

## 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.

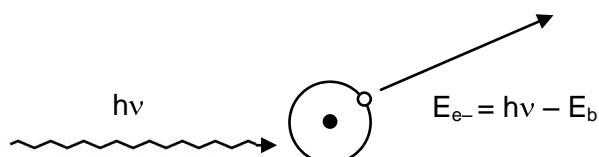


Fig. 1: Process of photoelectric absorption

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  $h\nu'$  in terms of its scattering angle  $\theta$  is given by

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

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

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

Two extreme cases can be identified:

- ❖ A grazing angle scattering or one in which  $\theta \approx 0$ . In this case, Eqs. (1) and (2) predict that  $h\nu' \approx h\nu$  and  $E_{e^-} \approx 0$ . 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.

$$h\nu' \Big|_{\theta=\pi} = \frac{h\nu}{1 + 2h\nu/m_0c^2} \quad (3)$$

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

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.

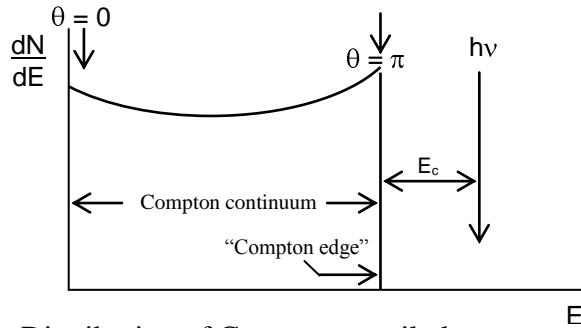


Fig. 4 : Distribution of Compton recoil electrons

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

$$E_c = h\nu - E_{e^-} \Big|_{\theta=\pi} = \frac{h\nu}{1 + 2h\nu/m_0c^2} \quad (5)$$

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

$$E_c \cong \frac{m_0c^2}{2} = 0.256 \text{ MeV} \quad (6)$$

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

$$E_{e^-} + E_{e^+} = h\nu - 2m_0c^2 \quad (7)$$

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.

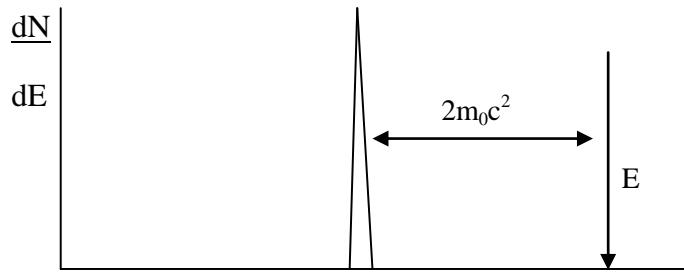


Fig. 5: Peak corresponding to the total kinetic energy of the pair (electron+ positron) created during pair production process

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.

## 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:  $\text{J kg}^{-1}$ ; 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:  $\text{s}^{-1}$  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,  $\alpha$ .  
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 ( ${}^4\text{He}$ ) 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  $\text{s}^{-1} = \text{Bq}$ .

1 Bq	=	$27 \times 10^{-12}$	=	27 pCi
1 kBq	=	$27 \times 10^{-9}$	=	27 nCi
1 MBq	=	$27 \times 10^{-6}$	=	27 mCi
1 GBq	=	$27 \times 10^{-3}$	=	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  $3.7 \times 10^{10}$  nuclear disintegrations or isomeric transitions per second  $1 \text{ Ci} = 3.7 \times 10^{10} \text{ s}^{-1}$ .

$$1 \text{ Ci} = 37 \text{ GBq}$$

$$1 \text{ mCi} = 37 \text{ MBq}$$

$$1 \mu\text{Ci} = 37 \text{ kBq}$$

$$1 \text{ nCi} = 37 \text{ Bq}$$

$$1 \text{ pCi} = 37 \text{ mBq}$$

- **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:  $\text{J kg}^{-1}$ ; 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<sup>-1</sup> (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  $\gamma$ , 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 ( $\mu$ ):** It is given by  $0.693 / T_{1/2}$ , where  $T_{1/2}$  is the half value thickness.  $\mu$  is expressed in  $\text{cm}^{-1}$ .
- **Mass absorption coefficient ( $\mu/\rho$ ):** It is given by linear absorption coefficient ( $\mu$ ) divided by density ( $\rho$ ) of material. It is expressed in  $\text{cm}^2 / \text{gm}$
- **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:

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

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

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

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  $\mu\text{Ci}$ . 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?

$$\begin{aligned} \text{MDA} &= 3 \times 750 \frac{1}{2} \div 10 \text{ min} = 8 \text{ net cpm} \\ &= 8 \text{ cpm} / (0.5\text{c/d}) = 16\text{dpm or } 7.2 \times 10^{-6} \mu\text{Ci} \end{aligned}$$

$$\begin{aligned} 1\text{bq} &= 2.7 \times 10^{-11} \text{ Ci} \\ 16 \text{ dpm} &= 0.266 \\ &= 0.266 \text{ dps} \\ &= 0.266 \text{ Bq} \\ &= 0.266 \times 2.7 \times 10^{-11} \\ &= 0.7199 \times 10^{-11} \\ &\quad 7.199 \times 10^{-12} \\ &= 7.2 \mu\text{Ci} \end{aligned}$$

- **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 amount of 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.

$$\begin{aligned} A &= A_0 e^{-\lambda t} \\ &= A_0 e^{-(0.693/T_{1/2})t} \end{aligned}$$

Where,

A	=	Present activity
$A_0$	=	Activity as on previous date
$T_{1/2}$	=	Half life of source
t	=	Elapsed time
$\lambda$	=	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

$$\begin{aligned} \text{Activity } (A_0) &= 3.7 \text{ KBq, as on Oct' 2006.} \\ &= 3700 \text{ Bq} \end{aligned}$$

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

$$\begin{aligned} \text{Present activity } (A) &= A_0 e^{-(0.693/T_{1/2})t}; \text{ as on Sept' 2010} \\ T_{1/2} &= 28.5 \text{ yr} \\ t &= 3.9166 \text{ years} \\ A &= 3700 e^{-(0.693/28.5) \times 3.9166} \\ &= 3364 \text{ Bq} \end{aligned}$$

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

$$\begin{aligned}\text{Activity } (A_0) &= 11.1 \text{ KBq, as on Oct' 2006.} \\ &= 11100 \text{ Bq}\end{aligned}$$

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

$$\begin{aligned}\text{Present activity } (A) &= A_0 e^{-(0.693/ T_{1/2}) t}, \text{ as on Sept' 2010} \\ T_{1/2} &= 4 \text{yr} \\ t &= 3.9166 \text{ years} \\ A &= 11100 e^{-(0.693/ 4) \times 3.9166} \\ &= 5631 \text{ Bq}\end{aligned}$$

### GAMMA SOURCES:

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

$$\begin{aligned}\text{Activity } (A_0) &= 3.1 \mu\text{Ci, as on July 2007.} \\ &= 3.1 \times 3.7 \times 10^{10} \times 10^{-6} \\ &= 114700 \text{ Bq}\end{aligned}$$

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

$$\begin{aligned}\text{Present activity } (A) &= A_0 e^{-(0.693/ T_{1/2}) t}, \text{ as on Sept' 2010} \\ T_{1/2} &= 30 \text{yr} \\ t &= 3.1666 \text{ years} \\ A &= 114700 e^{-(0.693/ 30) \times 3.1666} \\ &= 106609 \text{ Bq}\end{aligned}$$

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

$$\begin{aligned}\text{Activity } (A_0) &= 3.7\mu\text{Ci}, \text{ as on July' 2007} \\ &= 3.7 \times 3.7 \times 10^{10} \times 10^{-6} \\ &= 136900 \text{ Bq}\end{aligned}$$

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

$$\begin{aligned}\text{Present activity } (A) &= A_0 e^{-(0.693/T_{1/2})t}; \text{ as on Sept' 2010} \\ T_{1/2} &= 5.3 \text{yr} \\ t &= 3.1666 \text{ years} \\ A &= 136900 e^{-(0.693/5.3) \times 3.1666} \\ &= 90486 \text{ Bq}\end{aligned}$$

