CHAPTER 4

EXPERIMENTAL INSTRUMENTATION

4.1 INTRODUCTION

The detection of most energetic form of electromagnetic radiation i.e. gamma radiation becomes the foremost important task to be done in certain fields, where people are likely to encounter them. The radiation detection task has numerous practical applications covering all spheres of life such as in understanding universe, nuclear medicine, nuclear reactor control, geological surveying. The basic requirements for the experimental study of gamma ray interactions in any material are:

1. The availability of gamma radioactive sources of suitable energy, half-life and strength.
2. A suitable detector and associated electronic tools.
3. The target material in which the gamma ray interactions are to be studied.

The detailed description of first two basic requirements i.e. of radioactive sources and the detector along with electronic equipments required for recording the data of present studies is given in this chapter.

4.2 RADIOACTIVE SOURCES

The primary requirement for the study of gamma interactions in any material is its radioactive source. To study the interaction of gamma radiation in different types of flyash shielding concretes, three radioactive sources, namely $^{241}$Am, $^{137}$Cs and $^{60}$Co have been used. Their photon energies, half-lives and approximate strengths are given in Table 4.1. These gamma ray sources are procured from Board of Radiation and Isotope Technology, Navi Mumbai, India.

As is clear from Table 4.1, all sources have sufficient half-life. As the strength of the sources remains same during the period of experimentation and their decaying possibility can be ignored. Also there is no problem of detection of gamma rays as the sources used are of suitable strength. The decay schemes of these isotopes are given in Fig. 4.1.
Table 4.1 Detail of used radioactive sources

<table>
<thead>
<tr>
<th>Radioactive source</th>
<th>Energy (keV)</th>
<th>Half-life (years)</th>
<th>Strength (mCi)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$^{241}$Am $\gamma$-rays</td>
<td>59.54</td>
<td>432.2</td>
<td>100</td>
</tr>
<tr>
<td>X-rays</td>
<td>32</td>
<td></td>
<td></td>
</tr>
<tr>
<td>$^{137}$Cs $\gamma$-rays</td>
<td>662</td>
<td>30</td>
<td>100</td>
</tr>
<tr>
<td>X-rays</td>
<td>32</td>
<td></td>
<td></td>
</tr>
<tr>
<td>$^{60}$Co $\gamma$-rays</td>
<td>(1173 + 1332)</td>
<td>5.2</td>
<td>5</td>
</tr>
</tbody>
</table>

4.3 DETECTOR AND ASSOCIATED ELECTRONICS

The important aspects of the detector used in the present studies and related electronic accessories i.e. preamplifier, amplifier, power supply and computerized multi channel analyzer (MCA) are discussed in the following sections.

4.3.1 Scintillation detector

The gamma radiation when interact with the material results in deposition of energy in the medium traversed by the radiation. When gamma radiation falls on detector, they deposit their energy in the crystal of detector. The energy deposited in crystal is transformed into voltage pulse, multiplied by amplifiers and then analyzed. The pulse height is proportional to the energy of incoming radiation. From the deposited energy, intensity of incoming radiation can be measured. The various stages of radiation detection in the scintillation counter can be described as following:
Fig. 4.1. Decay scheme of radioactive sources.
the absorption of radiation in detector crystal resulting in excitation and ionization.
the conversion of deposited energy into scintillations.
the conversion of scintillations to photoelectrons.
the multiplication of electrons in photo multiplier tube.
the analysis of voltage pulses from photo multiplier tube.

In the present study, NaI(Tl) detector is used as it meets the requirements necessary for the experimental measurements. The scintillation detector having a NaI crystal doped with thallium [NaI(Tl)] as activation impurities is one of the best instruments for counting gamma rays. The most prominent property of NaI(Tl) is its excellent light yield. The high atomic number of iodine in NaI results in high efficiency for gamma ray detection. Iodine, the main detecting material is in gaseous state, so it cannot be grown into a crystal. It is taken in the form NaI. The photons emitted by de-excitation of electrons are in ultra violet region. The detection of light becomes difficult. This problem is solved by using thallium as an activator. Thallium added to it brings this wavelength into visible region (410 nm). The main advantages of NaI(Tl) detector are:

- it can be grown into large size.
- it is transparent to its own emitted scintillations.
- it has highest value of conversion efficiency.
- it has a lowest fluorescence decay time (230 ns) to get faster response.
- it is very suitable for detection of gamma rays because its high atomic number and density gives rise to large value of cross sections for the different interaction processes.

