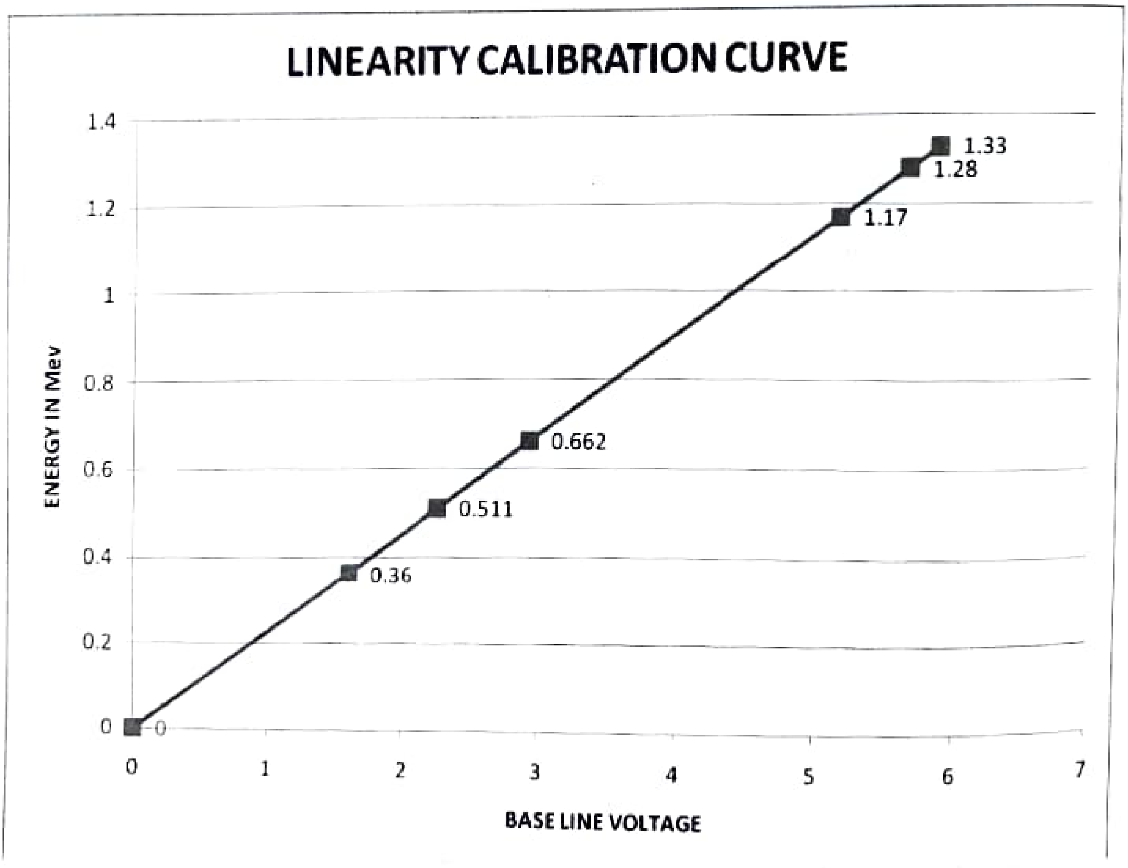

Fig.30 : Baseline voltage Vs. energy graph (energy linearity graph)

EXPERIMENT - 5

5.5 SPECTRUM ANALYSIS OF Co-60 & Cs-137 AND TO EXPLAIN SOME OF THE FEATURES OF COMPTON EDGE AND BACKSCATTER PEAK

The purpose of this experiment is to explain some of the features, other than the photo-peak, that are usually present in a pulse-height spectrum. These are the Compton edge and the backscatter peak.

THEORY: The Compton interaction is a pure kinematic collision between a gamma photon and what might be termed a free electron in the NaI (TI) crystal. By this process, the incident gamma gives up only part of its energy to the electron. The amount given to the recoil electron (and hence the intensity of the light flash) depends on whether the collision is head-on or glancing. For a head-on collision the gamma imparts the maximum allowable energy for the Compton interaction. The energy of the scattered gamma can be determined by solving the energy and momentum equations for this billiard-ball collision. The solution for these equations in terms of the scattered can be written approximately as

$$E_\Upsilon' \cong \frac{E_\Upsilon}{1 + 2\,E_\Upsilon\,(1 - \cos\theta)} \tag{8}$$

where

E_Υ'= energy of the scattered gamma in MeV

θ = the scattering angle for gamma

E_Υ = the incident gamma ray energy in MeV

If $\theta = 180^\circ$ due to a head on collision in which gamma is scattered directly back, Eq. (8) becomes

$$E_\Upsilon' \cong \frac{E_\Upsilon}{1 + 4\,E_\Upsilon} \tag{9}$$

As an example, we will calculate E_Υ' for an incident gamma energy of 1 MeV :

$$E_\Upsilon' \cong = \frac{1\ \text{MeV}}{1 + 4} = 0.2\ \text{MeV} \tag{10}$$

The energy of the recoil electron (E_e) for this collision would be 0.80 MeV. This is true since

$$E_e = E_\Upsilon - E_\Upsilon' \quad (11)$$

Hence the position of the Compton edge, which is the maximum energy that can be imparted to an electron by the Compton interaction, can be calculated by Eq. (11).

PROCEDUE :

- o The experimental setup is same as that was shown in Fig. 15/16.
- o Make system interconnections & default settings for either GR611M or 612 model.
- o Place a Cs-137 radioactive standard source on the scintillation detector preferably 2 to 3 cm away from the face of the detector.
- o Set controls on the instrument to default settings for HV & amplifier gain, as was done for recording Cs-137 spectrum (i.e., Cs-137 source if placed will have its photopeak approx. 3.0V in amplitude)
- o Set HV on the instrument to **operating voltage (750V)**, specified by the manufacturer of scintillation detector.
- o Now adjust amplifier gain such that the photopeak pertaining to 662 keV energy of Cs-137 is approx. 3.0V (amplitude). [Described in previous section also refer to Fig.13. in the previous pages.]
- o This we do usually with the idea of using the GRS to study the gamma energies in the range of 100 keV to 2.0 MeV over which NaI scintillation detectors are used and to cover within 8V /10V linear range of the amplifier.
- o Now set the single channel analyzer controls in GRS as below: MODE switch, to WINDOW (WIN) position, LLD/Base line dial to 0.0V and ULD / window dial to: 1.0 turns (equal to 100mV window)
- o Operate the GRS in preset time mode with preset time set to 60 sec.
- o Take reading with LLD (Base line) starting from 0.1 V in steps of 0.1(100mV window) till you cross Cs-137 photopeak i.e., may be up to 3.6 V.
- o Tabulate the readings (Table-21) and plot graph of count rate Vs LLD on a graph sheet or in EXCEL in PC as shown in the Fig.31.
- o Replace Cs-137 source by Co-60 source.
- o Take reading with LLD (Base line) starting from 0.1 V in steps of 0.1(100mV window) till you cross Cs-137 photopeak i.e., may be up to 6.3 V.

- Tabulate the readings (Table-22) and plot graph of count rate Vs LLD on a graph sheet or in EXCEL in PC as shown in the Fig.32.
- Note down LLD / Baseline values for Cs-137 (0.662 MeV) and Co-60 (1.17 & 1.33 MeV) photopeaks.
- Plot LLD / Baseline Vs. Peak energy on a graph sheet or in EXCEL in PC as shown in Fig.33.

Tabel-21

Energy Calibration (Cs-137)

LLD	Counts
0.20	17210
0.30	17468
0.40	16305
0.50	15249
0.60	15298
0.70	15285
0.80	18264
0.90	20628
1.00	17886
1.10	15230
1.20	13632
1.30	12907
1.40	12270
1.50	11781
1.60	11923
1.70	11942
1.80	12914
1.90	12853
2.00	8905
2.10	5313
2.20	4162
2.30	3517
2.40	3530

Tabel-22

Energy Calibration (Co-60)

LLD	Counts
0.10	22604
0.20	22723
0.30	22574
0.40	22460
0.50	21790
0.60	21695
0.70	21556
0.80	21793
0.90	25159
1.00	26933
1.10	24386
1.20	21665
1.30	20188
1.40	18745
1.50	17744
1.60	17335
1.70	16630
1.80	16477
1.90	16209
2.00	16011
2.10	15753
2.20	15952
2.30	15433

Table -22 Contd.....

2.50	3994
2.60	6905
2.70	29112
2.80	80021
2.90	81964
3.00	60171
3.10	8410
3.20	786
3.30	459
3.40	412
3.50	381
3.60	353

2.40	15684
2.50	15359
2.60	15511
2.70	15545
2.80	15549
2.90	15851
3.00	16303
3.10	16210
3.20	16592
3.30	16756
3.40	17526
3.50	18050
3.60	18393
3.70	18524
3.80	18366
3.90	16607
4.00	15180
4.10	13682
4.20	13456
4.30	13390
4.40	13074
4.50	12161
4.60	13936
4.70	29977
4.80	42864
4.90	33536
5.00	13460
5.10	6147
5.20	8332
5.30	18284
5.40	31564
5.45	33860
5.50	31835

Table -22 Contd.....