## b. DOSE RATE CALCULATION

Doserate can be calculated by using the following formula

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

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

$$\text{Doserate} = \frac{10 \times 3300}{(20)^2} = \frac{33000}{400} = 82.5 \text{mR}$$

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

$$50 \text{mR} = \frac{20 \times 13200}{(\text{Distance})^2}$$

$$\text{i.e. } (\text{Distance})^2 = \frac{20 \times 13200}{50} = 5280 \text{ cm}^2$$

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

## **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)

## B.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]**

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

### **4. SINGLE CHANNEL ANALYSER [TYPE: SC 530]**

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

### **COUNTER TIMER [TYPE: CT 541A]**

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

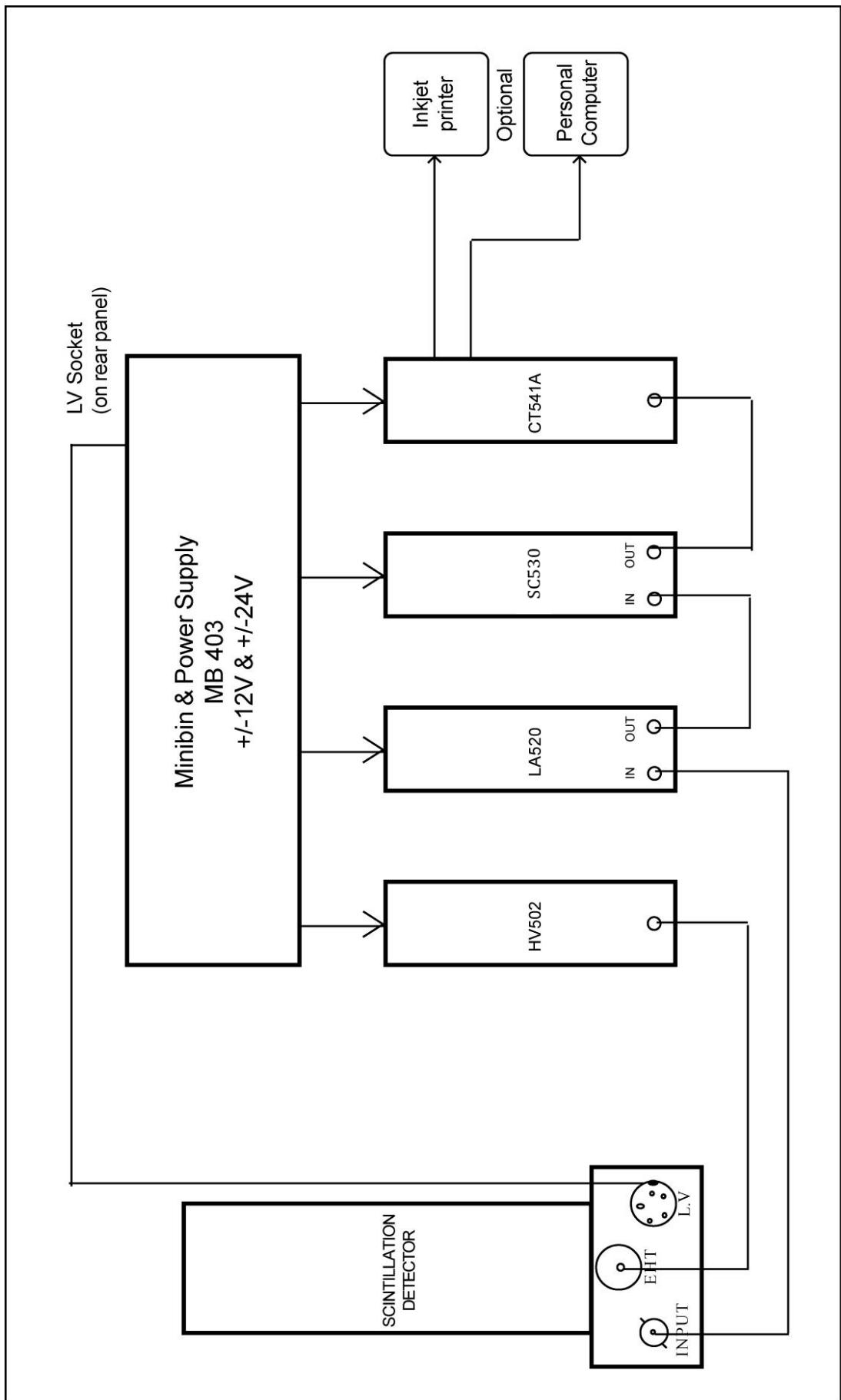


Fig. 10: Block diagram of MINIM based Gamma Ray Spectrometer

## **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)

- o **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.

- o **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.

<b>Gamma Isotope</b>	<b>Energy MeV</b>	<b>Nominal Activity</b>	<b>Half life</b>
Co-57	0.123	2-5 $\mu$ Ci	273 Days
Ba-133	0.36 (Main)	2-5 $\mu$ Ci	7.5 years
Cs-137	0.662	2-5 $\mu$ Ci	30 years
Co-60	1.17; 1.33	2-5 $\mu$ Ci	5.3 years
Na-22	0.511; 1.280	2-5 $\mu$ Ci	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  $\approx$  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:

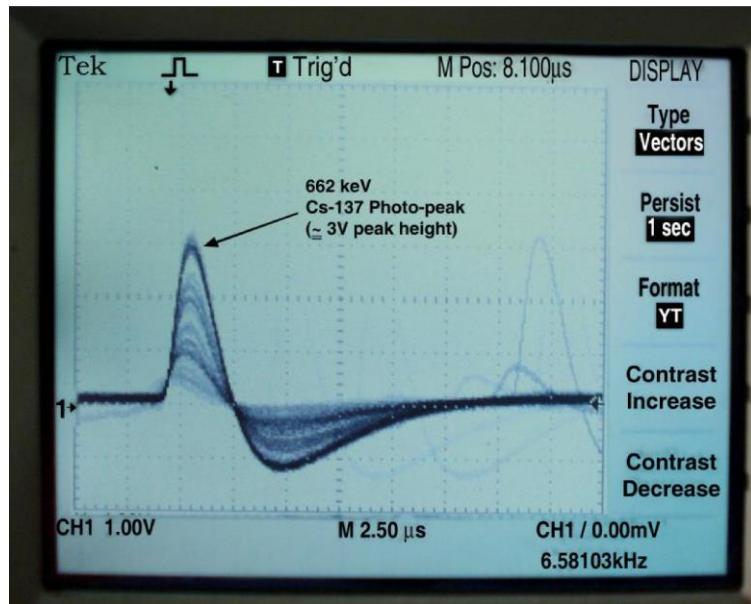


Fig.13 : Amplifier output of GR611M/612 as seen in 60 MHz oscilloscope Tek Make, with Cs-137 source placed on scintillation detector. Approximately 3 V photopeak height can be noticed.

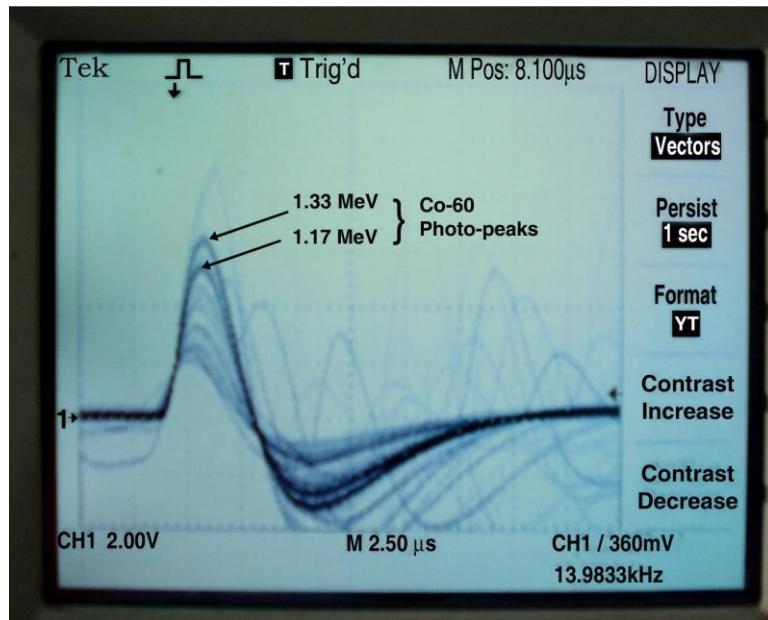


Fig.14: Co-60 Photopeaks of 1.17 & 1.33 MeV as seen on oscilloscope, after amplification in GR611M/612. Second peak (1.33 MeV) height can be noticed to be of 6.0 V in amplitude approximately.