The best resolution achievable for the detector used in study is about 7.5% for the 662 keV gamma ray from $^{137}$Cs for a 3 inch diameter by 3 inch long NaI(Tl) crystal (CANBERRA, model: 802). As the crystal is hygroscopic in nature, therefore needs to be housed in an air-tight enclosure. Therefore it is hermetically sealed in an aluminum can. The 3”×3” NaI(Tl) scintillation detector is a hermetically sealed assembly which includes a NaI(Tl) crystal, a photo multiplier tube (PMT), a PMT base with a pre-amplifier, an internal magnetic/light shield, an aluminum housing and a 14-pin connector. To avoid any loss of scintillation due to absorption by aluminum can, the inside of aluminum can is coated with highly reflecting material like magnesium oxide. To prevent stray visible light from falling on the scintillator, the scintillation head is wrapped with black tape.
4.3.2 Photo multiplier tube

The light output from the scintillation crystal is quantified and converted into an electrical signal by a photo multiplier tube (PMT). The detector is plugged directly into the model 2007 P tube base.

A photo multiplier tube, useful for light detection of very weak signals, is a photo emissive device in which the absorption of a photon results in the emission of electrons. The detector works by amplifying the electrons generated by a photocathode exposed to a photon flux from known source. Photo multipliers acquire light through a glass or quartz window that covers a photosensitive surface, called a photocathode, which then releases electrons. The effects of these emitted electrons are amplified by use of the principle of secondary emission. The electrons emitted from the photocathode are focused onto the first of a series of electron multiplier plates called dynodes. At each dynode, the incoming electrons cause additional electrons to be emitted. A cascade effect occurs, and the incident photon has been amplified or detected. At the end of the dynode chain is an anode or collection electrode. The resultant output signal at the anode is in the form of a measurable pulse for each photon detected at the photocathode and is passed to the processing electronics. The pulse carries information about the energy of the original incident radiation on the scintillator. Thus both intensity and energy of the radiation can be measured.

The photo multiplier is operated by progressively increasing positive potential to the dynodes using potential dividing arrangements. The multiplication factor, the ratio of the numbers of secondary and primary electrons, depends upon the potential difference between each consecutive pair of dynodes.

4.3.3 Pre-amplifier

The primary function of a preamplifier is to extract the signal from the detector without significantly degrading the intrinsic signal to noise ratio. Therefore, the preamplifier is located as close as possible to the detector and the input circuits are designed to match the characteristics of the detector. It provides impedance matching and couples the low capacitance input to a high capacitance output. The weak detector pulse enters the preamplifier which has two main functions: pulse shaping and amplitude gain. The charge created within the detector
by interaction with the gamma radiation is collected by the pre-amplifier. Model 2007 P tube including pre-amplifier was used in the present investigations.

4.3.4 Linear amplifier

The output from pre-amplifier is fed to linear amplifier. Its main function is the amplification of signal to the detectable range and the other function is to shape the output signal for proper spectrometer performance with minimum noise and non-linearity. The main reasons for pulse shaping are to decrease the response time required for each pulse, to increase the signal to noise ratio and to make amplification independent of variation in input pulse rise time. In the present investigations, 572 A amplifier has been used.

4.3.5 Power supply

A regulated voltage supply module 4006 mini bin and power supply (ORTEC, U.S.A.) was used in the present investigations. The bin has an attached power supply to power all the constituent units of the system. This supply bin is capable of providing continuously regulated voltage in the range 0 to 3000 V.

4.3.6 Multi channel analyzer

The amplified pulse is then fed to the multi channel analyzer (MCA). This signal contains the different pulses representing various gamma ray energies. These pulses are then sorted out according to their pulse height by the pulse height analyzer i.e. multi channel analyzer. The multi channel analyzer can record the entire spectrum in a single operation. These numbers are displayed in a graphical form whose horizontal axis represents height of the pulse or energy of radiation and vertical axis represents number of pulses or intensity of radiation.

The key functioning part of multi channel analyzer is an analog-to-digital converter (ADC), which converts the analog signal into a digital number. This part converts each pulse amplitude (energy) into an equivalent time interval. The digital output given by the number of the clock pulses recorded in scalar, are provided by a built-in periodic oscillator. The digital information given by the number of clock pulses is directly proportional to the input pulse amplitude. This digital information is stored in a specific channel in the memory of the analyzer.
In the present work, the pulse height spectra were recorded with a computerized 2K MCA plug-in-card supplied by EG & G ORTEC plugged in a personal computer combined with Maestro II software (version 6.01). The Maestro II software acts as the link between operator, spectrum and hardware.

The spectrometer was calibrated time to time using the calibration radioactive sources of $^{133}$Ba, $^{22}$Na, $^{137}$Cs and $^{60}$Co for each experimental setup. The response of the spectrometer was found to be linear at every time.