Chapter 3

GAMMA RAY COUNTER
Introduction:

Nowadays detectors are the important tools in radiation physics as they are playing an important role in radiation measurements. Radiations lose their energy directly or indirectly by ionization or by excitation atoms or molecules in the medium they pass through. Alpha and β are charged particles while γ and x-rays are neutral. There are many detectors for detecting radiations and they are classified as follows.

I. Detectors Based on ion collection Method.

Saturation Collection  Multiplicative ion collection
(Ionization Chamber)

In gases In Semiconductor  Proportional counter  G.M.Counter

II. Detectors based on other than ion collection method

counters based on light emission  Image forming devices

Scintillation  Cerenkov counter  Cerenkov counter

Photographic cloud chamber  Bubble chamber  Spark chamber emulsion.

3.1 Selection of detector:

Selection of detector depends upon the type of radiation to be detected. We are interested in gamma ray detection and the detector should have the following characteristics,

1. High efficiency of detection of gamma rays.
2. Good resolution power.
3. Linear response to electrons.
4. Good mechanical and electrical stability. These properties are seen in the scintillation detector. For Scintillation detector the scintillation material should be ideal and should 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 luminances should be short so that fast signal pulses can be generated.

4. Its index of refraction should be near that of glass (i.e.1.5) to permit efficient coupling of the scintillation light to a photomultiplier tube.

3.2.1 Scintillation process:

When the photon strikes the crystal the electrons are raised from the valence band to the conduction band, leaving behind vacancy of electrons in the valence band. From the conduction band the electrons either directly jump to the valence band or via one of the intermediate levels called as traps or activator centers. The balance energy in the latter cases is emitted out as useful photon. In the instances when the incident photon energy is not sufficient to raise an electron to the conduction band, the electron is raised to a level just below the conduction band. This forms electron-hole pair and is not free to move independently in the crystal. Such a pair wanders in the crystal and is called
excitation. The movement of the electron and hole continues as a pair till they either annihilate or the electron is excited to the conduction band.

3.2.2 Types of scintillation detectors:

The scintillation detectors are classified into three groups 1. Organic Scintillation detectors, 2. Inorganic Scintillation detectors and 3. Light collection and Scintillation detector Mounting.

On comparing these detectors, the inorganic scintillation detectors are found to be the best detectors for gamma ray detection. The comparison shown is in the table 3.1. (J.F.Knoll) in which the fifth column gives rise time of a typical output from PM tube that collects the light with a long time constant measuring circuit. The seventh column lists the calculated absolute scintillation efficiency for fast secondary electrons produced by gamma ray interaction in the material. The last column shows relative pulse amplitude. From table 3.1 we concludes that NaI(Tl) is the best detector for gamma ray detection. CsI(Tl) is non hygroscopic and has higher density as compared to NaI(Tl) but, it is not used because of
1. Due to smaller forbidden gap, its light yield in photons is almost double than that from NaI(Tl).
2. Its decay time is nearly 4 times lesser than that of NaI(Tl) and thus is more suitable for higher counting rates.(i.e.decay
constants for NaI(Tl) and CsI(Tl) are 0.23 and 1.0 respectively).

In 1948, Robert Hofstadter first demonstrated that crystalline sodium iodide which is activated with thallium produces an exponentially large scintillation light output compared with the organic material. The high-purity sodium iodide is activated with about $10^{-3}$ moles of fraction of thallium for growing the large ingots. NaI(Tl) will damage due to water absorption if exposed to atmosphere for a small time. Crystal must be inserted in air-tight container for use. Its response to electron is nearly linear over most of the significant energy range as shown in fig 3.1.

3.2.3 Fluorescent emission in NaI(Tl) detector with manufacturer details.

The NaI(Tl) detector function to detect a gamma photon can be well understood in terms of band structure of crystals. As shown in figure 3.2. A pure NaI crystal has all the energy levels completely filled and the exists in conduction valence band. The forbidden gap is about 8 ev and is sufficiently wide to stop any electron getting excited to conduction band at room temperature. Thus a pure NaI crystal acts as a perfect insulator at room temperature. The forbidden gap also contains certain energy levels either due to impurities in the crystal or due to crystal imperfections. Such levels behave either traps or as recombination centers. The impurities like Tl in NaI acts as an activator. The coupling of scintillation material (NaI(Tl)) with the
photomultiplier tube is as shown in the fig.3.3.