**(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)	OUTPUT 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.

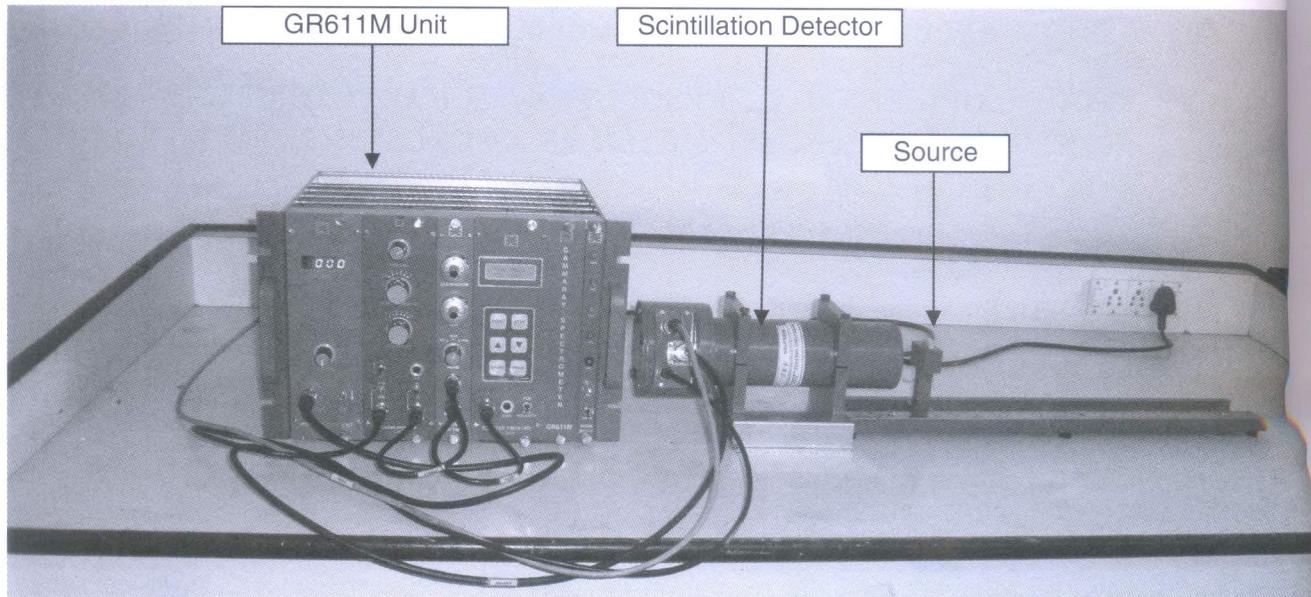


Fig. 15 : Experimental setup with GR611M unit

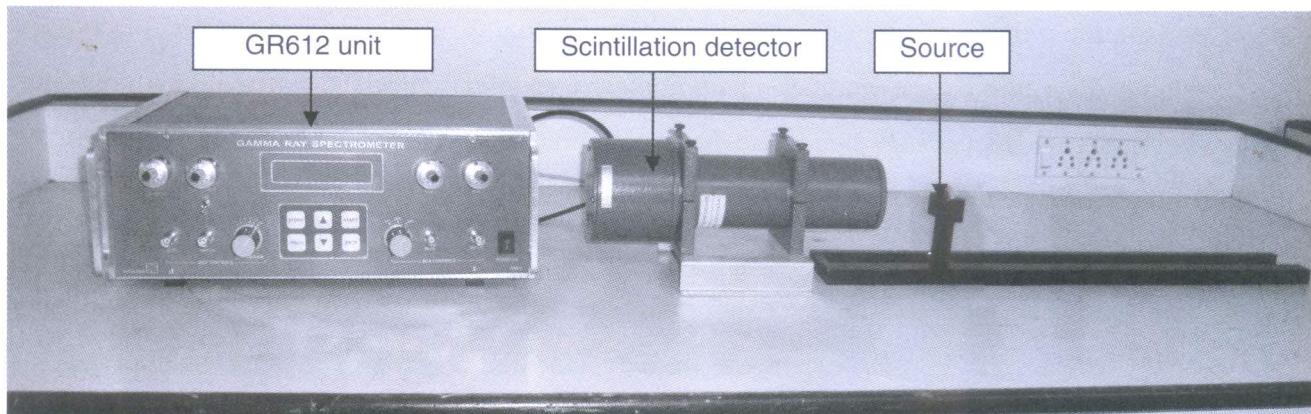


Fig. 16 : Experimental setup with GR612 unit

### PROCEDURE:

- 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 controls on the instrument to default settings as described in the earlier section.
- o Set HV on the instrument to **650 Volts.** .
- 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 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 .
- o 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)
- o 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.
- o 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.
- o 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.
- o 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 : $0.24/2.9 = 8.3\%$