5.60	17578
5.70	6361
5.80	2818
5.90	2395
6.00	2409
6.10	2241
6.20	2387
6.30	2382

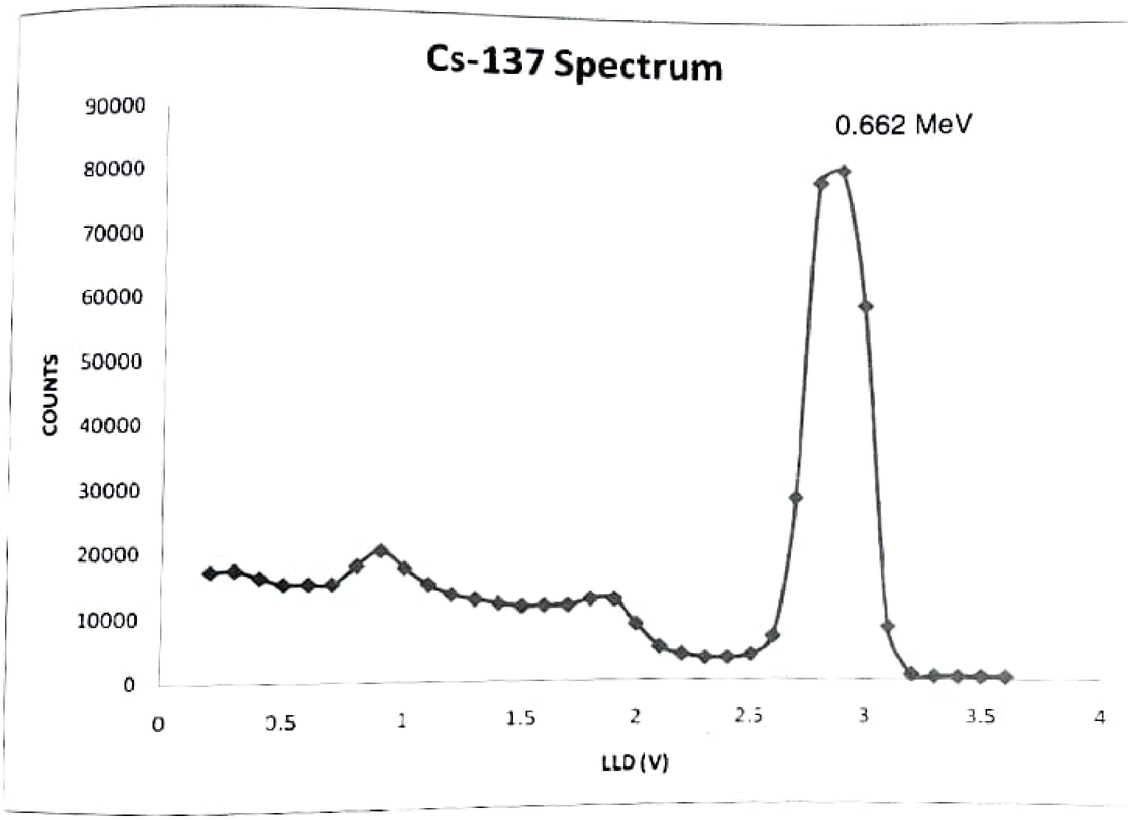

Fig. 31 : Cs-137 energy spectrum

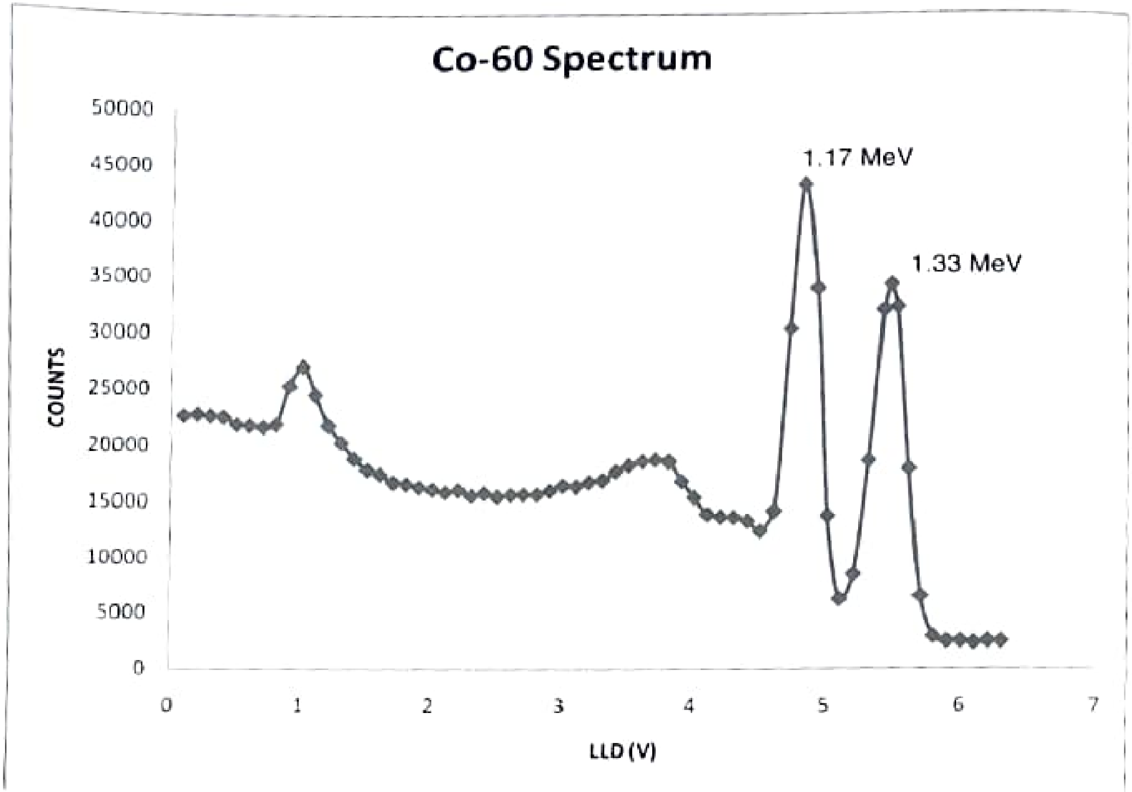

Fig. 32 : Co-60 energy spectrum

Exercise a: Calculate the energy of the Compton edge for the 0.662 MeV gammas from Cs-137. Enter this value in Table-23. From your plot and calibration curve, does this calculation agree with your measured value?

Exercise b: Backscatter occurs when gammas make Compton interactions in the material that surrounds the detector. Fig. 34. is a good illustration of the various events that can take place in a typical source NaI (TI) detector lead shield arrangement. Backscattered gammas from these interactions (E) make photo-electric interactions in the NaI (TI) when they enter the crystal. The energy of the backscattered peak can be found by solving Eq. (9).

Solve Eq. (9) for the backscatter gammas of 0.662 MeV from Cs-137 and for the 1.33 MeV gammas from Co-60. Also calculate the Compton edge of 0.662 MeV of Cs-137 from Eq. (11). Fill in the rest of Table-23. How do your measured energies compared with the theoretical energies calculated from (9&11)? If the backscatter peak is not very pronounced in your spectrum, it can be improved by accumulating a spectrum with a sheet of lead absorber placed on either side of the source, in case lead castle is not available to house the detector.

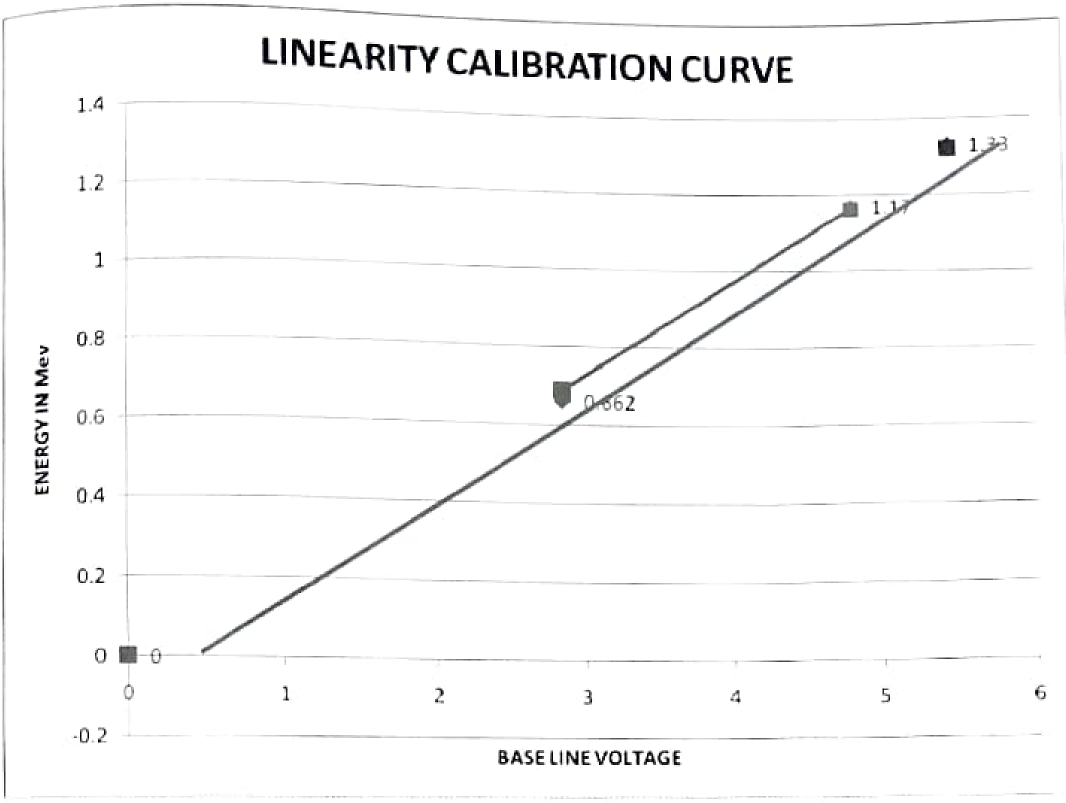

Fig. 33 : Co-60 energy spectrum

Table - 23			
Event Energy	Baseline (Volts)	Energy (MeV) Experimental value	Theoretical value (MeV)
0.662-MeV Photo Peak	2.85	0.662	0.662
1.17-MeV Photo Peak	4.80	1.17	1.17
1.33-MeV Photo Peak	5.45	1.33	1.33
Compton Edge ^{137}Cs	1.95	0.462	0.481
Back scatter ^{137}Cs	0.85	0.200	0.181
Back Scatter ^{60}Co	1.00	0.22	0.21

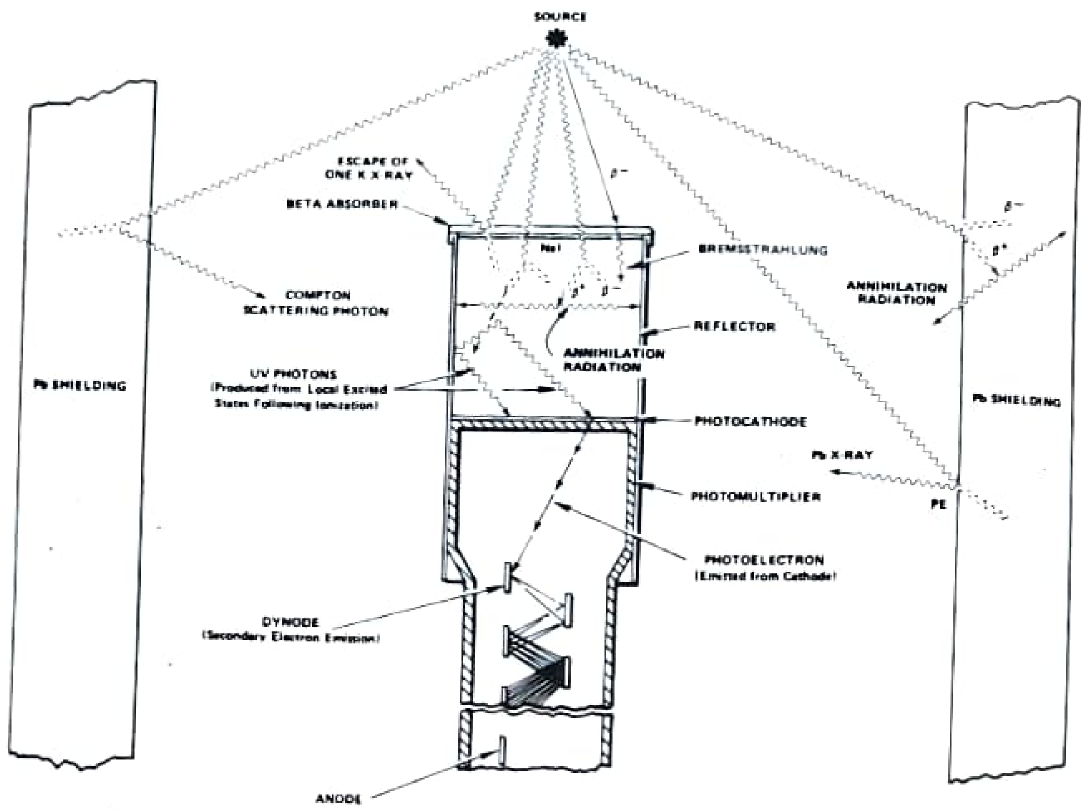

Fig:34 : Various Events in the Vicinty of a Typical Source-Crystal Detector- Shield Configuration

EXPERIMENT – 6

5.6 UNKNOWN ENERGY OF A RADIOACTIVE ISOTOPE

AIM :

Unknown masked (covered) disc source may be given to student to find out its energy, along with a set of at least three known energies.

