Chapter 2

Experimental set up and the method for measurement

2.1 Introduction

The measurements of bremsstrahlung spectral photon energy distributions produced by continuous beta particles in thick targets, particularly at low and medium photon energy region of 5-30 keV requires a high resolution Si (Li) detector. The earlier measurements (mentioned in section 1.8, Chapter 1) of bremsstrahlung were made with the ionization chamber, proportional counters, and G. M. counters. Later, various researchers (mentioned in section 1.8.2 and 1.8.3, Chapter 1) have used the NaI (Tl) detectors having high efficiency and more effective to make the measurements of bremsstrahlung at high energies, particularly above photon energy of 30 keV. The present measurements were taken to obtain the total bremsstrahlung spectral photon distribution, produced by the continuous beta particles in thick metallic targets, in the photon energy regions of 5-30 keV. So in view of range of photon energy region a high efficiency and high resolution Si (Li) detector X-PIPS have been used in the present measurements.

X-PIPS Si (Li) detector is a compact system with a PIPS (Passivated Implanted Planar Silicon) detector. X-PIPS Si (Li) detector (Canberra make) is sensitive to ionizing radiation, particularly X-rays and low energy gamma rays. The detector is more suitable for the study of bremsstrahlung spectra owing to its high efficiency (97 % to 15 %) and high resolution (≤ 190 eV at 5.9 keV photon energy), in the photon energy from 5 keV to 30 keV. A high resolution X-PIPS (Canberra make) Si (Li) detector has been shielded with a Lead bricks and is further connected to power supply (ORTEC make), spectroscopy amplifier (ORTEC make) and multichannel analyzer (ORTEC make) with Maestro 32 software, was used to measure the total bremsstrahlung spectral photon distributions in metallic targets produced by beta particles of
different beta emitters, having different end point energies, in the photon energy region of 5 -30 keV. The block diagram of electronic set up of X-PIPS Si (Li) detector is shown in the Fig. 2.11. The X-PIPS Si (Li) detector has a thermo-electric cooler (TEC), which act as a heat pump and is cooling down the X-PIPS detector. The thickness of X-PIPS Si (Li) detector chip is \(8\text{mm}^2\times500\mu\text{m}\). This detector has a Silicon chip of thickness 500\(\mu\text{m}\), Beryllium (Be) window of thickness 25\(\mu\text{m}\), Preamplifier, HV bias supply, Peltier cooler and Temperature controller system. A collimator of width 1.1 mm is embedded in the detector.

![Block diagram of electronic set up of X-PIPS Si (Li) detector](image)

**Figure 2.11** Block diagram of electronic set up of X-PIPS Si (Li) detector

This chapter explains the method of measurements of the total bremsstrahlung spectra, produced by the complete absorption of beta particles in different thick target element, and describes the geometrical set up used for the measurement of bremsstrahlung spectra. The various detectors parameters such as; energy resolution, photo-fraction and detector efficiency needed for the exact response function of the detector has been discussed in detail. The various corrections
factors used for converting the measured bremsstrahlung spectra into the true bremsstrahlung spectra have also been discussed.

2.2 **Experimental set up for measurement of total bremsstrahlung spectra**

The experimental set up used for the measurement of the bremsstrahlung spectra produced by the absorption of continuous beta particles in thick metallic targets is shown in Fig. 2.21. X-PIPS Si (Li) detector was used to measure the total bremsstrahlung spectral photon distributions in thick metallic targets of Al, Ti, Cu, Sn and Pb, produced by beta particles of $^{147}$Pm, $^{45}$Ca, $^{90}$Sr and $^{204}$Tl beta emitters, in the photon energy region of 5 -30 keV. The rectangular lead bricks of thickness of 4 cm lined with aluminum foil were used to shield the detector and preventing the scattered photons from reaching the detector and further minimizing the background to a low level.

The Perspex stand consisting of the source holder in which the beta radioactive source, under study was placed at a distance of 1.6 cm from the X-PIPS detector. In order to take into account the slowing down and angular scattering of the electrons and intrinsic angle of emission of bremsstrahlung, targets having large area and thicknesses greater than the range of the beta particles were exposed to beta particles, out of which a small area was visible to the detector for total bremsstrahlung measurement.
Figure 2.21  Experimental setup

4. X-PIPS Si(Li) detector;  5. Be window;  6. Collimator;  
7. Si(Li) chip;  8. Shielding Lead bricks;  9. Standard working axis;

A: the position of the target on the Perspex beta stopper;
B: the position of the target below the Perspex beta stopper;
2.3 Method for measurement of total bremsstrahlung spectra

In order to obtain the correct information about the total bremsstrahlung spectra produced by the complete absorption of the continuous beta particles in thick metallic targets, it is important to eliminate the contribution of internal bremsstrahlung (IB), bremsstrahlung produced from the source, gamma rays and the room background. Perspex beta stopper technique has been employed to eliminate the contributions of IB, bremsstrahlung produced from the source, gamma rays and the room background, to get correct information about the BS spectra produced in a particular target material.