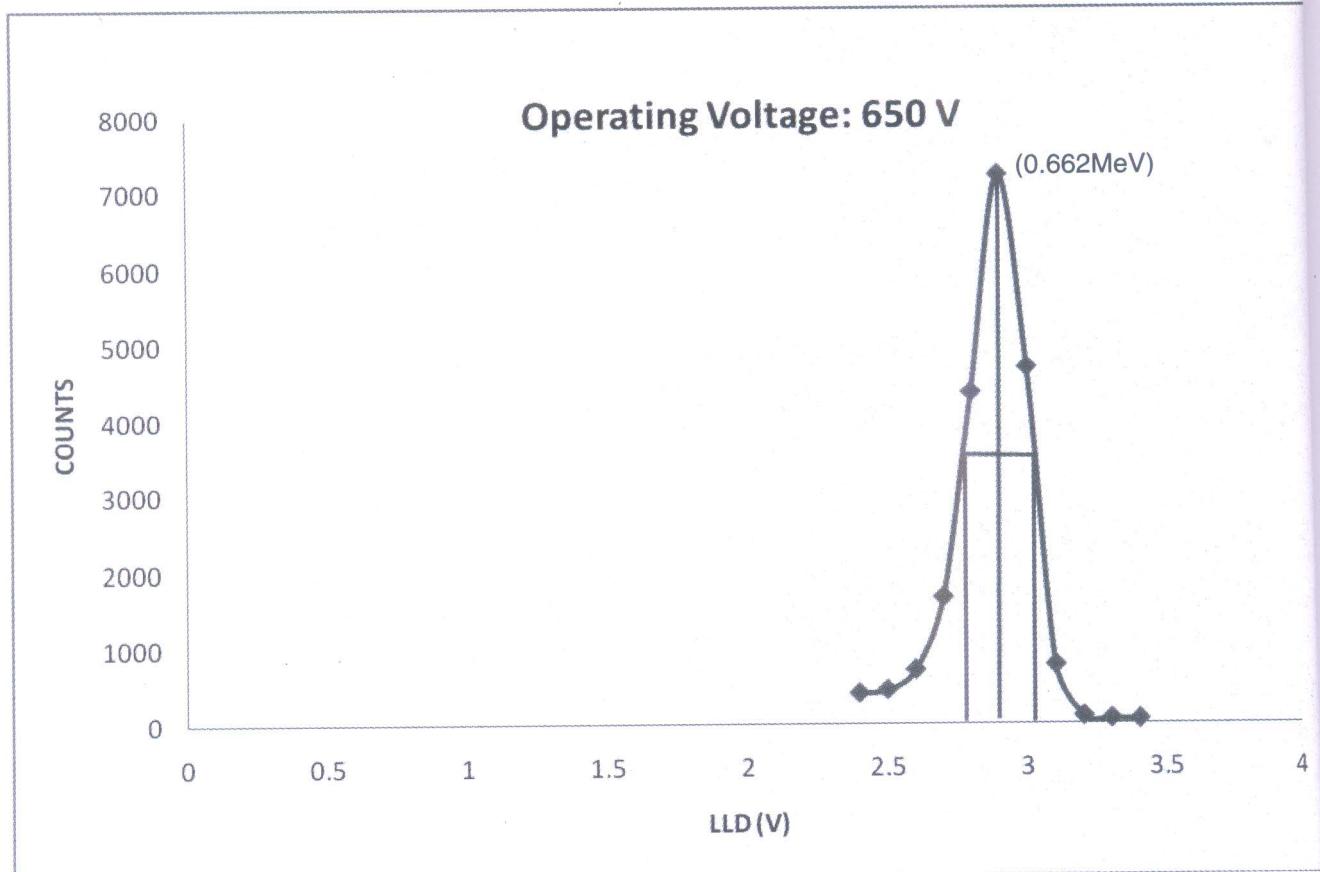


Fig. 17 : Cs-137 photopeak spectrum at 650V

## OPERATING VOLTAGE: 700 V:

**Table -3**

Base Line (V)	Counts
3.4	75
3.3	93
3.2	169
3.1	785
3	6389
2.9	6722
2.8	2896
2.7	1154
2.6	611
2.5	392
2.4	387

**Table - 4**

Operating Voltage : 700V
FWHM = 0.24V
Max. Height at 2.95V
Resolution : $0.24/2.95 = 8.1\%$