PROCEDURE :

- To do this experiment, proceed with the steps as explained under Experiment-4 and plot energy Vs base line (LLD) graph which is a straight line, with the set of given known sources (energies).
- Now place unknown masked source and observe in the oscilloscope its photo-peak height amplitude if oscilloscope is provided. If not, scan the whole base line from 0.1V to 10.0V and tabulate the data.
- From the data obtained, one can know the peak data counts and its corresponding LLD/baseline, which can be extrapolated on to the energy curve to calculate the energy of unknown peak. This energy thus obtained should be matched to a known radioactive standard source. Tabulate the energy mismatch reported.

EXPERIMENT – 7

5.7 VARIATION OF ENERGY RESOLUTION WITH GAMMA ENERGY

PURPOSE :

To Study the Variation of Energy Resolution as a function of Gamma Energy.

THEORY : The Resolution varies primarily from the statistical fluctuation of the number of photo electrons that are produced at the photo cathode surface in the photomultiplier tube. The number of photo electrons in turn depend on the energy of the incident photon for a constant interdynode potential (given applied voltage). So in NaI (Tl) detectors, the energy resolution varies appreciably with the energy of the incident photons. The present experiment aims to study how this resolution varies with the energy of the incident radiation.

PROCEDURE :

The experimental part is same as in Experiment-4 (Energy calibration of Gamma Ray Spectrometer). The same data is useful for this study also.

- Plot the photopeak spectrum of each energy (for Cs-137, Co-60, Na-22 & Ba-133).
- From the graph calculate the FWHM of each photopeak and calculate the energy resolution of each energy as detailed in Experiment -1.
- Draw a graph between the energy of gamma ray (X-axis) and the corresponding obtained resolution (Y-axis).
- Report how the resolution varies with the energy of the gamma radiation.

DATA ANALYSIS & COMPUTATIONS:

For CS-137 (0.662 MeV)

Table -24

Base Line (V)	Counts
3.4	161
3.3	213
3.2	533
3.1	6761
3	18860
2.9	21173
2.8	7083
2.7	1565
2.6	1129
2.5	1126
2.4	1150

Table - 25

Operating Voltage : 750V
FWHM = 0.22V
Max. Height at 2.92V
Resolution : 7.5%

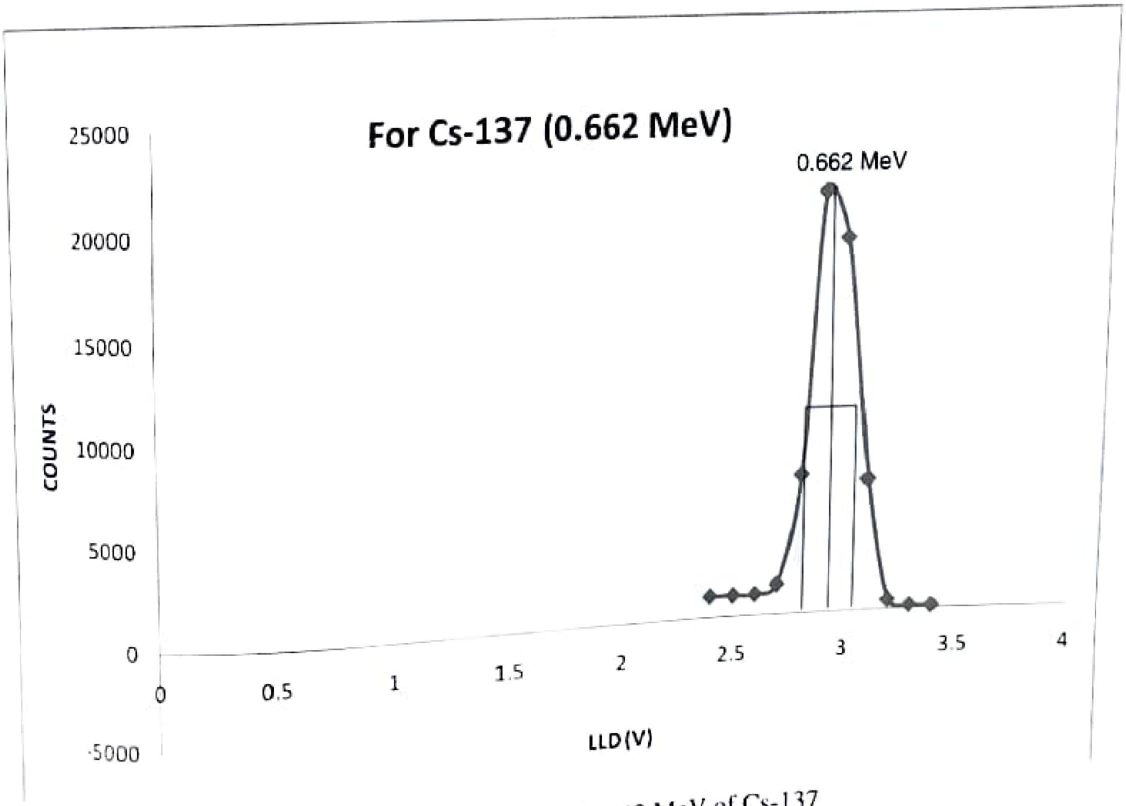

Fig.35 : Photopeak spectrum for 0.662 MeV of Cs-137

For Co-60 (1.33 & 1.17 MeV)

Table -26

Base Line (V)	Counts
6.4	530
6.3	557
6.2	775
6.1	1748
6	5639
5.9	11031
5.8	10506
5.7	6210
5.6	2692
5.5	1768
5.4	2865
5.3	8232
5.2	13664
5.1	13502
5	7478
4.9	4106
4.8	3806
4.7	4140
4.6	4214
4.5	4256

Table - 27

For 1.33 MeV
Operating Voltage : 750V
FWHM = 0.32V
Max. Height at 5.86V
Resolution : 5.5%
For 1.17 MeV
Operating Voltage : 750V
FWHM = 0.32V
Max. Height at 5.16V
Resolution : 6.2%

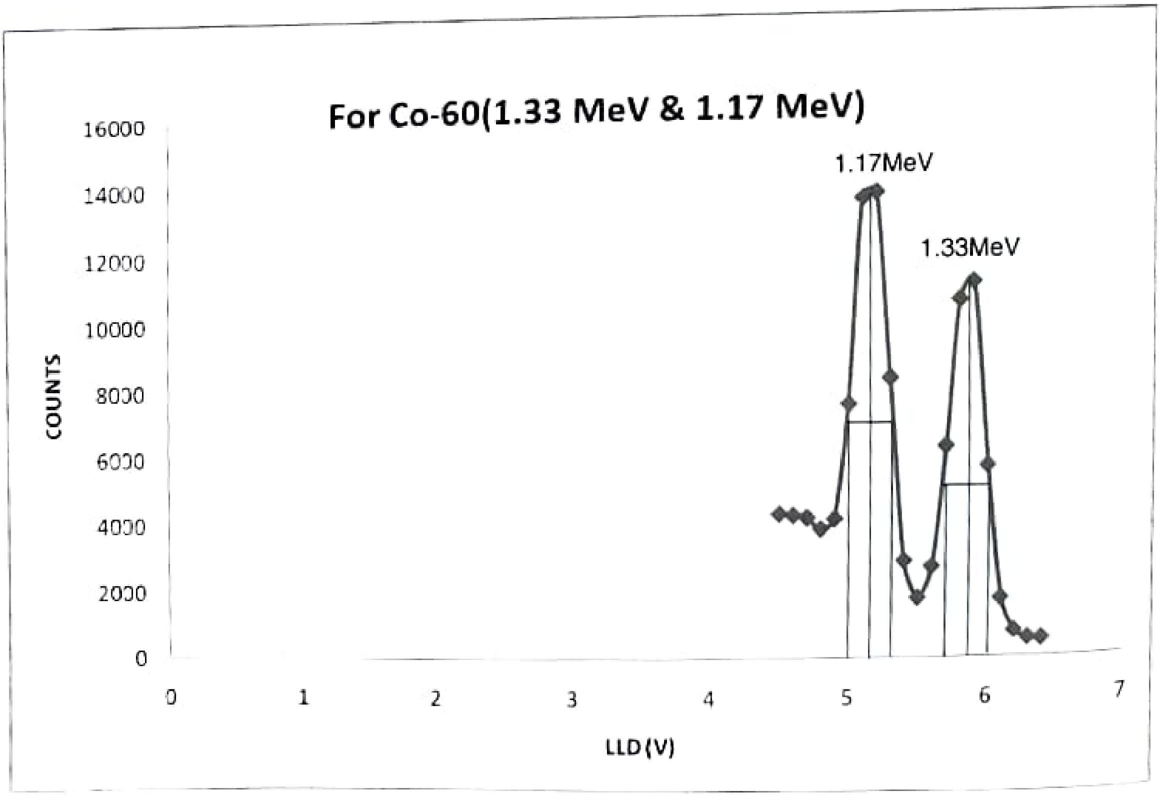

Fig. 36 : Photopeak spectra for 1.17 & 1.33 MeV of Co-60

For Na-22 (0.511 MeV)

Table -28	
Base Line (V)	Counts
2.7	1032
2.6	996
2.5	985
2.2	2701
2.1	21620
2.25	26500
2.2	20412
2.1	4084
2.0	2561
1.9	2412

Table - 29
Operating Voltage : 750V
FWHM = 0.18V
Max. Height at 2.25 V
Resolution : 8%

