Chapter 3
Detectors and Instrumentation
3.1 Introduction

We have known about that the measurement or detection of radiation through the interaction with some material which is sensitive to the radiation and generate a signal, this electrical signal can be used to characterize the radiation and its properties. For this purpose necessary step in building a detector is to understand the interaction mechanisms of radiation in the detection medium. All the methods for the experimental detection of radioactivity are based on the interaction of charged particles as the result of interaction ions are produced and reduction in the energy absorbed. An ideal detector is able to differentiate between various types of radiation and particles and give a signal which is proportional to the energy of radiation. The detectors are mostly classified as electric detectors and optical detectors; all the electric detectors are working on the ions collection methods, which are produced by gamma radiation interaction with the material of detector, such detector is Ionization chambers, semiconductors detectors, Proportion counter and GM counter. All the optical detectors are not based on ions collection method such detectors are Scintillation counter, Cerenkov counter, Photographic emulsion, Cloud chamber, Bubble chamber and Spark chamber, Sharma R. C. (2007). The detector not only records the presence of nuclear radiation but also gives information about its energy; we can describe the basic principle of most commonly used detectors so this chapter is devoted to exactly this task. We will look at different types of radiation detectors in the subsequent chapters.

3.2 Gas detectors

Gas doctors working are based on the ions collection method, as a result, electric pulses is detected by the detector; ions are produced due to the interactions of gamma radiation when it is passed through the gas within the detector. Normally used gas detector is the Ionization chamber, Proportion counter, and Geiger-Muller counters. The drawback of gas detectors are due to the measuring weakly ionizing particles, therefore, they are not efficient for measuring the high energy gamma rays.
3.3 Geiger-Mueller Counter

A Geiger-Muller in 1920 is developed a counter for radiation detection, thus the counter is called as GM counter and the original operating principle was discovered in 1908 by Rutherford and Geiger. It detects the emission of nuclear radiation like alpha, beta and gamma rays by the ionization produced in the gas filled in a Geiger-Muller tube, which its name to the instrument.

3.3.1 Construction

The G.M. tube consists of a central electrode of Tungsten wire of about 0.1 mm diameter. The outer electrode is the metal tube which can be contained inside a glass envelope acting in the dual role of electrode and container. The metal tube well insulated from the central electrode and the applied voltage is about 1000 volt to 3000 volt through a high resistance. The tube is filled with a gas mixture at the pressure of 10 cm of Hg.

3.3.2 Operation

The G. M. counter is connected with an electronic circuit which record pulse height proper to this region. It is seen that until the voltage reaches the starting voltage the pulses are too small to be detected and it increases above this limit rate. The counting rate increases until the threshold voltage $V_G$ of GM region is reached. Above threshold voltage, the counting rate remains almost constant. This is known as Geiger plateau. Beyond this plateau a continuous discharge takes place and counting is not possible. In the GM region ionization pulse depends on general characteristics and construction of GM tube.

3.3.3 Disadvantage of GM counter

1) It is insensitive for the period of 200 to 400 µs following each plus, which prevents its use at very high counting rates.
2) It cannot provide information about the particle or photon causing the pulse.
3) It is not energy selective. Podgorsak E. B. (2010).
3.4 Scintillation detector

Earliest method for the detection of gamma radiation was by luminescence, they produced in the certain substances. The scintillation counter consists of the luminescent material known as the scintillator.

3.4.1 Construction

The crystalline Sodium iodide which is activated with thallium produces an approximately large scintillation light output as compared with organic material, so in the scintillation detector the reflecting layer of aluminum foil containing the luminescent substances which facilitated to the collection of light and luminescent substance in scintillation detector usually a thallium activated sodium iodide [NaI(Tl)] crystal. Since NaI(Tl) crystal is hygroscopic and schematic view of nuclear electronic system is shown in figure 3.1.

![Schematic view nuclear electronic system of a scintillation spectrometer](image)

The NaI(Tl) crystals are usually in the form of the circular cylinder, the scintillator is covered from all sides by the layer of reflecting material. The glass window is provided at one end so that light produced by the scintillator which can be passed on to the dynode of a photomultiplier tube, which releases the number of photoelectrons and is increased from dynode to dynode inside the photo multiplier tube (PMT) as the result is a brief pulse at output, which can be amplified and processed by subsequent electronic devices. Thus the scintillation detector can be used not only for counting but also for energy analysis. On comparing these detectors
the inorganic scintillation detector are found to be the best detector and gives a typical output from PMT. That collects the light with a long time constant measuring circuit. The scintillation counters have the good efficiency for secondary electrons produced by gamma-ray interaction in the material.