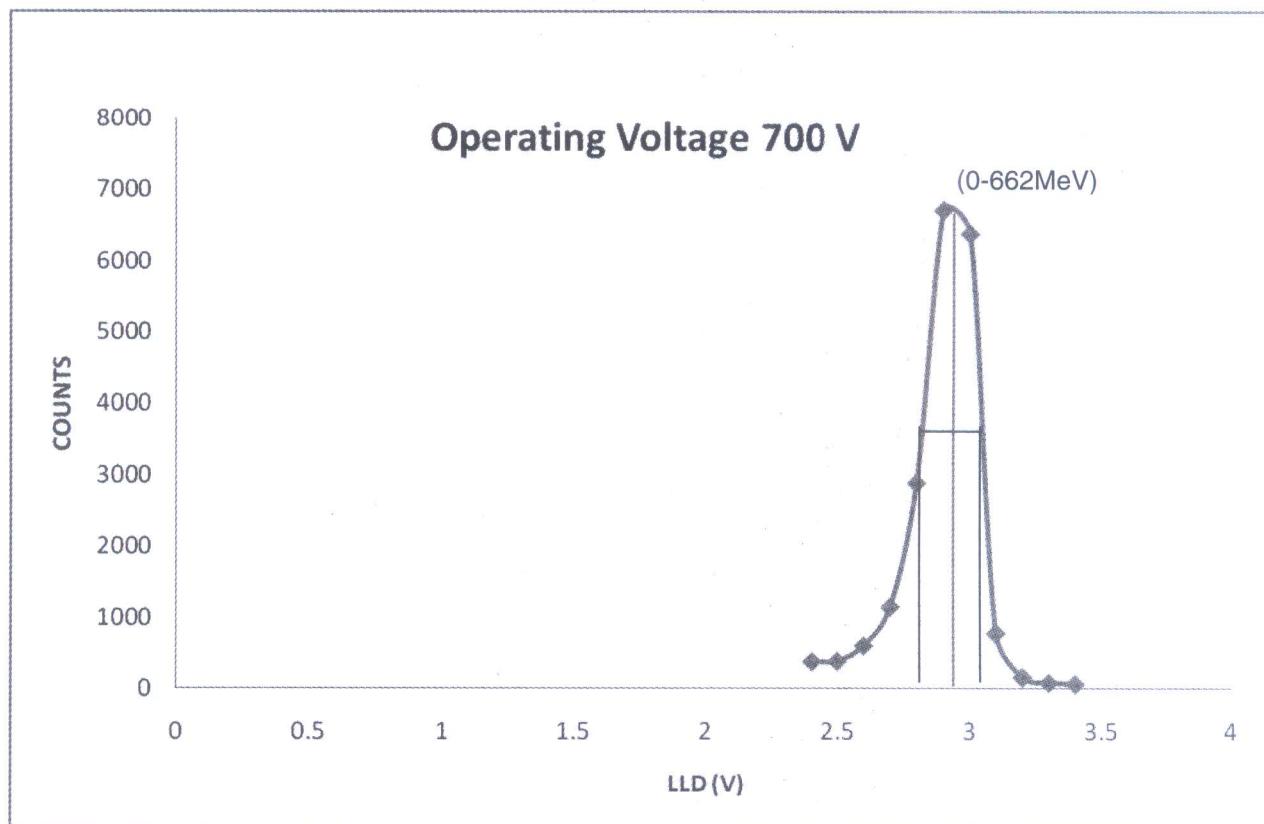


Fig. 18 : Cs-137 photopeak spectrum at 700V

## 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 : $0.22/2.85 = 7.7\%$

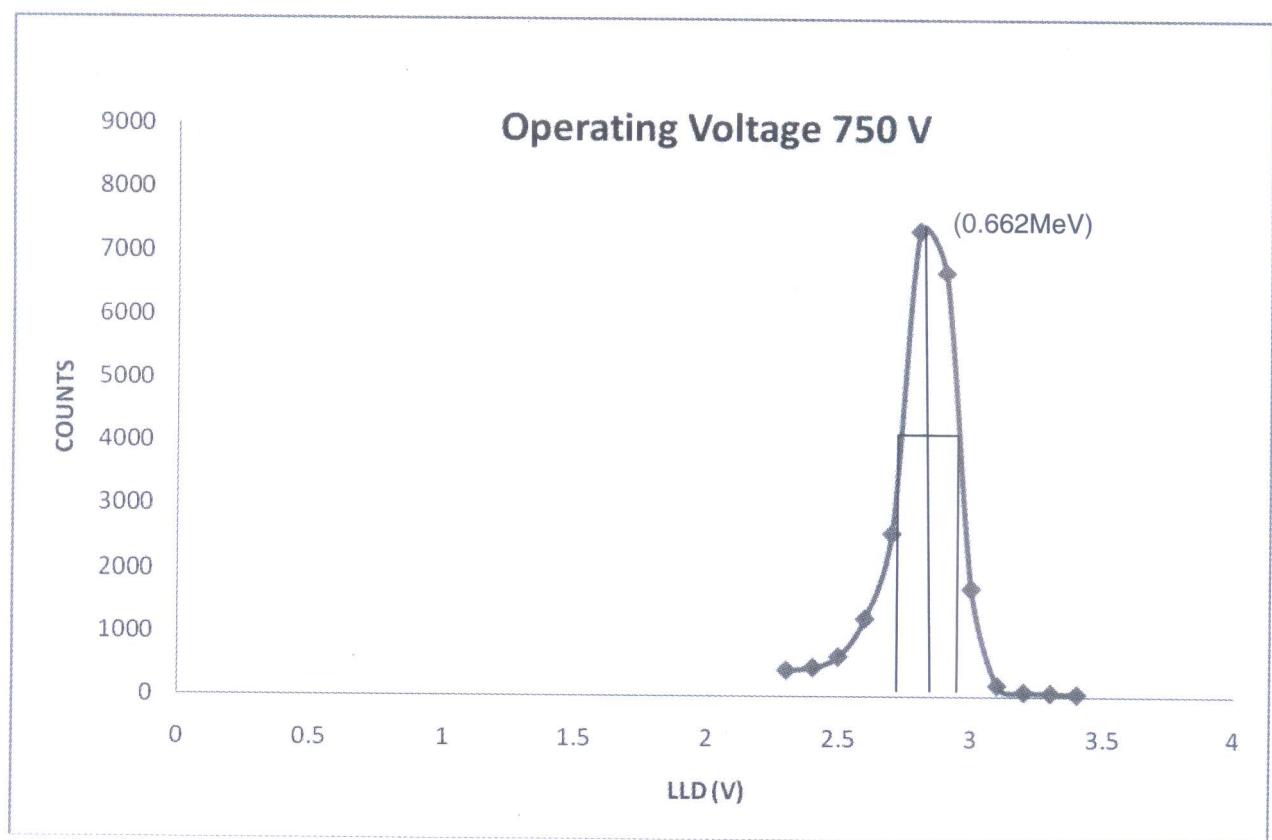


Fig. 19 : Cs-137 photopeak spectrum at 750V

## **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 : $0.22/2.75 = 8\%$

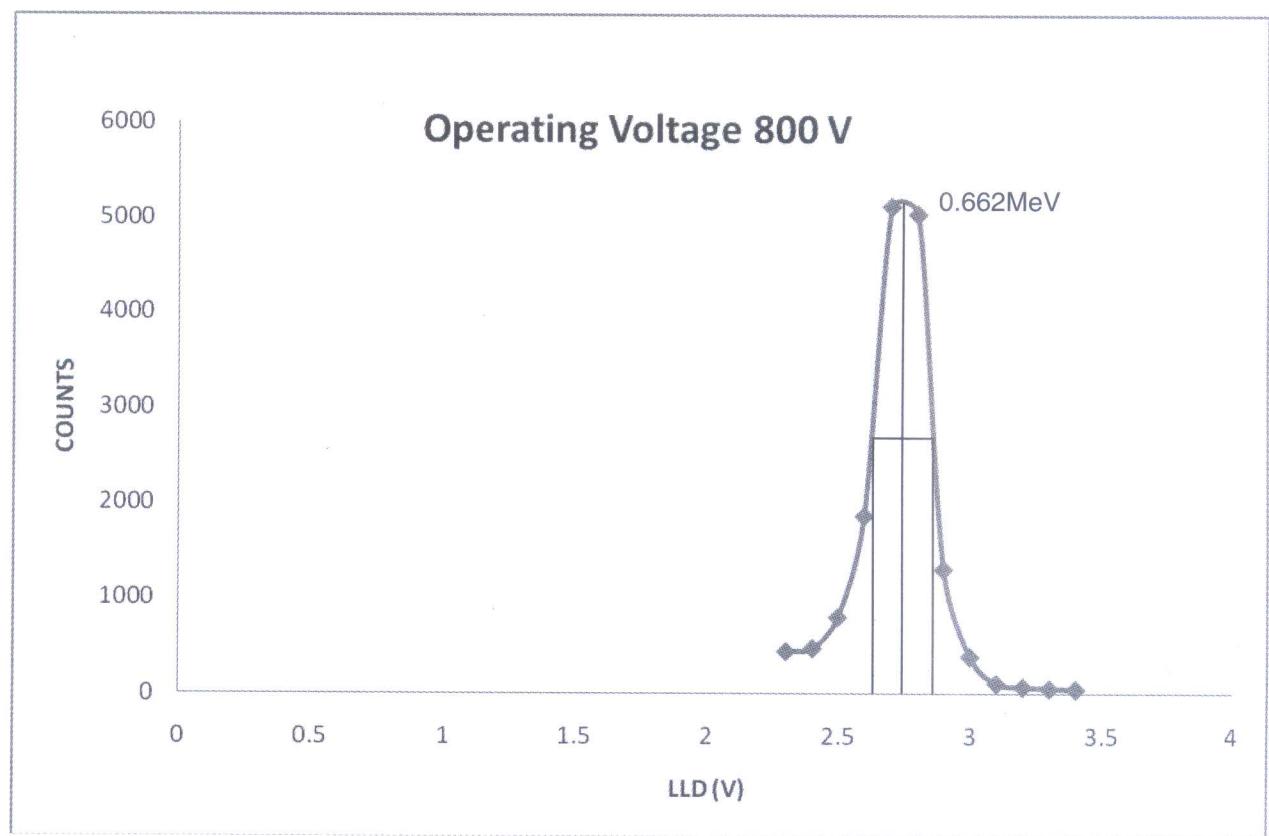


Fig.20 : Cs-137 photopeak spectrum at 800V

## 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 : $0.22/2.95 = 8.5\%$

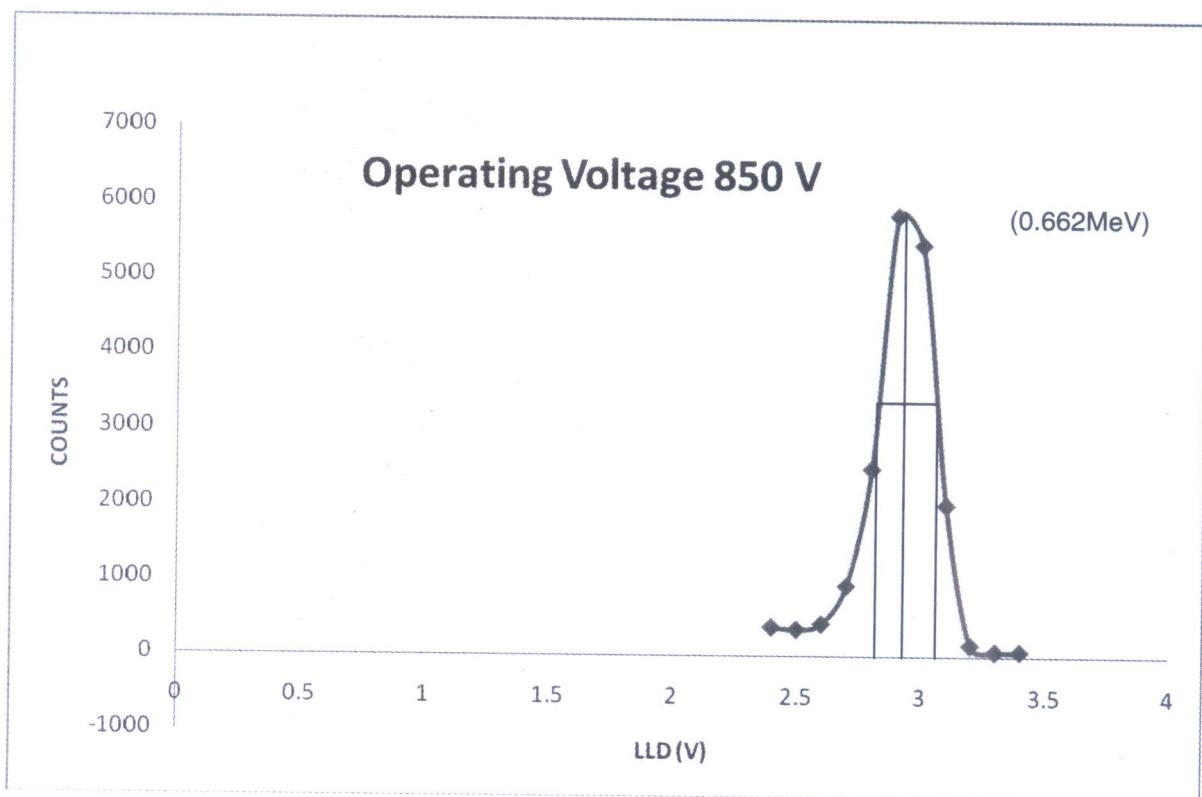


Fig. 21 : Cs-137 photopeak spectrum at 850V

- **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.

$$\text{Hence, FWHM} = (3.02 - 2.78) \text{ V}$$

$$= 0.24$$

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

$$\text{Resolution} = \left[ \frac{0.24}{2.9} \right]$$

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

- 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:

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

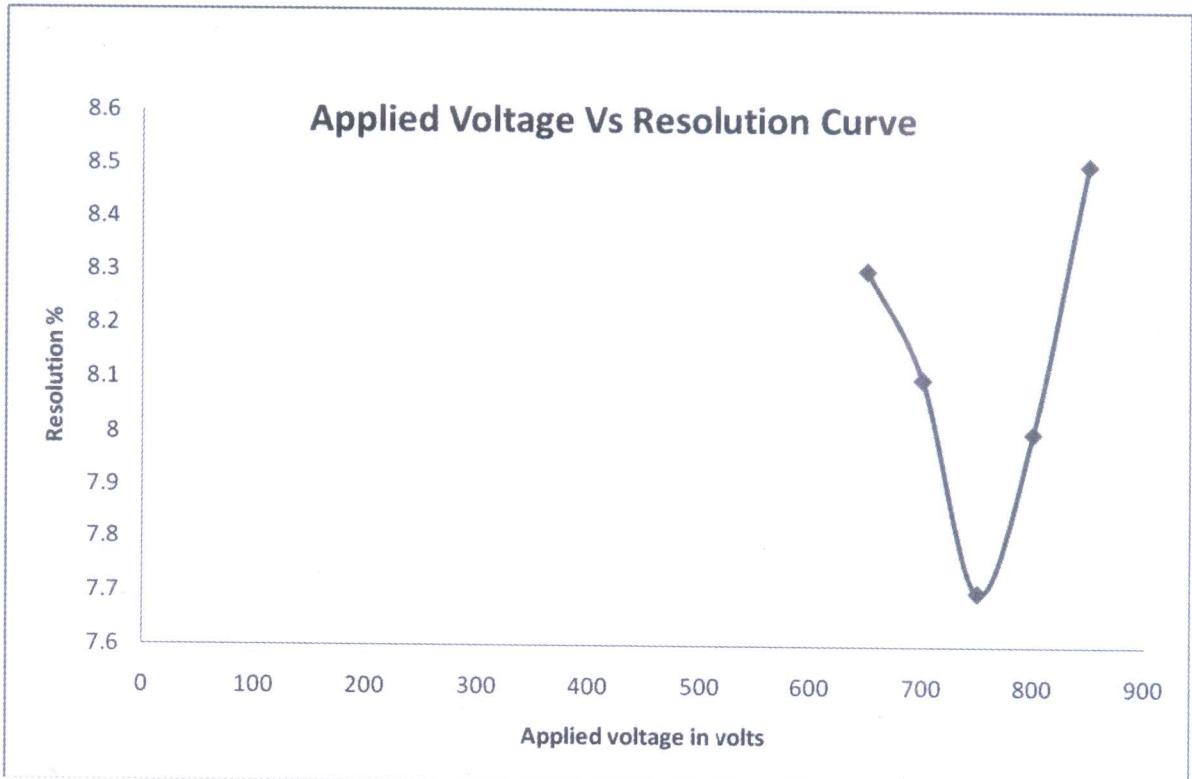


Fig.22 : Applied voltage Vs. resolution characteristics.

### 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.

## **Gamma Ray Spectroscopy Part 2**

### **Introduction**

Gamma ray spectroscopy is one of the most developed and important techniques used in experimental nuclear physics because gamma ray detection and its energy measurement form an essential part of experimental nuclear physics research. The purpose of this experiment is to acquaint one with this field using a gamma ray spectrometer comprising of **thallium activated sodium iodide (NaI(Tl)) scintillator, photo multiplier tube, associated electronics and multi channel analyzer**. The scintillation spectrometers with their high detection efficiency and moderately good energy resolution have made tremendous contribution to our present knowledge of nuclear properties.

### **Objectives:**

- To calibrate the MCA
- To determine the energy of unknown gamma radiation
- To determine the photopeak efficiency
- To determine strength of given source

### **Apparatus:**

- NaI detector with accessories
- Amplifier with ADC.
- Sources which radiate gamma rays.

## **Description of the components:**

### **Scintillation Gamma Ray Spectrometer:**

A spectrometer is an instrument to study the energy or wavelength spectra of radiation. Scintillation gamma ray spectrometer is one of the most popular and successful spectrometers. This is based on the fact that there are certain substances which emit light flashes (or scintillation) when charged particle, X-rays and  $\nu$ -rays pass through them. In a scintillation detector these light flashes are allowed to fall on the photocathode of a photo multiplier tube and a pulse is extracted out to signal the passage of nuclear radiation in the scintillator. The height of this output pulse can be made proportional to the energy dissipated by the ionizing radiation in the scintillator. Thus a scintillation detector can be used not only for counting but also for energy analysis.

This spectrometer employs a scintillation detector which is a thallium activated sodium iodide crystal as a scintillator. This crystal is enclosed in an aluminum can (Fig.2). Further, the scintillator is covered by a layer of reflecting material like MgO or AlO powder. There is a glass window at one end so that the light produced by scintillator can pass onto the photocathode. The sensitive part of the detector is a scintillator, which consists of a cylindrical NaI crystal with a diameter of 5 cm. The incoming gamma quanta deposit all their energy, or part of it, to the electrons in the crystal due to collisions (Compton effect) or photo-electric effect. The resulting fast electrons collide with the atoms of the crystal, which are excited and subsequently de-excited by emitting photons with a wave length in the region of visible light. The photons reach the photo cathode of a photo multiplier tube (PM tube), which is optically coupled to the crystal. Here the photons will cause the emission of electrons through the photo-electric effect. The number of electrons emitted from the photo cathode is proportional to the energy of the gamma radiation. The electrons are accelerated in the PM tube towards a structure of metal plates (dynodes). At the first dynode the electrons emit more electrons (see figure 1). The shower of electrons is amplified at each dynode (in total 10). The potential difference between each consecutive dynode is about 75 V. The resulting shower of electrons gives rise to an electric pulse, whose amplitude is directly proportional to the amount of light collected on the photo cathode, and thus directly proportional to the energy of the gamma radiation. By measuring the amplitude, the energy of the corresponding gamma quantum can be determined.

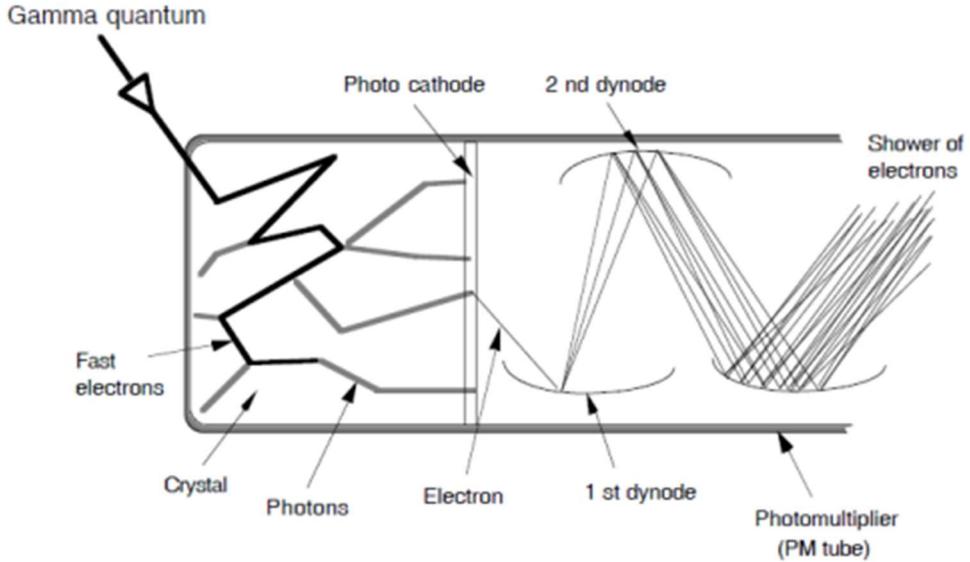


Figure 1: The schematic of the scintillator and photomultiplier tube.

Under proper conditions the voltage pulse formed is linearly related to the energy spent by the incident photon in the crystal. The pulses extracted from the photo-multiplier are fed to the single channel analyzer (SCA) or multi channel analyzer (MCA). The pulses coming out from SCA are standard positive pulses and are fed to the decade scalar which counts the number of pulses allowed by SCA during the time interval set by the timer. The multi channel analyzer acquires the data simultaneously for all particles. The function of the MCA is described later. The spectrometer is coupled to the nuclear electronic system as shown in Fig.2.

### Pre-Amplifier

The first element in a signal processing chain is a preamplifier which provides an interface between the detector and the pulse processing and the analysis electronics that follows. The preamplifier is generally located as close as possible to the detector to maximize the signal to noise ratio. It also serves as an impedance matcher presenting high impedance to the detector to minimize loading, while providing a low impedance output to drive succeeding components. It conventionally provides no pulse shaping and its output is a linear tail pulse with fast rise time and slow decay time.