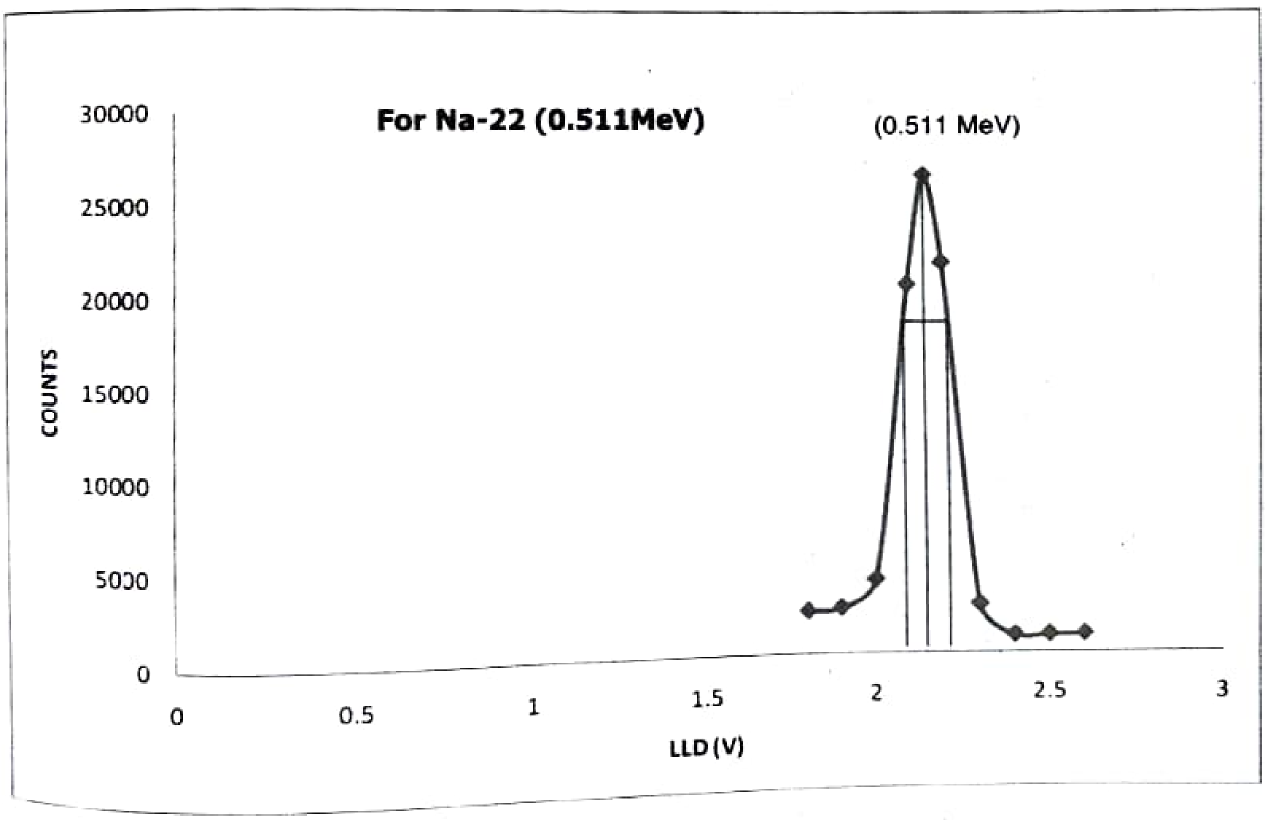

Fig.37 : Photopeak spectrum for 0.511 MeV of Na-22

For Na-22 (1.28 MeV)

Table -30	
Base Line (V)	Counts
6.0	134
5.9	486
5.8	1789
5.7	3650
5.6	3689
5.5	1944
5.4	713
5.3	314
5.2	266

Table - 31
Operating Voltage : 750V
FWHM = 0.33V
Max. Height at 5.65 V
Resolution : 5.8%

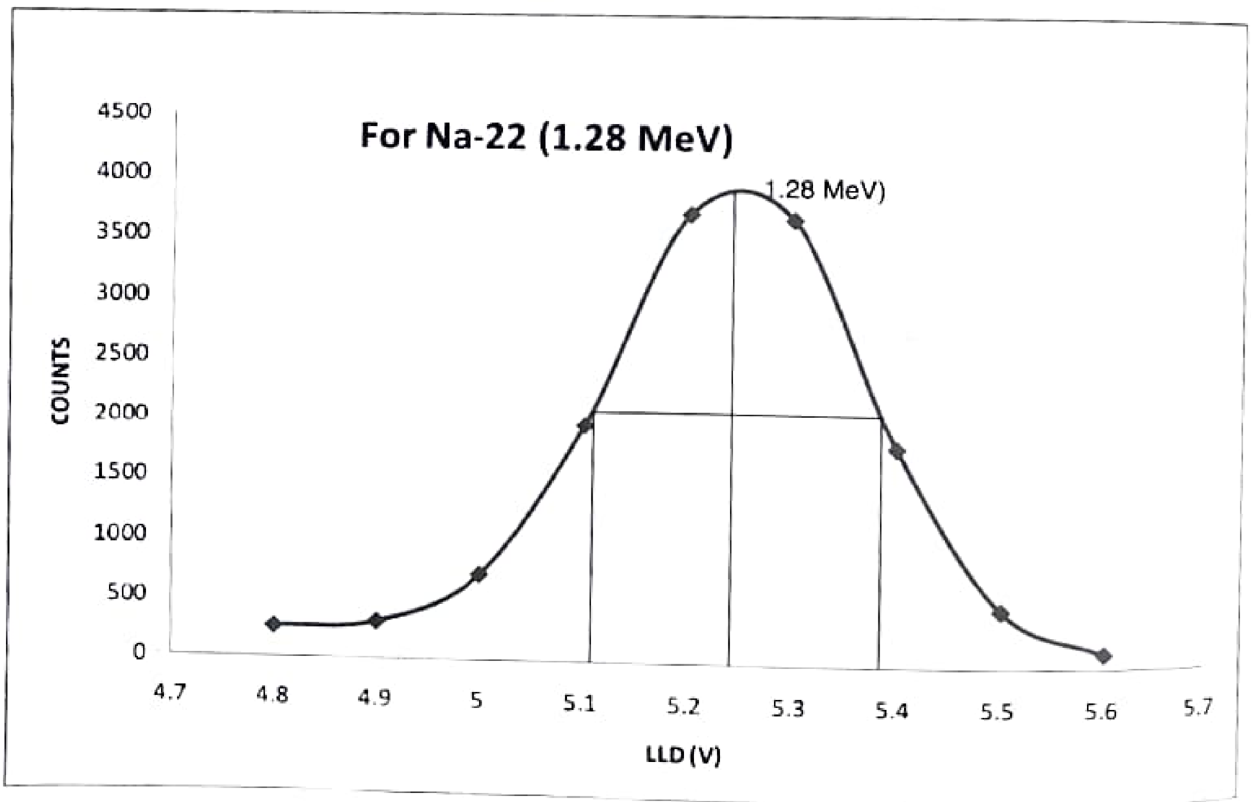

Fig.38 : Photopeak spectrum for 1.28 MeV of Na-22

For Ba-133 (0.36 MeV)

Table -30	
Base Line (V)	Counts
2.2	492
2.1	988
2.0	1758
1.9	1846
1.8	4087
1.7	8500
1.6	33653
1.5	13414
1.4	6459
1.3	6966

Table - 31
Operating Voltage : 750V
FWHM = 0.16V
Max. Height at 1.6 V
Resolution : 10%

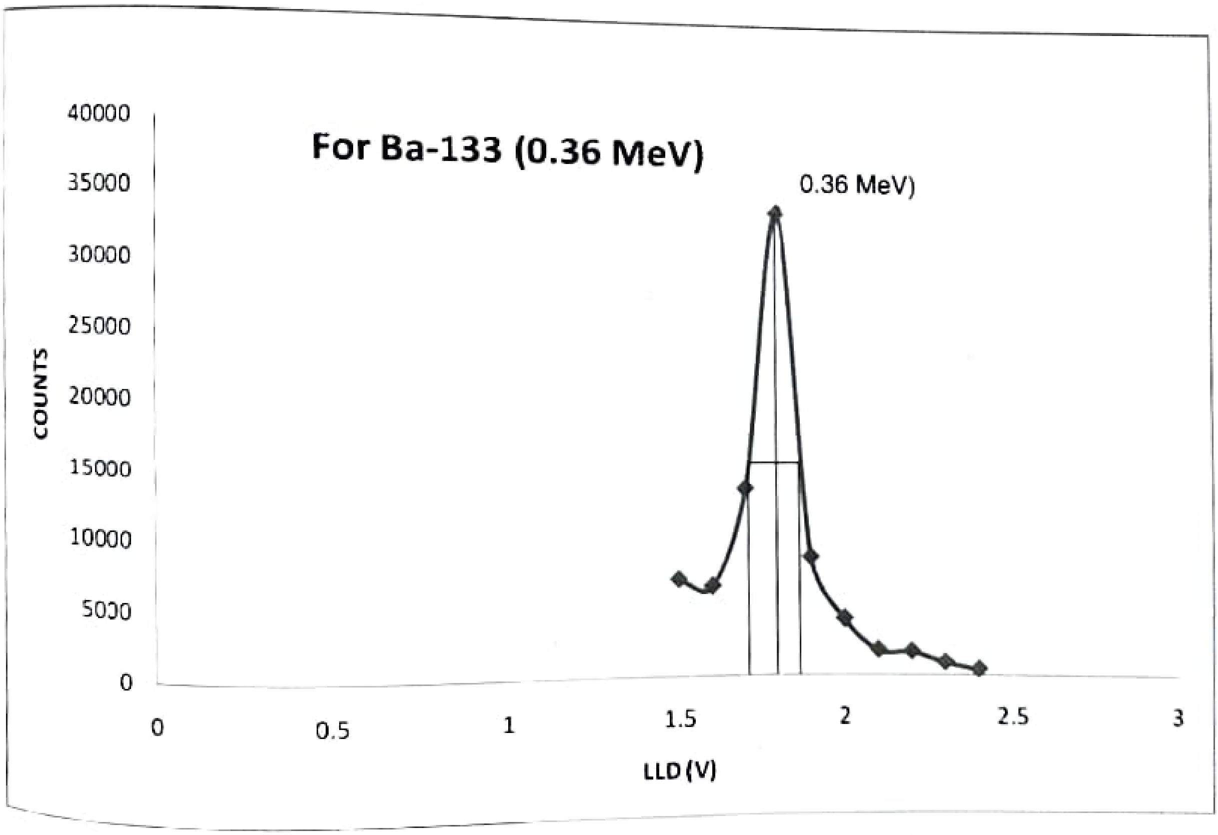

Fig.39 : Photopeak spectrum for 0.36 MeV of Ba-133.

SUMMAY:

Table - 34		
Source	Energy (MeV)	Resolution
Ba-133	0.36	10%
Na-22	0.511	8%
Cs-137	0.662	7.5%
Co-60	1.17	6.2%
Na-22	1.28	5.8%
Co-60	1.33	5.5%

CONCLUSION: From the above results, it can be concluded that resolution improves with increase of gamma energy.

EXPRIMENT – 8

5.8 VARIATION OF GAMMA INTENSITY AS A FUNCTION OF DISTANCE (VERIFICATION OF INVERSE SQUARE LAW)

PURPOSE: To study the variation of Intensity of gamma intensity as a function of distance using a gamma source Cs-137.

THEORY: There are many similarities between ordinary light rays and gamma rays. They are both considered to be electromagnetic radiation, and hence they obey the classical equation

$$E = h\nu \qquad (12)$$

where

E = energy of the photon in ergs,

ν = the frequency of the radiation in cycles/ sec.,

h = Planck's constant (6.624×10^{-27} erg-sec).

Therefore in explaining the inverse square law, it is convenient to make the analogy between a light source and a gamma-ray source.