The scintillation detector we used is of Electronic Corporation of India Limited and it is described as below.

The SG644 is primarily designed for use with ECIL modular Gamma Ray Spectrometers. The Scintillation Head is built into a complete unit comprising of scintillator, Photomultiplier and preamplifier. The Detector is Sodium iodide (Tl) crystal and is optically coupled to a multistage high stability photomultiplier. The preamplifier features a solid state design and provides the output pulse at low impedance. The specifications are as follows.

Phosphor: \( \text{NaI(Tl)} \frac{3}{4} " \times 2" \text{ type 7DB} \)

Photomultiplier tube \( \text{9656 KL (EMI)} \)

Operating Voltage \( +600 \text{ to } 1.5 \text{ KV.} \)

Resolution (with EC GRS23) \( \text{better than 12% for Cs}^{137} \)

Dynode Chain Resistance \( 1.9 \text{ Meg.Ohms.} \)

Background (Shielded) \( 600 \text{ counts/minute (Approx). above a bias level of 100 KV.} \)

Preamplifier

Gain \( 0.9 \text{ (approx)} \)

Rise Time \( 0.1 \text{ micro Second.} \)

Decay time \( 5 \text{ micro Second} \)

Polarity \( -\text{ve} \)

Output impedance \( 50 \text{ ohm.} \)

Power Requirement \( +12 \text{ V at 10 mA.} \)

\( -12 \text{ V at 10 mA} \)
Temperature Range: 10 to 50°C

3.3 Photomultiplier tube with manufacturer details:

Light from scintillation material (scintillator) strikes the cathode, which is usually made of Antimony and Cesium, and ejects electrons. The glass tube is vacuum evacuated and has several dynodes to which higher potentials are applied step by step. The photo electrons are accelerated in the electrostatic field in the space between the cathode and first dynode kept at a positive potential relative to that of the cathode. They strike the dynode and emit secondary electrons in a multiplied number. These are further accelerated to the third dynode as so on. The finally largely multiplied electrons are collected at the anodes and supplied to the preamplifier for electronic counting. The typical diagram of photomultiplier tube is shown in the fig 3.4.

The input pulse at the anode may be more than a million times as great as the current originally emitted from the cathode.

In Nuclear radiation detector, the pulse height is of the order of micro volt. The pulses emitted by the detector being too small to operate the scalar, it needs amplification before getting detected. without first being amplified. The type PA 521 is a solid state pulse amplifier specially designed by ECIL.

The amplifiers are required to feature excellent non overload characteristics, a high gain, low equivalent input noise and flexibility of pulse shaping. The type PA521 is ideally suited for
use with nuclear counting systems such as the gas flow proportional counting, Scintillation counting and liquid Scintillation counting.

The instrument features compact modular construction and its power requirements are met standard instrumentation bin and power supply LV4755 ECIL, Its further Specifications are the following.

Input Polarity : Positive or Negative
Input Impedance : 93 Ohms.
Total gain : Typical 1800 $\pm$ 10% with 1 micro second differentiation and integration
Gain Adjustment : Controlled by three gain controls. Accuracy: $\pm$ 10%
 a) Input attenuator : Attenuator factors 1, 2, 5, 10, 20 and 50
 b) Course gain : 0.1, 0.3 and 1.
 c) Fine Gain : About 1 to 3.
Pulse shaping : Differentiating and integration RC time constants variable from 0.1 micro second to 5 micro seconds in sequence of 0.1, 0.2, 0.5, 1, 2, 5 with a provision of switching integration out.

Amplifier Rise time : Better than 100 nano seconds with no integration and 1, 0.1 micro second differentiation constant.