A gamma ray source of $^{133}$Ba and the emitted X-rays peaks of Ti, Cu, Mo and Sn as given in Table 2.1, were used for calibration of the detector.

<table>
<thead>
<tr>
<th>Target Elements</th>
<th>$K_{\alpha,\beta}$ X-ray energy (keV)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Titanium (Ti)</td>
<td>04.55</td>
</tr>
<tr>
<td>Copper (Cu)</td>
<td>08.14</td>
</tr>
<tr>
<td>Molybdenum (Mo)</td>
<td>17.78</td>
</tr>
<tr>
<td>Tin (Sn)</td>
<td>25.77</td>
</tr>
</tbody>
</table>

In this method the targets of thickness more than the range (R) of the continuous beta particles of a particular beta emitter, were used in the present measurements. Target materials were procured from the Sigma – Aldrich with a purity of 99.999 %. The beta source was placed on a Perspex stand at a distance of 1.6 cm in collimation with the face of the detector as shown in the Fig.
2.21. After calibrating the spectrometer, the two sets of measurements were taken over a long interval of time each to improve the statistics of data. In the first measurement, the target was placed on the Perspex beta stopper at position A [Fig. 2.21]. This measurement included the contribution of BS (target), IB, BS generated in the source material and room background, attenuated in the target and the Perspex beta stopper, having thickness more than the range of beta emitter. For the second measurement, the target was placed below the Perspex beta stopper at position B, so that the beta particle did not reach it. This measurement recorded the contribution of IB, BS generated in the source material, BS generated in the Perspex stopper and room background. The Perspex beta stopper and the target below it further attenuated these contributions. The contribution of BS produced in the first few layers of the Perspex beta stopper was very small as these contributions were attenuated by the rest of its thickness and was further attenuated by the thick target below it. The difference of the above two measurements gives the information about the BS produced in target elements only.

The statistical accuracy of the data was better than 1% for all the targets in the photon energy region of 5 – 30 keV. Reproducibility of the data and any peak shift due to electronic set up were checked by taking the intermediate measurements. These measurements were taken with the different beta sources ($^{147}$Pm, $^{45}$Ca, $^{90}$Sr and $^{204}$Tl) and in the different thick metallic targets (Al, Ti, Cu, Sn and Pb), by using a geometrical set up given in Fig. (2.21). The detail about the beta emitters used in the present measurement is given in Table 2.2
Table 2.2 Details of the beta emitters used for the measurement

<table>
<thead>
<tr>
<th>Beta Source under study</th>
<th>End Point energy (keV)</th>
<th>Half Life</th>
<th>Activity</th>
<th>Range* (mg/cm²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$^{147}$Pm</td>
<td>225</td>
<td>2.6 yrs</td>
<td>0.1 mCi</td>
<td>50.5</td>
</tr>
<tr>
<td>$^{45}$Ca</td>
<td>257</td>
<td>164 days</td>
<td>0.5 mCi</td>
<td>62.3</td>
</tr>
<tr>
<td>$^{90}$Sr</td>
<td>546</td>
<td>28 yrs</td>
<td>5 μCi</td>
<td>185.3</td>
</tr>
<tr>
<td>$^{203}$Tl</td>
<td>765</td>
<td>3.77 yrs</td>
<td>500 μCi</td>
<td>291.6</td>
</tr>
</tbody>
</table>

*Range (R) of beta particles coming from a beta emitter in a target material is given as, \( R = 412E^{1.265-0.0954\ln E} \), here ‘E’ is the end point energy of beta emitter in MeV. [Evans (1955)].

2.4 Determination of detector parameters

A gamma ray source of $^{133}$Ba and the emitted K X-rays of Ti, Cu, Fe, Mo and Sn materials were used for determining the following parameters of the X-PIPS Si (Li) detector;

(i) Energy resolution

(ii) Photo-fraction

(iii) Detector efficiency

In order to determine the various detector parameters the following procedure has been used.
2.4.1 Energy resolution

The percentage energy resolution \( R \) of X-PIPS Si (Li) detector is defined as

\[
R = \frac{\text{Full width at half maximum}}{\text{Pulse height}} \times 100
\]

The energy resolution of X-PIPS Si (Li) detector is found to be \( \leq 190 \text{ eV} \) at photon energy 5.9 keV.

2.4.2 Photo-fraction

The photo-fraction \( f(k) \) is defined as the ratio of the number of counts under the full energy peak to the total number of counts under the total height spectrum (corrected for X-rays and backscattered peaks). The values of photo-fraction \( f(k) \) of X-PIPS detector were determined by using the \(^{133}\text{Ba}\) source and K X-rays peaks of Ti, Cu, Mo and Sn target materials. The plot of photo-fraction \( f(k) \) values at different photon energies are given in Fig 2.41.