Let us assume that we have a light source that emits light photons at a rate N_0 photons/sec. It is reasonable to assume that these photons are given off in an isotropic manner, that is, equally in all directions. If we place the light source at the centre of a clear plastic spherical shell, it is quite easy to measure the number of light photons per second for each cm^2 of the spherical shell. This intensity is given by

$$I_0 = N_0 / A_0 \qquad (13)$$

where N_0 = total number of photons/sec. from the source, and

A_0 = total area of the sphere in cm^2.

Since $A_0 = 4 \Pi R_0^2$ where R_0 is the radius of the sphere, equation (13) can be written as

$$I_0 = N_0 / 4 \Pi R_0^2 \qquad (14)$$

Since N_0 and 4Π are constants, I_0 is seen to vary as $1/R_0^2$. The purpose of this experiment is to verify Equation (14).

PROCEDURE:

Place the Cs-137 source at a distance of 5 cm from the face of the scintillation detector.

Make interconnections & default settings and proceed with the recording of Cs-137 spectrum by following the steps as detailed in Experiment No-2. Record data only in the peak portion of Cs-137 by taking about +/- 6 channels on either side of the 662 keV photo-peak.

After the photo-peak spectrum is obtained, set the single channel analyzer MODE switch controls to Normal position, and LLD & ULD levels to accommodate the photo peak spectrum.

(For example, if the maximum height of the photo peak is at 3.0 V, set the LLD at 2.4 V and ULD at 3.6 V).

- Set the preset time to 60 seconds.
- Observe the counts with the source at 5 cm distance from the detector.
- Move the source to 6 cm distance and observe the counts.
- Repeat the measurements at distances 7,8,9,10,11,12,13,14,15,16,20,25,30 & 35 cm.
- Observe the Background counts for 60 sec. and subtract it from each of the above observations to get the net counts.
- Tabulate the data as below.

Table - 35

Distance (R)	Net Counts / 60 sec	Net Counts / sec (A)	$K = AR^2$	Average	% deviation from average
5	89122	1485.36	37134		+2.39
6	60158	1002.63	36094		-0.47
7	44365	739.41	36231		-0.09
8	33672	561.20	35917		-0.96
9	26614	443.56	35928		-0.92
10	21553	359.21	35921		-0.95
11	17983	299.71	36265		0
12	15153	252.55	36367		+0.28
13	13158	219.30	37062	36265	+2.2
14	11164	186.06	36468		+0.56
15	9799	163.31	36745		+1.32
16	8530	142.16	36393		+0.35
20	5382	89.70	35880		-1.06
25	3456	57.60	36000		-0.73
30	2393	39.88	35892		-1.03
35	1761	29.35	35954		-0.86
		Total	580251		

Exercise (a): Plot the Net Counts as a function of distance on a linear paper. Since the net counts is proportional to the activity of the source this plot should have the $1/R_0^2$ characteristics exhibited by Eqn. (14)

$$\text{Hence the Net counts} \quad A = K / R^2 \tag{15}$$

Where R = the distance for the measurement (cm),

A = the net counts, and

K = a constant which is to be determined from the individual entries in the Table.

Exercise (b): Find K for each entry in the Table. Calculate the ' average K ' from all the values.

What is the percentage deviation of each individual K from ' average K ' ?

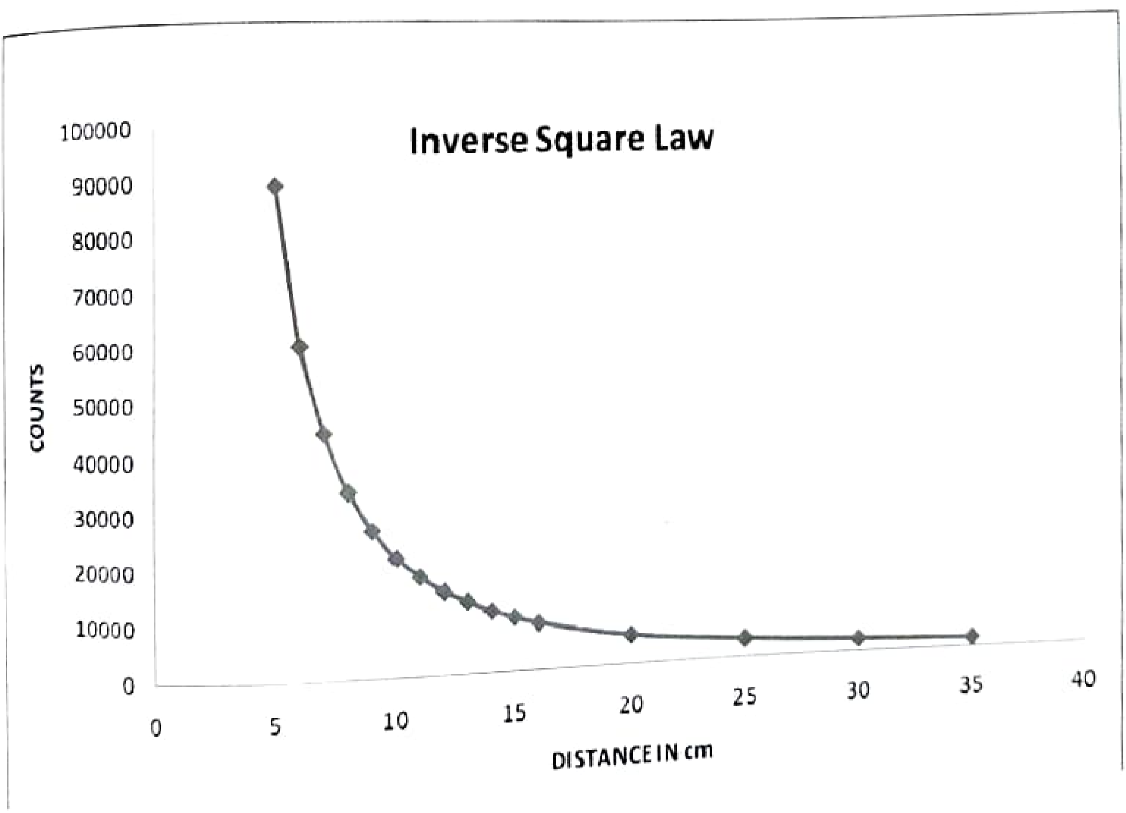

Fig.40 : Disptance Vs. net counts graph

EXPERIMENT – 09

5.9 ACTIVITY OF A GAMMA EMITTER (RELATIVE METHOD)

PURPOSE: In Experiment-6, procedure was given for determining the energy of an unknown gamma source. Another unknown associated with the gamma source is the activity of the source, which is usually measured in curies (Ci); 1 Ci = 3.7×10^{10} disintegrations/sec. Most of the sources that are used in nuclear laboratory experiments have activities of the order of micro curies (μCi). The purpose of this experiment is to outline one procedure by which the activity of a source can be determined, called the relative method.

In using the relative method, it is assumed that we have already identified the unknown source from its gamma energies. For this example, assume that the source has been found to be Cs-137. Then all that is necessary is to compare the activity of the unknown source to the activity of a standard Cs-137 source that will be supplied by the laboratory instructor. For convenience, call the standard source S1 and the unknown source U1.

PROCEDURE:

1. Make interconnections & default settings and proceed with the recording of Cs-137 spectrum by following the steps as detailed in Experiment No-2. Record data only in the peak portion of Cs-137 by taking about +/- 6 channels on either side of the 662 keV photopeaks.
2. After the photopeak spectrum is obtained, set the single channel analyzer MODE switch controls to Normal position, and LLD & ULD levels to accommodate the photopeak spectrum.(For example, if the maximum height of the photopeak is at 3.0 V, set the LLD at 2.4 V and ULD at 3.6 V).
3. Set the preset time so as to get at least 10,000 counts in the photopeak spectrum for both standard and unknown sources individually, when each is kept 5 cm away from the face of the detector.
4. To start the actual experiment, first place the standard source S1 at a distance of 5 cm from the face of the detector. Observe the counts ($\sum_{S1}$) for the preset time.
5. Remove S1 and place the unknown source U1 at the same distance of 5cm and at the same position. Observe the counts ($\sum_{U1}$) for the same preset time.
6. Observe the background counts ($\sum_{b}$) for the same preset time.

Data & Computations:

$\sum_{S1} = 201912$

$\sum_{U1} = 87216$

$\sum_{b} = 864$

Activity of S1 = 0.66 μCi

The activity of the U1can be calculated with the help of the following equation

$$\frac{\text{Activity of U1}}{\text{Activity of S1}} = \frac{\sum_{U1} - \sum_{b}}{\sum_{S1} - \sum_{b}} \qquad (16)$$

$$\text{Activity of U1} = \frac{0.66 \text{ X } 86352}{201048}$$

$$= 0.28\ \mu\text{Ci}$$

EXPERIMENT – 10

5.10 ACTIVITY OF A GAMMA EMITTER (ABSOLUTE METHOD)

PURPOSE : The activity of the standard used in Experiment - 9 can be determined by the absolute method. The purpose of this experiment is to outline the procedure for this method. Here the source that is to be measured will be called U1.

PROCEDURE : Make interconnections & default settings and proceed with the recording of Cs-137 spectrum by following the steps as detailed in Experiment-2. Record data only in the peak portion of Cs-137 by taking about +/- 6 channels on either side of the 662 keV photopeak.

After the photopeak spectrum is obtained, set the single channel analyzer MODE switch controls to Normal position, and LLD & ULD levels to accommodate the photopeak spectrum.
(For example, if the maximum height of the photo peak is at 3.0 V, set the LLD at 2.4 V and ULD at 3.6 V).

- Place the U1 source 9.3 cm away from the face of the detector.
- Set the preset time so as to get at least 10,000 counts in photo peak spectrum.
- Now observe the actual counts $\sum_{U1}$ recorded in the set preset time.
- Also observe the background counts $\sum b$ for the same preset time.
- Use the following formula to calculate the activity of U1 :

$$\text{Activity of U1} = \left(\frac{\sum_{U1} - \sum b}{t}\right) \frac{1}{G e_p f} \tag{17}$$

where

t = Preset time in seconds,

e_p = intrinsic peak efficiency for the gamma energy and detector size used (see Fig. 41).

f = the decay fraction of the unknown activity, which is the fraction of the total disintegrations in which the measured gamma is emitted

G = area of detector (cm^2) / 4 πs^2,

s = source – to – detector distance in cm.