Output : 0 to 6V Positive, 12 V maximum unipolar.
Output Impedance: Approximately 93 Ohms.
Amplifier Noise: Equivalent input noise 10 micro volts r.m.s. typical at maximum gain and 1 micro second integration and differentiation. Installed in a modular instrumentation bin. The power requirement is
+24 V at 45 mA +12 V at 20 mA
-24 V at 40 mA -12 V at 5 mA

3.4 Multichannel analyzer:

Multichannel analyzers are sophisticated devices which sort out incoming pulses according to pulse height and keep count at each height in a multichannel memory. The contents of each channel can then be displayed on a screen or printed out to give a pulse height spectrum.

Multichannel analyzers are commonly used over a single channel analyzer, which uses a microprocessor technology together with high speed, high density, smaller size, easily computable semiconductor memories. The acquisition on input data signal (Digital) from pure amplifier, attenuator of discriminator are done with the help of comparators shift registrars, counter and random access memory displaying no.of counts on channels. Now generally 4K and 8K, (1 k=1024) multichannel analyzers are available in the market. The interface of output ports of control
units are led to cathode ray tube in order to display output in terms of channel versus counts.

We used MCA with computer interfaced is supplied by Nucleonix Systems PVT. LTD. It consists of three parts which,

3.4.1. Nuclear ADC (Type AD 560)
The amplified and shaped signal from the linear amplifier is connected to the ADC. The ADC accepts the analog signal and converts it into a binary address which is proportional to the peak amplitude of the input signal.

3.4.2. 4K multichannel Buffer Card with Emulation Software.
At the end of conversion the address is transferred to a multichannel Buffer card, which is computer interfaced. This multichannel card primarily functions as an acquisition interface to the computer and contains a memory sub-system within it.

3.4.3. Personal Computer with keyboard, Display Color Monitor and printer.
The data acquired is transferred to PC.
The specifications given by the Nucleonix are as follows,
1. ADC (AD560).
Amplitude : 0 to 10 V
Rise Time : 0 to 10 micro second.
Duration : 1 micro second.
Impedance: 1 k Ohm
Coupling: DC, AC
Restorer: Passive
Internal
Delay: None
Range: 4K (with 1K, 2K, 3K, 4K Choice)
MCA: With 0 to 4094 Channels.

Many MCA also allow a selection of the number of channels into which spectrum is to be fitted. The selected spectrum are smoothed to avoid the statistical variation raised from random nature of radiations.

3.4.5 Resolution of peak

Resolution is a ratio of full width half maximum counts to energy of peak.

For MCA channels.

\[ R = \frac{\text{FWHM}}{\text{Position of peak}}. \]

for spectrum measurements which only expanded portions are desired.

Calculated Resolution of MCA = 9.8 % for Cs\textsuperscript{137}

3.4.6 Calibration of Gamma ray energy.

In general sources of the same type of radiation as is to be
measured in the experiment with energies as close as possible to the desired energy range, which avoid any possible differences in detector response for different particle types or energy coverage, an alternative method is to measure the energy distribution of electron coming from the compton scattering of $\gamma$ rays in the detector and secondary X-rays. The calibration line is as shown in the fig 3.5 and is linear of the form.

\[
\text{pulse height} = a + b \text{ channel}
\]

where $a$ is the zero offset and $b$ is related to the gain. zero offset control shift the spectra i.e. calibration line passing through Zero (origin). Analog to digital converter has linearity 0.1%. The non linearity of the detector calculated by adding the non linearity quadratically.

\[
\delta^2 \text{(tot)} = \delta^2 \text{(MCA)} + \delta^2 \text{(detector)} + \delta^2 \text{(amp)} + \ldots.
\]

the calibration line may be fit with a quadratic form.

\[
E = a \text{ (channel)}^2 + b \text{ (channel)} + c.
\]
### Table 3.1 Properties of common Inorganic Scintillator.