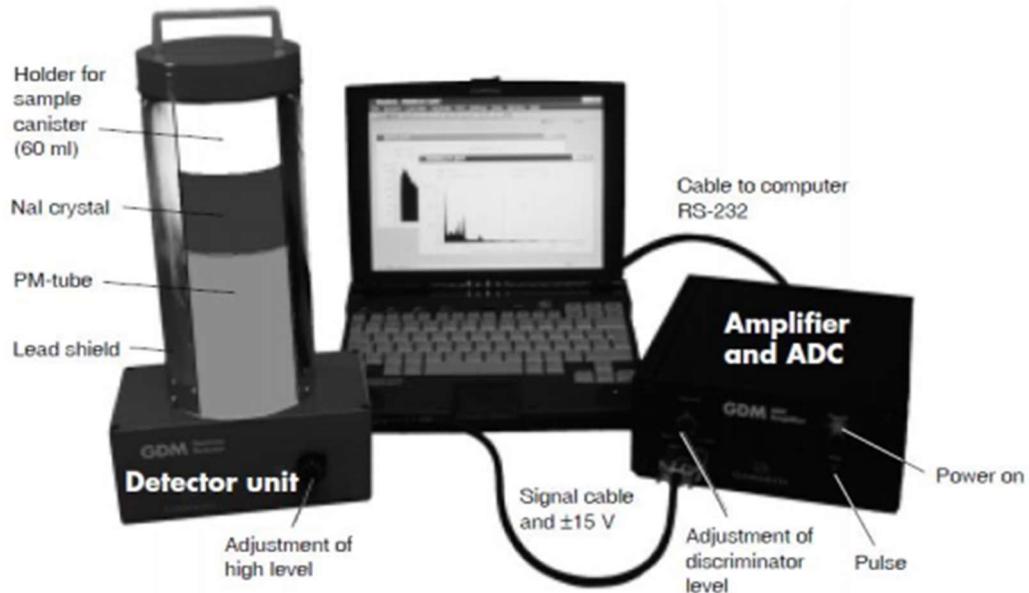


Figure 2: The schematic sketch of the Gamma-ray spectrometer.

### Pulse Height Analyzer (PHA)

The amplified pulses are next sorted out according to their pulse height. The pulse height is directly proportional to the energy deposited by the incident gamma particles in the detector. The pulse height analysis can be done by

- i. Single Channel Analyzer (SCA)
- ii. Multi Channel Analyzer (MCA)

A PHA is normally operated either in an integral or a differential mode. In integral mode a PHA is just a discriminator. In differential mode the analyzer is said to work as an SCA. Recording data with SCA involves many operations and it takes long time to collect the entire spectrum.

### Multi Channel Analyzer

A modern multichannel analyzer operation is based on the principle of counting an analog signal (the pulse amplitude) to an equivalent digital number. In this case both the amplifier and ADC are integrated in a one unit (Fig.2). Once this conversion has been accomplished the extensive technology available for the storage and display of digital information can be brought to bear on the problem of recording pulse height spectra. So the analog to digital converter (ADC) is a key element of MCA, which converts each pulse amplitude (or energy) into an equivalent digital number. A built-in periodic oscillation sends out clock pulses and the number ( $N$ ) of such pulses occurring in this time interval are recorded in a scalar (address register). In this way the output of the ADC is stored in a computer type memory, which has many addressable locations as the maximum number of channels into

which the recorded spectra can be subdivided. The number of memory locations is usually made a power of two, memories like 256, 512, 1024, 2048, etc. channels being common choices. The maximum content of any one memory location is typically  $10^5$  or  $10^6$  counts. So the basic function of the MCA involves the ADC memory and display. In this way the entire histogram plot of count versus pulse height can be recorded almost simultaneously and displayed on the computer screen as a spectrum.

### How is a spectrum created?

The electric pulses from the PM tube are amplified in the amplifier and then registered by the computer and sorted into a histogram according to their amplitude. Since the amplitude is proportional to the gamma energy, the histogram reproduces the energy distribution of the detected gamma quanta.

The analogue information (the amplitude) must be converted to suitable digital information (binary number) for the computer. The electronic circuit which carries out the conversion is called an A/D converter (Analog-to-Digital converter). The process is illustrated in the simplified drawing of figure 3. The incoming pulses are read by the A/D converter, which makes a classification, i.e. sorts the pulses into different boxes ("channels") according to their pulse height. The GDM 10 detector system uses an A/D converter with 1024 channels. The channels are numbered according to increasing pulse height, and the channel number is thus proportional to the gamma energy.

For example, pulse **A** is put into channel number 1, pulse **B** into channel number 2, pulse **C** and **D** into number 3, and so on. One thus obtains a histogram of the pulse height distribution for all detected gamma quanta. Since the pulse height is proportional to the gamma energy, the histogram reproduces the distribution of the corresponding gamma energies. The histogram is usually referred to as an energy spectrum.

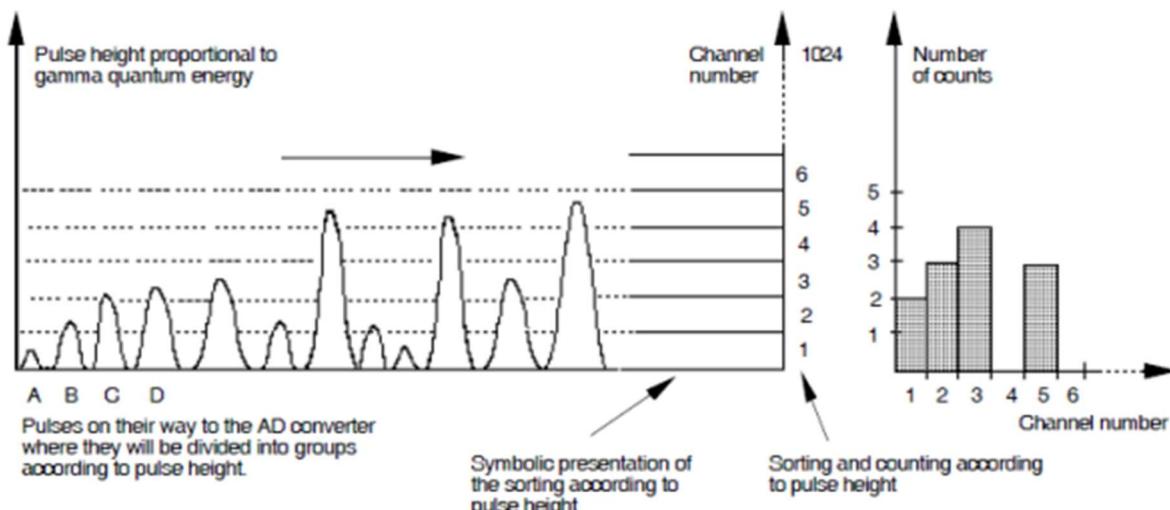


Figure 3: The flow chart which shows, how the spectrum created.

In order to find out which channel number corresponds to which energy, it is necessary to make an energy calibration, which is obtained by using radioactive sources which emit gamma quanta with known energies.

### **Procedure:**

Make the connections as per schematic diagram given in Fig. 3. The system is connected to PC using a RS-232 interface. Turn all the electric units “ON” and allow a warm up period of about 15 min. Adjust the high voltage for PMT **between 400 to 600 volts (Don't exceed 600V)**. Now choose a source which gives maximum gamma ray energy. Adjust the discriminator of the preamplifier such that the Compton distribution should not have very high counts in the initial channels. It is advisable to collect the spectra from channel no 50, by suitable discriminator level selection. Keep all the settings undisturbed throughout the experiment. Start spectrum acquisition following the menu on the PC screen. One can observe the accumulation of data (spectrum) on the screen.

### **Experiments:**

Create a subdirectory of your name and save all the data in your directory. Note down the distance and position (as accurately as possible) of the source from the detector in all the cases. This is important for subsequent analysis, especially for finding the activity of the source.

#### **i. Measurement of a gamma-Ray spectrum**

a) Collect a spectrum of a  $^{137}\text{Cs}$  source. Store the spectrum. Identify photopeak, Compton distribution and Compton edge.