Table - 36		
Isotope	Gamma Energy (MeV)	f
Cs-137	0.662	0.92
Co-60	1.17	0.99
Co-60	1.33	0.99
Na-22	1.276	0.99
Na-22	0.511	0.99
Mn-54	0.842	1

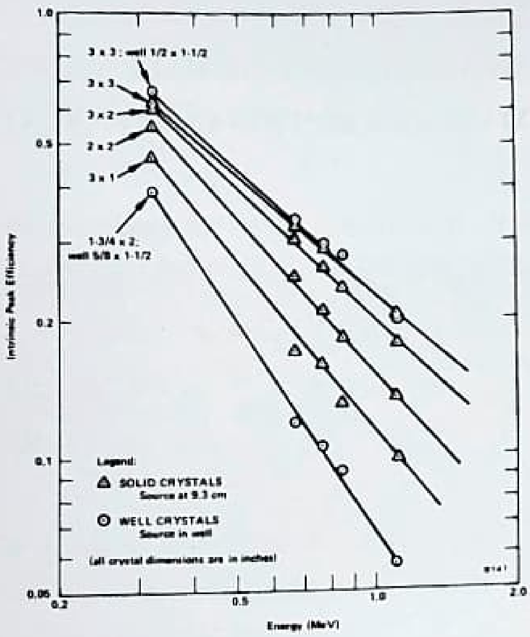

Fig.41 : Intrinsic peak efficiency of various NaI (TI) crystals Vs Gamma Energy

Data and computations

$\sum u_1 = 17999$

$\sum b = 4014$

$t = 150$ sec.

$e_p = 0.23$

$f = 0.92$

Radius of detection 'r' = 2.54cm

$s = 9.3$ cm

$G = \Pi r^2 / 4\Pi s^2 = 0.01865$

By substituting the above values in equation (17), we get

Activity of the unknown source = 23625 Bq = 0.6385 μCi .

This unknown source which we have chosen is the standard source used in Experiment 9. We know that the activity of that standard is 0.66 μCi.

The value 0.6385 μCi obtained in this experiment very well matches with the value of 0.66 μCi.

EXPERIMENT – 11

5.11. MEASUREMENT OF HALF VALUE THICKNESS AND EVALUATION OF MASS ABSORPTION COEFFICIENT

THEORY: It is well known that gammas interact with matter primarily by photoelectric, Compton, or pair-production interactions. The total-mass absorption coefficient can be measured easily with a gamma-ray spectrometer. In this experiment we will measure the number of gammas that are removed from the photo-peak by photo-electric or Compton interactions that occur in Aluminium and copper absorbers placed between the source and the detector.

From Lambert's law, the decrease of intensity of radiation as it passes through an absorber is given by

$I = I_{0}e^{-\mu t}$,

Where

I = intensity after the absorber,

I_0 = intensity before the absorber,

μ = Linear attenuation coefficient in cm^{1},

t = Thickness of the absorber in cm.

The half –value thickness (HVT) is defined as the thickness of the absorbing material that will reduce the original intensity by one-half.

From the above Eq.

In $I / I_0 = -\mu t$,

If $I / I_0 = 0.5$ and t = HVT,

In $0.5 = -\mu \times$ HVT or In $(1/0.5) = \mu \times$ HVT

i.e. In $2 = 0.693 = \mu \times$ HVT

HVT $= 0.693/\mu$ or $\mu = 0.693$ / HVT

In this experiment, we will measure Half value thicknesses of Aluminium and Copper for the 0.662 MeV gammas from Cs-137.

After measurement of HVT, the linear absorption coefficient is given by

$\mu = 0.693$/HVT

and mass absorption coefficient μ/ρ = Linear absorption coefficient / Density of absorber

EQUIPMENT AND ACCESSORIES REQUIRED

1. GRS unit
2. Sliding bench
3. NaI scintillation detector
4. Cs-137 source
5. Absorbers (Al, Cu) and absorber stand

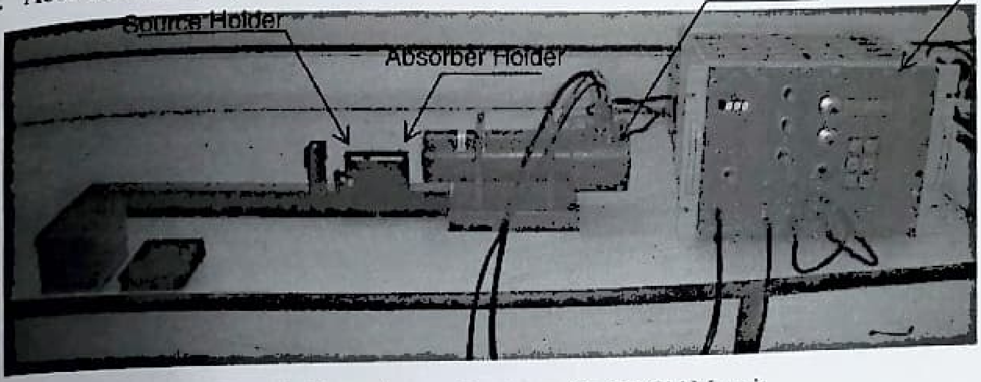

Fig. 42: Experimental setup with GR611M unit

PROCEDURE

The experimental setup is shown in Fig.42 above.

1. Make System interconnections & default settings for either GR611M or 612 model
2. Set controls on the instrument to default settings for HV & amplifier gain, as was done for recording Cs-137 spectrum (i.e., Cs-137 source if placed will have its photo-peak approximately at 3.0 V in amplitude.
3. Now set the Single Channel Analyzer controls in GRS as below:

Switch to NORMAL MODE (NOR) position & LLD and ULD levels to accept the Photo-peak Spectrum of Cs-137. Normally if the Cs-137 photo-peak position is at 3.0V, LLD level is set to 2.4V and ULD level is set to 3.6V.

Now place the Cs-137 source at 5 cm from the NaI (TI) detector and accumulate the spectrum counts long enough for the sum under the 0.662 MeV peak (observed counts - background counts) to be around 20,000 counts. Normally a counting time of 60 sec is selected.

- Observe the counts for 60 Seconds.
- Insert the first piece of Aluminum Absorber (Thickness-6mm) between the source and detector. Observe the counts for the same period (60 Sec).
- Add another piece of Aluminum Absorber (6mm thick) to the first piece making the total thickness 12mm. Observe the counts.

- Repeat with additional pieces of Aluminum Absorber in increments of 6mm until the observed counts fall up to one-fourth of the initial counts without absorber.
- Remove source & absorber
- Observe the background counts for 60 sec.
- Record the Absorber Thickness versus Net counts (observed Counts-background counts) in the table given below.

Data for half value thickness of Al

Thickness (mm)	Net Counts
0	15858
6	14419
12	12844
18	11613
24	10361
30	9435
36	8580
42	7579
48	7081
54	6486
60	5840
66	5008
72	4615

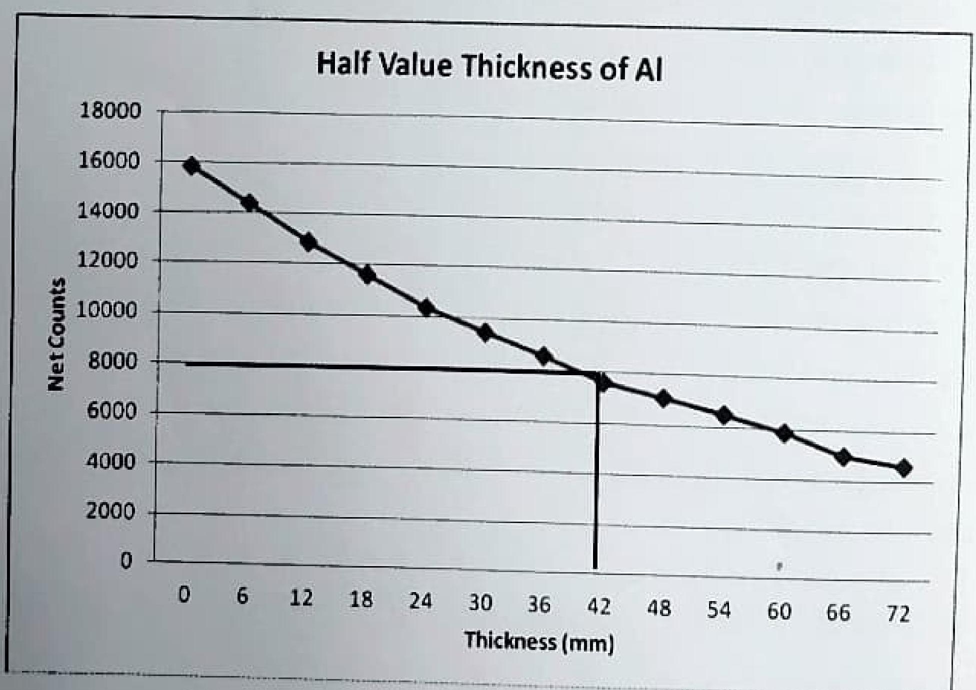

Fig. 43: Plot of Half value thickness for Aluminium

Exercise A:

- Plot the Net Counts versus Absorber Thickness in 'mm' as shown in the Fig.43 and determine the Half Value Thickness in terms of thickness (mm) from the Curve.

DATA COMPUTATION & RESULT

The observed value of HVT from the graph is 38mm or 3.8 cm.

Hence Linear attenuation coefficient: $\mu = 0.693/3.8 = 0.1824 \text{ cm}^{-1}$

Mass absorption coefficient: $\mu/\rho = 0.1824/2.7 = 0.06755 \text{ cm}^2/\text{g}$

Exercise B: (Optional)

The above experiment with other materials such as copper absorber can be repeated. Data and results are included here for copper absorber set.

For Copper :

Thickness (mm)	Net Counts
0	18398
2	16434
4	15109
6	13864
8	12674
10	11679
12	10940
14	10051
16	9176
18	8523
20	7769

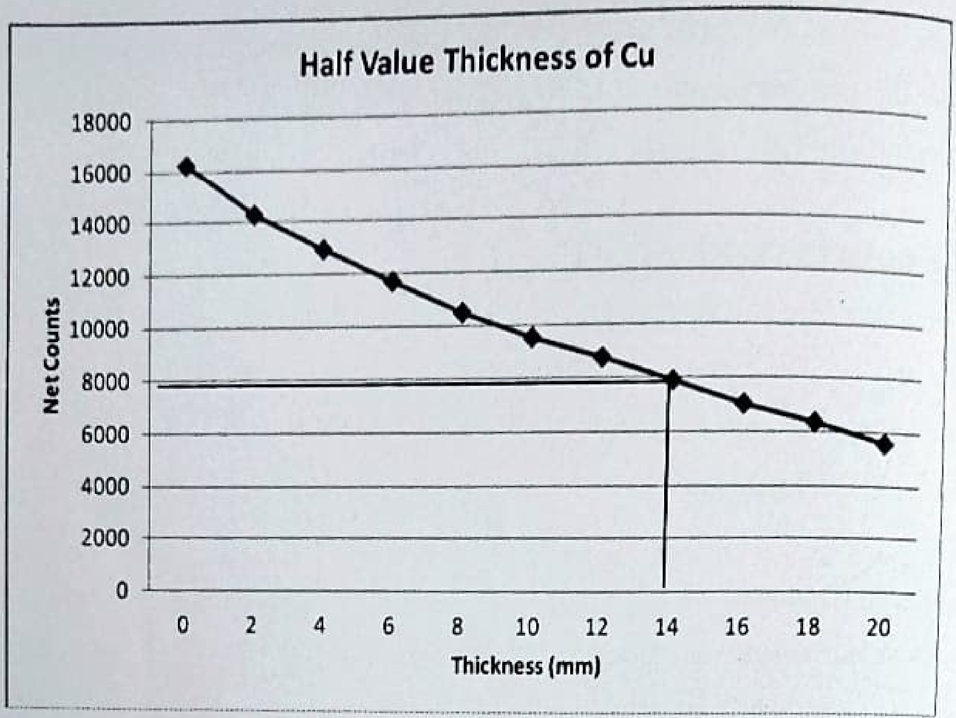

Fig. 44 : Plot of Half value thickness for Copper

The observed value of HVL from the graph is 13.8mm or 1.38 cm.