<table>
<thead>
<tr>
<th>Material</th>
<th>Specific Gravity</th>
<th>Wavelength of Maximum Emission (nm)</th>
<th>Index of Refraction at $\lambda_{\text{max}}$</th>
<th>Principal Decay Constant (μs)</th>
<th>Pulse Rise Time (μs)</th>
<th>Total Light Yield in Photons/MeV</th>
<th>Absolute Scintillation Efficiency for Fast Electrons</th>
<th>Relative $\gamma$-Ray Pulse Height with Bialkali PM Tube</th>
</tr>
</thead>
<tbody>
<tr>
<td>NaI(Tl)</td>
<td>3.67</td>
<td>415</td>
<td>1.85</td>
<td>0.23</td>
<td>0.5</td>
<td>38000</td>
<td>11.3%</td>
<td>1.00</td>
</tr>
<tr>
<td>CsI(Tl)</td>
<td>4.51</td>
<td>540</td>
<td>1.80</td>
<td>1.0</td>
<td>4</td>
<td>52000</td>
<td>11.9</td>
<td>0.49</td>
</tr>
<tr>
<td>CsI(Na)</td>
<td>4.61</td>
<td>420</td>
<td>1.84</td>
<td>0.63</td>
<td>4</td>
<td>39000</td>
<td>11.4</td>
<td>1.11</td>
</tr>
<tr>
<td>LiF(Eu)</td>
<td>4.08</td>
<td>470</td>
<td>1.96</td>
<td>1.4</td>
<td>—</td>
<td>11000</td>
<td>2.8</td>
<td>0.23</td>
</tr>
<tr>
<td>BGO</td>
<td>7.13</td>
<td>505</td>
<td>2.15</td>
<td>0.30</td>
<td>0.8</td>
<td>82000</td>
<td>2.1</td>
<td>0.13</td>
</tr>
<tr>
<td>BaF$_2$, slow component</td>
<td>4.89</td>
<td>310</td>
<td>1.49</td>
<td>0.62</td>
<td>3</td>
<td>11000</td>
<td>4.5</td>
<td>0.13</td>
</tr>
<tr>
<td>BaF$_2$, fast component</td>
<td>4.89</td>
<td>220</td>
<td>—</td>
<td>0.0006</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>0.03*</td>
</tr>
<tr>
<td>ZnS(Ag) (polycrystalline)</td>
<td>4.09</td>
<td>450</td>
<td>2.36</td>
<td>0.2</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>1.30*</td>
</tr>
<tr>
<td>CaF$_2$ (Eu)</td>
<td>3.19</td>
<td>435</td>
<td>1.44</td>
<td>0.9</td>
<td>4</td>
<td>24000</td>
<td>6.7</td>
<td>0.78</td>
</tr>
<tr>
<td>CsF</td>
<td>4.11</td>
<td>390</td>
<td>1.48</td>
<td>0.004</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>0.05</td>
</tr>
<tr>
<td>Li glass$^5$</td>
<td>2.5</td>
<td>395</td>
<td>1.35</td>
<td>0.075</td>
<td>—</td>
<td>—</td>
<td>1.5</td>
<td>0.10</td>
</tr>
</tbody>
</table>

For comparison, a typical organic (plastic) scintillator:
NE 102A

<table>
<thead>
<tr>
<th>Specific Gravity</th>
<th>Wavelength of Maximum Emission (nm)</th>
<th>Index of Refraction at $\lambda_{\text{max}}$</th>
<th>Principal Decay Constant (μs)</th>
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<th>Relative $\gamma$-Ray Pulse Height with Bialkali PM Tube</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.03</td>
<td>423</td>
<td>1.58</td>
<td>0.002</td>
<td>10000</td>
<td>3.0</td>
<td>0.25</td>
<td></td>
</tr>
</tbody>
</table>

$^*_{\text{Using UV-sensitive PM tube.}}$

$^5_{\text{Properties vary with exact formulation. Also see Table 15-1.}}$

$^6_{\text{For alpha particles.}}$

Source: Data derived primarily from Refs. 56–58.
Fig. 3.1 The light output of NaI(Tl) for totally absorbed electrons expressed as total light per unit initial energy.
Fig. 3.2 Band Structure of crystal.
Fig. 3.4 Photomultiplier tube.
Fig. 3.3 Schematic diagram of a Scintillation detector.
Fig. 3.5 Calibration of peak as observed on MCA.