2.4.3 Detector efficiency

The geometrical full energy peak detector efficiency of X-PIPS Si (Li) detector is given by the product of the photo-fraction values \( f(k) \) and the intrinsic efficiency of the detector at particular photon energy. The intrinsic efficiency \( I(k) \) of the X-PIPS Si (Li) detectors is varying from 97 % to 15 % at 5 keV and 30 keV photon energies respectively. The plot of intrinsic efficiency of X-PIPS Si (Li) detector is shown in Fig. 2.42. The geometrical full energy detector efficiency of X-PIPS detector was determined by taking the product of \( I(k) \times f(k) \) at particular photon energy. The plot of geometrical full energy peak detector efficiency of X-PIPS Si (Li) detector versus photon energy is shown in Fig. 2.43.
Figure 2.4  
Variation of Photo-fraction $f(k)$ versus photon energy $(k)$ of X-PIPS Si (Li) detector
Figure 2.42  Percentage Intrinsic efficiency $I(k)$ of X-PIPS Si (Li) detector versus photon energy (k)
Figure 2.43 Percentage Geometrical full energy peak detector efficiency of X-PIPS Si (Li) detector versus photon energy (k)
2.5 Corrections for experimentally measured total bremsstrahlung spectrum

The experimentally measured total bremsstrahlung spectrum was converted into true spectrum by applying the following corrections;

(a) Correction due to the self absorption of BS photons in the target element and the Perspex beta stopper

(b) Correction due to electron backscattering

(c) Correction due to geometrical full energy peak detector efficiency

The procedure used for applying the various corrections for converting in the experimentally measured spectrum into true spectrum is given below.

2.5.1 Correction due to self absorption of photons

The experimentally measured BS spectrum was corrected by applying the correction due to the absorption of BS photons in the target material and in the Perspex beta stopper. These corrections were applied by using the mass attenuation coefficient values for different target element at different photon energy, tabulated by Chantler et al. (2008). These corrections play an important role to describe the shape of bremsstrahlung spectral photon energy distributions at lower photon energy regions. This correction is applied by using the following relation, [Beer’s Lambert Law]

\[ I = I_o \exp (-\mu x) \]

\[ \Rightarrow I_o = I \exp (\mu x) \]  \hspace{1cm} (2.5.1)

Where, ‘I_o’ is the bremsstrahlung intensity at x=0.

‘I’ is the measured bremsstrahlung intensity with target thickness ‘x’.

The application of this correction makes the measurements target thickness independent.
2.5.2 Correction due to electron backscattering

The electron backscattering correction to the BS spectrum is important at lower part of the photon energy spectrum. This correction has been applied by using the relation for the electron backscattering factor \( R \) given by Semaan and Quarles (2001)

\[
R = \frac{1 - \eta(W_e, Z)}{1 - \eta(W_e, Z) \frac{k^2}{W_e^2}}
\]

The details of this relation are given in Chapter 1 (section 1.6). The value of electron backscattering factor is almost independent of the incident electron energy and slowly dependent on the atomic number of the target element with increasing incident electron energy.

2.5.3 Correction due to geometrical full energy peak detector efficiency

The experimentally measured BS spectrum has been converted into true spectrum, by applying the various corrections and then dividing them by the geometrical full energy peak detector efficiency values of the detector. These values were obtained by taking the product of the values of intrinsic efficiency of the detector and photo-fraction values at particular photon energy. The corrected BS spectrum was then reduced to the number of photons of energy \( k \) per unit \( m_o c^2 \) by dividing the data by the common channel width (in \( m_o c^2 \) units). Finally, the corrected experimental bremsstrahlung spectra were converted into the number of photons of energy \( k \) per unit \( m_o c^2 \) per unit of total photon yield by dividing them by the values of the total photon yields in the target materials. This method makes the results independent of source strength and removes the uncertainties associated with its measurements and gives better
accuracy over the normalization procedure used by various workers as already explained in section 1.8, Chapter 1.

These measurements were taken, to study the total bremsstrahlung (BS) and ordinary bremsstrahlung (OB) spectral photon distribution in thick metallic targets of Al, Cu, Sn and Pb, produced by soft beta particles of $^{147}$Pm and $^{45}$Ca, and in thick targets of Al, Ti, Sn and Pb, produced by complete absorption of continuous beta particles of medium energy range beta emitters $^{90}$Sr and $^{204}$Tl, in the photon energy region of 5-30 keV. In the photon energy region of 5-10 keV, the number of photons emitted is much larger than the number of photons in the energy region of 10 – 30 keV. Therefore, the study of OB and BS spectra in thick targets, produced by these beta emitters has been reported separately into two energy region i.e. of 5-10 keV and 10-30 keV in Chapter 3 and 4 to explain the results in a systematic manner.