Hence Linear attenuation coefficient: $\mu = 0.693/1.38 = 0.5022\ cm^{-1}$

Mass absorption coefficient: $\mu/\rho = 0.5022/8.933 = 0.05622\ cm^2/g$

EXPERIMENT – 12

5.12. BACKSCATTERING OF GAMMA RAYS

THEORY: When Gamma Rays interact with matter, they lose their energy by way of the following three processes.

1. Photoelectric Absorption, in which the incident gamma ray transfers its full energy to an orbital electron of the atom.
2. Compton scattering, in which the gamma ray transfers part of its energy to an electron and both gamma ray and electron get scattered in different angles. The energy of the initial gamma rays gets shared between the scattered gamma ray and electron, depending on the scattering angles.
3. Pair production, in which the gamma ray of sufficient energy (greater than 1.02 MeV) converts its energy into mass by creating an electron-positron pair of Negative and Positive particles each with a mass equal to that of electron.

Now, for the present experiment, we are interested in Compton scattering only. Backscattering occurs when the angle of deflection is greater than 90^0. The backscattering is predominantly dependent on the atomic number Z of the backscattering material. For each incident gamma photon energy, the number of backscattered photons increases with increase in target thickness, and then saturates at a particular target thickness called the saturation thickness.

EQUIPMENT AND ACCESSORIES REQUIRED

1. GRS unit
2. Sliding bench
3. NaI scintillation detector
4. Cs-137 source
5. Absorbers (Al, Cu) and absorber stand

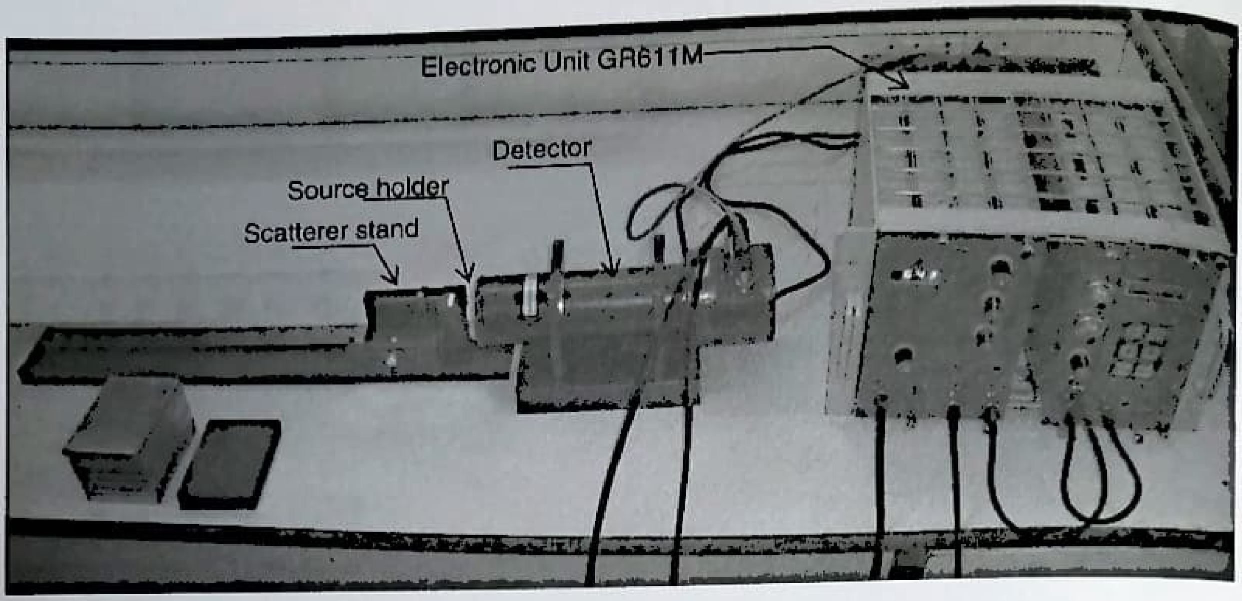

Fig. 45 : Experimental setup

PROCEDURE :

The experimental apparatus is shown in Fig.45. The Detector, Source and Scatterer stand are aligned properly.

Make System interconnections & default settings for GR611M.

Set controls on the instrument to default settings for HV & amplifier gain, as was done for recording Cs-137 spectrum (i.e., Cs-137 source if placed will have its photo-peak approximately 3V in amplitude.

Now set the Single Channel Analyzer controls in GRS as below

Switch to NORMAL MODE (NOR) position. Set the LLD and ULD levels to accept the back scattering spectrum of Cs-137. Normally if the 662KeV photo-peak position is at 3.0V, LLD level is set to 0.5V and ULD level is set to 1.6V.

For the 662 KeV gamma rays of Cs-137, the energy of backscattering gamma rays will fall between 150KeV to 300KeV. Accordingly, if the 662KeV photo-peak is at 3.0V, the back scattered gamma rays will lie between 0.5V and 1.6V. Hence to detect and count back scattered gamma ray, LLD level; is set at 0.5V and ULD is set at 1.6V.

Cs-137 source is kept at 3 cm. from the face of the detector. The scatterer stand is kept very close to the source. Now, proceed in the following steps.

1. Remove the radioactive source Cs-137 from the source stand and measure the background for 100 sec.
2. Replace the source in the source stand.

3. Keep the scatterer stand empty.
4. Monitor and record the source counts for 100sec.
5. Now load the scatter stand with 6 mm Aluminum sheet.
6. Monitor and record the counts for 100 sec.
7. Add one more 6 mm Al. sheet to the existing one to make the thickness 12mm.
8. Monitor the counts for 100 sec.
9. Repeat the experiment by increasing the thickness in steps of 6 mm till the saturation thickness arrives.
10. Monitor & record the counts for all the thicknesses.

Repeat the Experiment with copper sheets and tabulate the data.

EXPERIMENTAL DATA

Source: Cs-137 Activity: 0.1μCi Preset time: 100sec

For Al:

S.No	Thickness (mm)	Counts	Net counts
1	0	131913	-
2	6	137769	5856
3	12	141049	9136
4	18	143505	11592
5	24	146175	14262
6	30	146314	14401
7	36	147181	15268
8	42	147730	15817
9	48	147868	15955
10	54	148968	16055
11	60	147887	15974
12	66	148768	16855
13	72	148122	16209

For Cu:

S.No	Thickness (mm)	Counts	Net counts
1	0	135093	-
2	2	144585	9492
3	4	151703	16610
4	6	156068	20975
5	8	159881	24788
6	10	160348	25255
7	12	161394	26301
8	14	163348	28253
9	16	166324	31231
10	18	166045	30952
11	20	166650	31557

RESULTS AND CONCLUSION

From the results obtained, it can be observed and concluded that the backscattered counts will increase up to saturation thickness and remain almost constant beyond the saturation thickness.

6.0 IMPORTANT DEFINITIONS OF RADIATION TERMS

- **Absorbed dose:** The energy transferred to a material by ionising radiation per unit mass of the material.
  Unit: J kg^{-1}; Name of unit: Gray (see also Rad)

- **Absolute Efficiency:** The ratio of number of pulses recorded to the number of radiations emitted by the source.

- **Activity:** Measurement of quantity of radioactive material. It is the number of nuclear transformations or isomeric transitions per unit time.
  Unit: s^{-1} Name of unit: Becquerel (see also Curie)

- **Alpha decay: Alpha particles** consist of two protons and two neutrons bound together into a particle identical to a helium nucleus. They are generally produced in the process of alpha decay, but may also be produced in other ways. Alpha particles are named after the first letter in the Greek alphabet, α.
  A radioactive conversion accompanied by the emission of an alpha particle. In alpha decay the atomic number is reduced by 2 and the mass number by 4. Alpha decay occurs, with a few exceptions, only for nuclides with a proton number exceeding 82.

- **Alpha radiation:** Radiation that consists of high energy helium (^4He) nuclei emitted during alpha disintegration of atomic nuclei. Alpha particles possess discrete initial energies (line spectra) which are characteristic of the emitting nuclide.

- **Anode (in electron tubes):** An electrode through which a principal stream of electrons leaves the interelectrode space.

- **Attenuation coefficient:** The probability that a photon will be removed from the incident beam per unit thickness of material traversed.

- **Background counts (radiation counters):** Counts caused by ionizing radiation coming from sources other than that be to measured.

- **Becquerel (Bq):** Name of the derived SI unit of activity. Number of radioactive transformations or isometric transitions per seconds s^{-1} = Bq.

1 Bq	=	27×10^{-12}	=	27 pCi
1 kBq	=	27×10^{-9}	=	27 nCi
1 MBq	=	27×10^{-6}	=	27 mCi
1 GBq	=	27×10^{-3}	=	27 mCi
1 TBq	=	27 Ci	=	27 Ci

- **Beta decay:** Radioactive conversion accompanied by the emission of a beta particle, i.e. a negatively charged electron (b- decay) or a positively charged electron (b+ decay). When a negatively charged electron is emitted, a neutron in the atomic nucleus is converted to a proton with the simultaneous emission of an antineutrino, so that the proton number Z is increased by 1. When a positively charged electron (positron) is emitted, a proton in the nucleus is converted to a neutron with simultaneous emission of a neutrino, so that the proton number **Z** is decreased by 1.
- **Beta Radiation:** Radiation that consists of negative or positive electrons which are emitted from nuclei undergoing decay. Since the decay energy (or, if it is followed by gamma radiation, the decay energy less that photons energy) is statistically divided between beta particles and neutrinos (or antineutrinos), the energy spectrum of beta radiation is continuous, extending from zero to a maximum value characteristic of the nuclide concerned. The maximum beta energy is generally termed the "beta end-point energy of the nuclide".
- **Bremsstrahlung:** Radiation that results from the acceleration/deceleration of charged particles in the Coulomb field of atoms.
- **Curie (Ci):** Name for derived unit of activity. One Curie corresponds to 3.7×10^{10} nuclear disintegrations or isomeric transitions per second $1\ Ci = 3.7 \times 10^{10}\ s^{-1}$.

  1 Ci = 37 GBq
  1 mCi = 37 MB1
  1 µCi = 37 kBq
  1 nCi = 37 Bq
  1 pCi = 37 mBq
- **Dose:** See absorbed dose, exposure value, and dose equivalent
- **Dose equivalent:** A term used in radiation protection for the radiation dose. It is the product of absorbed dose times the quality factor.