### 3.4.2 Operation of Scintillation Detector

**Absorption process:** When gamma ray is incident on a scintillator, it may lose its energy with the material in three ways as the photoelectric effect, Compton Effect and pair production. In each case, electrons are produced and the energy of incident photons can transfer part of its energy into the kinetic energy of secondary electrons. These secondary electrons will give up their kinetic energy in excitation or ionization in the scintillation material.

**The scintillation process:** The emitted electrons will give up their kinetic energy in excitation or ionization in the scintillation material. This absorbed energy appears either as heat energy (in more than 60 percent cases) or as luminescence photons. In the latter process, the excited state of the scintillator material de-excite to lower states by light emission within $10^{-8}$ second. This emitted light is known as scintillation. The time dependence of the photons emission follows an exponential law.

$$\text{N} = \text{cons} (1 - e^{-t/\tau})$$

Where, N is a number of light photons emitted in the time t after the ionization radiation has arrived and $\tau$ is the mean life of the scintillator and each scintillation materials have a characteristic mean life, Tayal D. C. (2008) and Efrem M. (2006).

### 3.5 Selection of Detector

We are interested in gamma ray detection and the detector should have the following characteristics

1) It has high efficiency of detection of gamma rays.
2) Energy selective.
3) Linear response to the electron.
4) Good resolution power.
5) Good mechanical and electrical stability.
All these properties are seen in the scintillation detector so finally we concludes that NaI(Tl) is the best detector for gamma ray detection and scintillation material should be ideal and they possess following properties.

1) It should have very high scintillation efficiency.
2) The medium should be transparent to the wavelength of its own emission for good light collection.
3) The decay time of induced luminescence should be short so that fast signal pulses can be near that of glass (i.e. 1.5) to permit efficiency coupling of scintillation light to photomultiplier tube by Sharma H. C., Kharb R. and Sharma R. (2005) and Gurler O. and Tarim U. A. (2012).

3.6 Single Channel Analyzer

In the integrated mode, it operates like a discriminator in the window mode one can define both a maximum and minimum peak height. It consists of a lower level discriminator (LLD) and upper-level discriminator (ULD). The lower level discriminator allows only those voltage pulses to pass that are higher than a present value. The ULD allows voltage pulses higher than a present value to pass through. This level is higher compared to LLD level. Thus window or channel is opened that allows only pulses having the amplitude between the settings of the LLD and ULD. Several systems of nomenclature and adjustment persist for SCAs. In some units, the lower-level discriminator and upper level discriminator are independently adjustable from front-panel controls. In counting systems, the SCA can serve to select only a limited range of amplitudes from all those generated by the detector. In normal SCAs the time of appearance of the logic pulse is not closely coupled to the actual event timing and use of this logic pulse in timing measurements will often give imprecise results. If one of the time pick-off methods is incorporated into the SCA design, the logic pulse can be much more closely correlated with the actual event time. Modules with this feature are often called SCAs and widely used in coincidence applications or other time measurements. Most SCAs provide the option of switching out the upper-level discriminator and using the unit as a simple integral discriminator controlled by the lower level. The input linear pulse is intended to be shaped with typical 0.0 - 10 µs widths and a pulse height range that most commonly is 0 – 10 V positive. Bipolar pulses with positive leading edges are also normally acceptable.
3.7 Multi Channel Analyzer

The multi channel analyzer (MCA) is a circuit which capable of setting of a large number of individual channels to look at complete spectrum simultaneously. Normally MCA consists of 1024 channels and information are acquired simultaneously from each channel and displaced as an energy spectrum. MCA are commonly used over a single channel analyzer, which uses a microprocessor technology with high speed, high density, smaller size, easily computable and semiconductor memories. The interfaces of output ports of control units are lead to cathode tube in order to display output in terms of channel versus counts.