Note that a spectrum from a source with only one gamma-ray energy consists of a peak (the photo peak or the full-energy peak) and a distribution on the low-energy side (to the left) of the photo peak. If there are several photo peaks in a spectrum, the studied radiation must contain several different energies.

The low-energy distribution to the left of the photo peak originates from gamma quanta, which have collided with electrons in the detector crystal or in the lead shielding. The collision takes place in such a way that only part of the original energy of the gamma quantum is absorbed in the detector. This kind of collision is called Compton scattering and the low-energy distribution is the so-called Compton distribution. The Compton distribution always forms a background to the left of the photo peak with which it is associated.

Note that there is always a discriminator setting, which rejects the most low-energetic gamma quanta and the electronic noise. The discriminator setting can be adjusted with the knob on the amplifier box, but should not be changed during a measurement.

Note in your sketch of the  $^{137}\text{Cs}$  spectrum where the photo peak, discriminator level and Compton distribution are situated.

## ii. The relation between the channel scale and the energy of the radiation:

Determine the channel position of the photo peak in the spectrum of  $^{137}\text{Cs}$  by using the centroid routine, which is prepared by first placing the cross of the lower marker on the left edge of the photo peak and the cross of the upper marker on the right edge of the same peak. This is most easily done by using the right and the left button of the mouse. See figure 5.

Now use the command **Calculate >Centroid**, which gives the channel position of the centre of mass of the photo peak. Zero the spectrum on the screen (**File Clear**) and read the  $^{60}\text{Co}$  spectrum. Repeat the same procedure for the photo peak in the  $^{60}\text{Co}$  spectrum. Note that the number of pulses and the number of pulses per second in the photo peak are also given.

Draw a diagram of the energies of the two photo peaks as a function of the corresponding channel position, i.e. the energy along the vertical axis and the channel number along the horizontal axis. The energies of the gamma quanta of  $^{60}\text{Co}$  (two photo peaks) and  $^{137}\text{Cs}$  are 1.33 MeV, 1.17 MeV and 0.66 MeV, respectively.

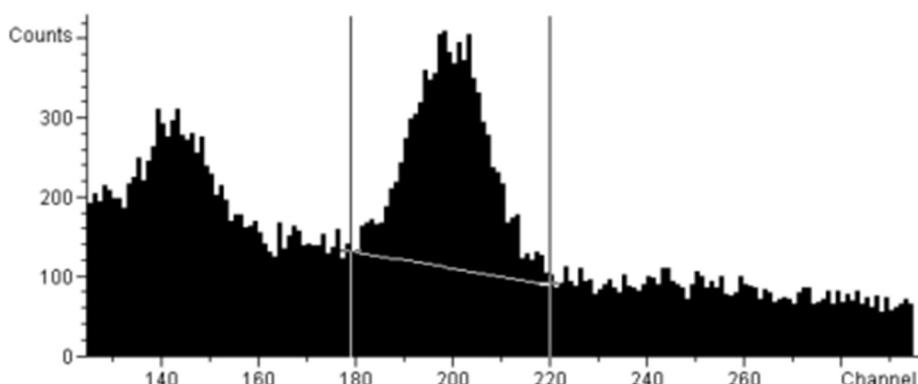


Figure4: The standard spectrum of  $^{137}\text{Cs}$  for calibration

Table 1: calibration of MCA, determining unknown source and resolution

Source	Energy(Mev)	Channel no.	FWHM	Max. Intensity	Resolution

### iii. Determination of the gamma-ray energies of an unknown gamma source

a) Collect a gamma-ray spectrum from an unknown source given to you by your teacher. Copy the spectrum to your folder and read it into your computer. Your earlier calibration may be used to calibrate the unknown spectrum.

b) Compare the gamma energies obtained with the decay schemes.

### iv. Determination of detector resolution and its variation with energy

The term resolution denotes the degree of broadening and is defined as the full width at half maximum divided by the pulse height at the peak multiplied by 100 as given below.

$$\% \text{Resolution} = \frac{\text{FWHM}}{\text{Pulse height at the peak value}} \times 100$$

Determine the percentage resolution for all photo-peaks and plot resolution vs.  $E^{-1/2}$  and study the relation.

### v. Determination of photopeak efficiency of NaI crystal of given dimensions for different energy gamma rays

The complete spectra of the sources which emit gamma rays energy, e.g.,  $^{137}\text{Cs}$ , and  $^{60}\text{Co}$  are taken and plotted on linear graphs. A suitable time is about 10-30 min, respectively, per spectrum. In each case the ratio of the area under the photopeak to the total area under the curve is determined.\*\* This ratio is plotted against the energy and a smooth curve is drawn. From this curve one can determine peak to total value for any energy. When this ratio is multiplied by the percentage efficiency at the same energy as calculated from standard graphs, it gives the photo-efficiency of NaI(Tl) crystal at that energy.

What is the conclusion drawn about the energy dependence of the efficiency? .....

Note: \*\* Photopeak efficiency (Ep) can be calculated as follows:

$$E_p = N(pp)/N(T)$$

**Table2:**

Energy (Mev)	Gamma Activity (Bq)	No. counts in photo peak	No. of counts in the total	Efficiency (%)

where  $N(pp)$  is the number of pulses contributing to full energy peak (photo peak) of the gamma ray spectrum and  $N(T)$  the number of pulses contributing to the total gamma-ray spectrum. But  $N(T)$  consists of all the counts which are detected by the detector and some of them are not due to gamma radiation and other factors such as mode of decay need to be taken into account. To calculate efficiency of detector, peak to total ratio  $R_{PT}$  also needs to be accounted. The modified formula is as follows. The absorption efficiency of the detector is given by

$$\eta_a = \frac{N_{pp}}{R_{PT} f_r f_b A t I G}$$

Where,

- $R_{PT}$  is the photo-fraction or peak-to-total ratio ( $\sim 0.47$  for  $^{137}Cs$ )
- $f_r$  is the branching ratio of the gamma line ( $0.851$  for  $^{137}Cs$ )
- $f_b$  is the branching fraction of the mode of decay ( $0.947$  for  $^{137}Cs$ )
- $A$  is the activity of the source in Bq
- $t$  is the duration of time in seconds
- $G$  is the geometrical factor given by ( $G = \frac{1}{2} \left(1 - \frac{d}{\sqrt{a^2 + b^2}}\right)$ ) where,  $a$  is the radius of the cylindrical detector and  $d$  is the source to detector distance (5 cm for this detector)
- $I$  is a factor considering the transmission of gamma by intervening materials between detector and the source ( $I \sim 1.00$ )

The total detector efficiency ( $\eta_d$ ) is given by

$$\eta_d = \eta_a I G$$

The photopeak efficiency  $E_p$  is given by

$$E_p = \eta_d R_{PT}$$

The value of  $R_{PT}$  for various scintillators including NaI(Tl) is available in Ref.(1). The procedure to extract counts in the photopeak ( $N_{pp}$ ) is described in the Ref 2, page 341).

### vii. Determination of the strength of a given source (in microcuries)

The strength of any source can be determined using the relation

$$N = N_0 E pG$$

where  $N_0$  is the total number of disintegrations per second,  $G$  is the solid angle subtended (geometric factor) by the detector at the source,  $E_p$  is the photopeak efficiency (as determined above), and  $N$  are the observed counts in the photopeak.

### References:

1. Efficiency calculation for Selected Scintillators. Saint-Gobain Ceramics & Plastic Inc. 2016 ([https://www.crystals.saint-gobain.com/sites/imdf.crystals.com/files/documents/efficiency\\_calculations\\_brochure\\_69670.pdf](https://www.crystals.saint-gobain.com/sites/imdf.crystals.com/files/documents/efficiency_calculations_brochure_69670.pdf))
2. Glenn F. Knoll. Radiation Detection and Measurement. 3<sup>rd</sup> ed. Wiley India Pvt. Ltd. 2012, ISBN:978-81-265-2260-6
3. S.S.Kapoor and V.S.Ramamurthy "Nuclear Radiation Detectors:", Wiley Eastern Ltd., 1986, Ch V. Page 176-185
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