  Unit : J kg^{-1}; Name of unit: Sievert (see also Rem)

- **Dose rate:** Dose absorbed per unit time
- **Dynode:** An electrode which performs a useful function, such as current amplification, by means of secondary emission.
- **Electron radiation:** Particle emission consisting of negatively or positively charged electrons.
- **Exposure dose:** The ratio of the amount of electric charge of the ions of one polarity that are formed in air by Ionizing radiation and the mass of the air.

  Unit: C. kg^{-1} (see also Roentgen)
- **Full width at half maximum (FWHM):** The full width of a distribution measured at half the maximum ordinate.
- **Gamma radiation: Gamma radiation,** also known as **gamma rays,** and denoted by the Greek letter γ, refers to electromagnetic radiation of extremely high frequency and therefore high energy per photon. Gamma rays are ionizing radiation, and are thus biologically hazardous. They are classically produced by the decay from high energy states of atomic nuclei (gamma decay), but are also created by other processes. Paul Villard, a French chemist and physicist, discovered gamma radiation in 1900, while studying radiation emitted from radium. Villard's radiation was named "gamma rays" by Ernest Rutherford in 1903.

  Natural sources of gamma rays on Earth include gamma decay from naturally occurring radioisotopes, and secondary radiation from atmospheric interactions with cosmic ray particles. Rare terrestrial natural sources produce gamma rays that are not of a nuclear origin, such as lightning strikes and terrestrial gamma-ray flashes. Additionally, gamma rays are also produced by a number of astronomical processes in which very high-energy electrons are produced, that in turn cause secondary gamma rays via bremsstrahlung, inverse Compton scattering and synchrotron radiation. However, a large fraction of such astronomical gamma rays are screened by Earth's atmosphere and can only be detected by spacecraft.
- **Gray:** The SI unit of absorbed radiation dose. 1 Gray of absorbed dose corresponds to 1 joule of energy per kilogram of mass.

  1 Gray = 100 rad
- **Half-value thickness ($T_{1/2}$):** The thickness of material layer that reduces the initial intensity of radiation by a factor of two.

- **Intrinsic Efficiency:** The ratio of number of pulses recorded to the number of radiations incident on the detector.
- **Ionising radiation:** Radiation that consists of particles capable of ionizing a gas.
- **Isotopes:** Nuclides with the same atomic number but different atomic weights (Mass numbers).
- **Linear absorption coefficient (μ):** It is given by $0.693 / T_{1/2}$, where $T_{1/2}$ is the half value thickness. μ is expressed in cm^{-1}.
- **Mass absorption coefficient (μ/ρ).** It is given by linear absorption coefficient (μ) divided by density (ρ) of material. It is expressed in cm^2 / gm
- **Mass per unit area:** Product of the density of a material and its thickness.
- **Minimum Detectable Activity (MDA):** The minimum detectable activity (MDA) is that amount of activity which in the same counting time gives a count which is different from the background by three times the standard deviation of the background counting rate:

$$MDA = Bkg\ cpm + 3x\ (Bkg)^{1/2} \div t$$

Example: What is the MDA for a counter with a background of 750 counts in ten minutes?

$$MDA = 75\ cpm + 3x\ (750)^{1/2} \div 10\ min = 83\ gross\ cpm$$

Thus, any gross count over 83 cpm can be considered to be due to radioactivity. However, the MDA for a counting system must be expressed in terms of a net count so that the results can be converted to dpm or μCi. Thus, the MDA becomes.

$$MDA = 3x\ (Bkg)^{1/2} \div t$$

To calculate the MDA (in dpm) for a known nuclide, divide by the efficiency of the nuclide. Report the MDA for any nuclide for which a net count of zero is calculated or whenever the standard deviation of the sample counting rate brings the net count at or below the MDA. Note that the MDA can be reduced by increasing the counting time and lowering the background. The lower the MDA, the more accurately the activity of samples with low counting rates can be determined.

Example: What is the MDA (in dpm) for a counter with a background of 750 counts in ten minutes and an efficiency of 50% for the nuclide of interest?

MDA $= 3 \times 750\ ½ \div 10$ min = 8 net cpm

$= 8$ cpm / (0.5c/d) = 16dpm or 7.2×10^{-6} µCi

$1bq = 2.7 \times 10^{-11}$ Ci

16 dpm = 0.266

= 0.266 dps

= 0.266 Bq

$= 0.266 \times 2.7 \times 15^{-11}$

$= 0.7199 \times 10^{-11}$

7.199×10^{-12}

= 7.2µCi

- **Nuclide:** Generic term for neutral atoms that are characterized by a specific number of neutrons N and protons Z in the nucleus.
- **Photomultiplier Tube (PMT):** A phototube with one or more dynodes between its photocathode and output electrode (anode). It is a transducer which converts light energy into electrical pulses.
- **Photocathode:** An electrode used for obtaining photoelectric emission when irradiated.
- **Peak Channel:** Channel number corresponding to the peak of a distribution.
- **Quality factor:** A factor which in radiation protection allows for the effects of different types of radiations and energies on people.
- **Rad (Radiation Absorbed Dose):** An old unit used to measure absorbed radiation dose. 1 Rad of absorbed dose corresponds to 0.01 joule of energy per kilogram of mass (=100 ergs of energy per gram of mass).
  All measurements of absorbed dose depend on the absorbing medium as well as the level of radiation. 1R is equivalent to 0.871 rad in air.
- **RBE (Relative Biological Effectiveness)**
  The biological effect of radiation depends, not only on the energy absorbed, but also on the radiation concerned. To illustrate, the effect of 1 Gray of X-ray will be quite different from the effect of 1 Gray of neutrons. The RBE is an attempt to compensate

for this variation and may be considered as a weighting factor for different type of radiation.

RBE (for radiation of Energy E) is defined as the ratio; (Dose of 200 keV gamma rays producing a given biological effect) divided by (dose of radiation of energy E producing the same effect).

- **Radioactivity:** The property which certain nuclides have of emitting radiation as a result of spontaneous transitions in their nuclei.
- **Resolution (%):** Resolution of a NaI scintillation detector is defined as the ratio of FWHM divided by peak channel.
- **rem (Roentgen Equivalent Man):** The rem is an early unit used to measure the effect of a given type of radiation on living tissue, including compensation for the type of radiation involved.

  rem dose = rad dose x RBE
- **Roentgen-R:** An old unit used to measure radiation by its ability to ionize air. 1 Roentgen is that amountof radiation which releases a charge of 258 microcoulomb per kilogram of air. This measure is a specific quantity of radiation, but does not relate to the absorption by materials.
- **Sievert (Sv):** This is the SI unit used to measure the effect of a given type of radiation on living tissue, including compensation for the type of radiation involved.

  1 Sievert = 100 rem
- **Scintillation:** The optical photons emitted as a result of the interaction of a particle or photon of ionizing radiation with a scintillator.
- **Scintillator:** The material that emits light when particles traverse it. Alternatively, the material which absorbs energy and releases its energy in the form of light photons.
- **Scintillation counter:** The combination of scintillator, photomultiplier tube and associated circuitry for detection and measurement of ionizing radiation.

7.0 ACTIVITY & DOSERATE CALCULATION PROCEDURE

a. Activity calculation (as on date)

It is known that, given the activity at any previous date and by knowing its half-life we can calculate the present activity by using the following equation.

$$A = A_0 e^{-\lambda t}$$

$$= A_0 e^{-(0.693/T1/2)\,t}$$

Where,

A = Present activity

A_0 = Activity as on previous date

$T_{1/2}$ = Half life of source

t = Elapsed time

λ = Decay constant

TYPICAL CALCULATION OF ACTIVITY FOR TWO BETA AND TWO GAMMA SOURCES:

BETA SOURCES:

Sr-90: (3.7 KBq, Oct 2006); Half life for Sr-90 is $T_{1/2} = 28.5$Yrs

Activity (A_0) = 3.7 KBq, as on Oct' 2006.

= 3700 Bq

Elapsed time till Sept' 2010 = 3years 11months = 3.9166 years

Present activity (A) = $A_0 e^{-(0.693/T1/2)\,t}$; as on Sept' 2010

$T_{1/2}$ = 28.5yr

t = 3.9166 years

$A = 3700\, e^{-(0.693/28.5) \times 3.9166}$

= 3364 Bq

Tl-204: (11.1 KBq, Oct 2006); Half life for Tl-204 is $T_{1/2} = 4Yrs$

Activity (A_0) = 11.1 KBq, as on Oct' 2006.

= 11100 Bq

Elapsed time till Sept' 2010 = 3 years 11months = 3.9166 years

Present activity (A) = $A_0\, e^{-(0.693/T1/2)\, t}$; as on Sept' 2010

$T_{1/2}$ = 4yr

t = 3.9166 years

A = $11100\, e^{-(0.693/4) \times 3.9166}$

= 5631 Bq

GAMMA SOURCES:

Cs-137: (3.1 μCi, July' 2007) ; Half life for Cs-137 is $T_{1/2} = 30Yrs$

Activity (A_0) = 3.1μCi, as on July 2007.

= $3.1X3.7X10^{10}X10^{-6}$

= 114700 Bq

Elapsed time till Sept' 2010 = 3 years 2months = 3.1666 years

Present activity (A) = $A_0\, e^{-(0.693/T_{1/2})\, t}$; as on Sept' 2010

$T_{1/2}$ = 30yr

t = 3.1666 years

A = $114700\, e^{-(0.693/30) \times 3.1666}$

= 106609 Bq

Co-60: (3.7μCi, July' 2007); Half life for Co-60 is $T_{1/2} = 5.3$Yrs

Activity (A_0) = 3.7μCi, as on July' 2007

= $3.7X3.7X10^{10}X10^{-6}$

= 136900 Bq

Elapsed time till Sept' 2010 = 3 years 2 months = 3.1666 years

Present activity (A) = $A_0 e^{-(0.693/T_{1/2})t}$; as on Sept' 2010

$T_{1/2}$ = 5.3yr

t = 3.1666 years

A = $136900\, e^{-(0.693/5.3) \times 3.1666}$

= 90486 Bq

b. DOSE RATE CALCULATION

Doserate can be calculated by using the following formula

$$\text{Doserate} = \frac{\text{Source Activity x gamma constant}}{(\text{Distance})^2}$$

where

Doserate is in mR (milli Roentgen)

Source Activity is in mCi (milli Curies)

Distance is in cm (Centimeters)

Gamma constant for Cs-137 is 3300

and gamma constant for Co-60 is 13200

Examples:

1. Calculate the doserate at a distance of 20 cm from a Cs-137 source of activity 10 mCi

$$\text{Doserate} = \frac{10x3300}{(20)^2} = \frac{33000}{400} = 82.5\text{mR}$$

2. Calculate the distance from a Co-60 source of activity 20 mCi to obtain a doserate of 50mR

$$50\text{mR} = \frac{20x13200}{(\text{Distance})^2}$$

$$\text{i.e. } (\text{Distance})^2 = \frac{20x13200}{50} = 5280 \text{ cm}^2$$

$$\therefore \text{Distance} = \sqrt{5280} = 72.66 \text{ cm}$$