3.8 Narrow Beam Geometry

The narrow beam geometry prevents any scattered radiation or secondary particles reaching the detector. A collimated beam of gamma radiation penetrates through the absorber to produce the narrow beam geometry. About one-centimeter diameter or even less than that hole was drilled into a thick lead block to create the collimator. This produces a narrow beam of $\gamma$-rays approaching the attenuator. The lead collimator was tested for any $\gamma$-ray leakage. The source was placed at a certain distance away from the detector and the attenuators were placed in between the detector and the source. The distance between source and detector is varied and optimized for good attenuation. The collimated beam was then attenuated and allowed to fall on the detector after passing through the attenuator. The intensity of the attenuated beam was measured by the detector. Background counts were collected and the net count was obtained by subtracting time-normalized background counts reforested by Reddy and Murty (2012) and Cuddihy R. G. (1997). A schematic representation of the narrow beam geometry is shown in figure 3.2

3.9 Broad Beam Geometry

In broad beam geometry, there is no collimator used as in the narrow beam geometry. Broad beam geometry allows scattered and secondary particles to reach the detector in addition to the primary beam. Ideally, every scattered and secondary particle generated in the attenuator by a primary particle will strike the detector. A schematic representation of broad beam geometry in figure 3.3
3.10 Gamma Ray Sources

In the present work, the set of gamma sources is sealed on 25 mm (dia) x 5 mm plastic disc and all these disc sources are enclosed in a box made of the acrylic sheet. The details of activity, energy and half-life are mentioned on the label of box and here given in table 3.1

<table>
<thead>
<tr>
<th>Isotopes</th>
<th>$\gamma$ Energy (MeV)</th>
<th>Activity (µCi)</th>
<th>Half life (Years)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$^{133}$Ba</td>
<td>0.356</td>
<td>2.324</td>
<td>07.5</td>
</tr>
<tr>
<td>$^{22}$Na</td>
<td>0.511 and 1.275</td>
<td>1.973</td>
<td>02.6</td>
</tr>
<tr>
<td>$^{137}$Cs</td>
<td>0.662</td>
<td>2.622</td>
<td>30.0</td>
</tr>
<tr>
<td>$^{54}$Mn</td>
<td>0.840</td>
<td>3.054</td>
<td>0.83</td>
</tr>
<tr>
<td>$^{60}$Co</td>
<td>1.170 and 1.330</td>
<td>3.622</td>
<td>05.3</td>
</tr>
</tbody>
</table>

Table 3.1 Radio-isotopes with their energy, activity and half life
3.11 Energy Calibration

For Energy calibration one may enter the three calibration constants directly. The peak location found by find peak may also be used for energy calibration. The user should be familiar with the peak location and energies in the calibration spectrum. The user should select the energy calibration menu item. By clicking on the analysis menu and begin energy calibration by clicking on the energy calibration atom. For example, consider gamma ray isotopes of Ba\(^{133}\) whose energy is 0.356 MeV and having normal activity 2.324 \(\mu\)Ci with the half life of 10.5 years. In this Barium Isotopes if we take the count then it is observed that maximum counts are found with the base line voltage 1.60 volt (33653). Now consider the second gamma rays isotopes Na\(^{22}\) with energy 0.511 MeV and 1.28 MeV with normal activity 1.973 \(\mu\)Ci with half life 2.6 years. It is observed that for 0.511 MeV energy the maximum and baseline volt at 2.25 volt (26500), for Na\(^{22}\) with 1.275 MeV the maximum counts are observed at 5.65 volt (3689). Consider the next gamma ray isotope Cs\(^{137}\) having energy 0.662 MeV with normal activity 2.622 \(\mu\)Ci with half life 30 years. In this case, maximum counts are observed at 2.92 baseline voltage (21173) for next gamma ray isotope. The Co\(^{60}\) which is having two energies 1.170 and 1.330 MeV with normal activity 3.622 \(\mu\)Ci and half life 5.3 years; in this case for first energy 1.170 MeV the peak is at 5.16 volt (13664) and for second energy 1.330 MeV maximum height of peak is at 5.86 volt (11031) in this way we can find out the maximum height of peak at each energy for gamma ray isotopes by Beiser A. et al (2009) and we observed that as energy increases the baseline voltage increases and given in table 3.1

<table>
<thead>
<tr>
<th>Source</th>
<th>Energy (MeV)</th>
<th>Baseline voltage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ba(^{133})</td>
<td>0.356</td>
<td>1.60</td>
</tr>
<tr>
<td>Na(^{22})</td>
<td>0.511</td>
<td>2.25</td>
</tr>
<tr>
<td>Cs(^{137})</td>
<td>0.662</td>
<td>2.92</td>
</tr>
<tr>
<td>Co(^{60})</td>
<td>1.170</td>
<td>5.16</td>
</tr>
<tr>
<td>Na(^{22})</td>
<td>1.275</td>
<td>5.65</td>
</tr>
<tr>
<td>Co(^{60})</td>
<td>1.330</td>
<td>5.86</td>
</tr>
</tbody>
</table>

Table 3.1 Baseline voltage for corresponding energy
A plot is drawn between energy versus baseline voltage and obtained graph is a straight line which indicates at gamma ray spectrometer is linear over the entire energy range. This is a very important parameter of spectrometer and shown in figure 3.4 is follows

![Calibration curve](image)

Fig. 3.4 Calibration curve

In the present study, the photon transmission measurement was done under a narrow beam geometry of NaI(Tl)) as a photons detector. The NaI(Tl) is an inorganic scintillation crystal of alkali halides and are good inorganic scintillations. The energy gap between the valence band and conduction band is the order of 5 eV – 6 eV. When the photons energy is absorbed by the electrons from the valence band get excited to the conduction band leaving holes in the valence band. The photomultiplier tubes have good sensitivity for photons of the visible region; some of the photons reaching the photocathode of photomultiplier tube causes photoelectric effect and liberate electrons. These electrons are multiplied by a factor of about $10^6$ by series dynodes inside the PMT. The wavelength of the photons has to be shifted to the visible region. In NaI(Tl) crystal detector about 30 eV energy is needed to produce photons in the visible region.

### 3.12 Experimental Set-up

The experimental setup consists of Scintillation detector, low voltage circuit, high voltage circuit, multi channels analyzer and controller with peripheral IC circuits; all these circuits are integrated into a single motherboard and housed in the main electronic unit. The scintillation detector and the main electronic unit called as
gamma ray spectrometer. Scintillation detector consists of Sodium Iodide crystalline optically coupled to a photomultiplier. The output of the detector is given to the scintillation preamplifier input through a BNC cable. The scintillation preamplifier is basically a pulse shaping amplifier which amplifies scintillation detector output with both coarse and fine gain controls have been provided and amplified signals are analyzed with the multi-channel analyzer having 1024 channels connected to the PC.

The radioactive source was kept in the source holder which is placed subsequently in the lead castle well shielded from all side to reduce the external radiation exposure and background radiation contribution. The transmitted photon beam is detected by NaI(Tl) scintillation detector. The voltage chosen to provide good resolution characteristics for the isotope is about 650 volt. The detector was calibrated for various photons energies. The NaI(Tl) scintillation detector used in the present investigation is supplied by Nucleonix systems private limited, Hyderabad, India. A provision was made midway between collimators to introduced absorber which were in the form of thin uniform foils or pallets. The entire system was arranged vertically over the NaI(Tl) detector ensuring that the central axis of the incident and transmitted collimated are co-axial is shown in figure 3.5. Each sample pellets or foils were weighed in a sensitive digital balance having accuracy 0.001 mg. The weighing was repeated several times and the mean of this set of values was used. The areal densities of absorbers were obtained by comparing their weight measured on a microbalance, with their area. The counts under the full energy absorption peak of the recorded spectrum were taken without and with absorbers placed in sequence. The photons spectrum was recorded for several times for each additional foil of increasing thickness. For each added foil thickness average counts under the full energy absorption peak were obtained. The entire counting system was arranged in dust free room to minimize contribution from scatter photons and also from contamination arising from the atmosphere. Sealed radioactive sources that is kept in the laboratory. Care was also taken to maintain temperature variation due to environmental change as a minimum so as to avoid any shift in the photo peak position of recorded gamma spectra. The average number of transmitted photons through different absorber foils or pallets were corrected for background and plotted against thickness to represent a linear curve on a semi-log graph paper, Murty and Devan (2004).
Fig. 3.5 The schematic view of NaI(Tl) Scintillation detector
Photographs of
Nuclear Physics Research Laboratory
References


National Research Council, Health Ticks from exposure to low levels of Ionizing radiation, Beir VII phase2, National academy press.


