CHAPTER 3

EXPERIMENTAL SET-UP
FOR NON-DESTRUCTIVE TESTING

In the previous chapters, types of NDT techniques, a brief survey of X-ray/gamma ray based non-destructive techniques and detailed description for construction of experimental response function of NaI(Tl) detector has been described. In the present chapter principle for tomographic measurements, experimental arrangement, electronic set-up, calibration and efficiency of detector and evaluation of self absorption correction factor for transmission and scattering geometry are discussed.

3.1 Principle of tomographic scanning for non-destructive inspection

The Compton (incoherent) scattering of gamma photons can ascertain quantitative information of electron density of the target material. The process is of significant importance if changes in material composition are to be assessed non-invasively, such as in medical diagnostics (bone and lung densitometry, bone mineral content in osteoporosis), therapy (dose distribution calculations for radiotherapy treatment planning) and in industry (defect, inclusion, corrosion, impurity, fault detection etc.).

The principle of present tomographic scanning set-up relies on the fact that Compton scattering cross-section is proportional to the electron density of the target. Fig. 3.1 shows the scheme of components required for such a measurement. A radioactive source, a photon detector and two collimators (for both the source and scattered beams) are used in order to define the volume of interest. Most reported techniques, in literature, define the area of intersection of collimated source beam and detector’s field of view as volume of
Fig. 3.1: System utilizing Compton scattering technique for inspecting volume of interest.

inspection/voxel/cell/sensitive volume. Scattering inside measurement volume $V$ generates photons in all directions. In a more realistic form, the beams of incident and scattered photons suffer attenuation (more significant for low energy and low activity radioactive sources) in traveling from the source through the sample to the scattering volume and, hence to the detector. Incorporating these attenuations, the number of singly scattered photons detected at the detector [27, 52] is given as

$$N(E') = I_o(E) \cdot t \cdot \varepsilon \cdot \exp(-\int_0^l \mu_1(l, E) dl) \cdot \frac{d\sigma_{KN}}{d\Omega} \cdot S(q, Z) \cdot n_p \cdot \exp(-\int_0^l \mu_2(l, E') dl) \cdot dV \cdot d\Omega$$

(3.1)

Where, $I_o(E)$ is incident photon flux with energy $E$. $t$ is time in seconds during a counting period. $\varepsilon$ is detector’s photo peak counting efficiency at the scattered photon energy ($E'$). $\frac{d\sigma_{KN}}{d\Omega}$ is Klein–Nishina differential cross-section at
energy $E$ for a free electron. $\mu_1$ and $\mu_2$ are linear attenuation factors for attenuation of the primary and secondary photons within the sample. $l_1$ and $l_2$ are lengths of the paths of the photons in the sample from the source to the scattering centre and back to the detector respectively. $S(q,Z)$ is the incoherent scattering function. $n_e$ is the electron density of material. The quantity $d\Omega$ is element of solid angle in direction of the detector. The parameter $dV$ is differential volume considered for the radiation and its interaction with the matter.

The use of $n_e$ in the preceding equation means that every atomic electron is involved in Compton process, and the value of $n_e$ is given by

$$n_e = \rho N_A Z / A$$  \hspace{1cm} (3.2)

Where $\rho$ is the density of the sample, $N_A$ is Avogadro number, and $Z/A$ is the ratio of atomic number to atomic mass of target material under investigation. For a particular radiation source, geometry and collimation, it appears that the number $N(E')$ of detected photons is expected to be proportional to the density $\rho$ of the material. Moreover, as already mentioned in previous chapter, conversion of observed pulse-height distribution to true photon energy spectrum is further requirement in gamma spectroscopy. This can be done with the help of response function of detector that results in enhancement of observed intensity measurements.

In case of scattering geometry, signal depends upon the composition of the volume element defined by the overlap of the incident and scattered collimated beams rather than the transmission ray sum integrated along one direction (in case of transmission geometry). Moreover, the radioactive source and detector are positioned at opposite sides of each other (with respect to the sample to be investigated) in case of transmission geometry.
3.2 Experimental arrangement of present measurements

The experimental arrangement used for the present study consists of the following parts:

(i) Radioactive sources and their housing
(ii) NaI(Tl) scintillation detector assembly
(iii) High purity germanium (HPGe) semiconductor detector
(iv) Mechanical system for step wise motion of samples (objects)

The present measurements of tomographic non-destructive testing, for various samples, are performed with two different radioactive sources, namely, $^{137}\text{Cs}$ (222 GBq and 220 mBq) and $^{241}\text{Am}$ (7.4 GBq) procured from Radio Chemical Centre, Amersham, U.K. The decay schemes for the two sources are shown in Fig. 3.2 (a) and 3.2 (b). Owing to significant difference in respective strength of radioactive sources used in the present study, two different source housings with suitable collimation arrangements are used for non-destructive testing.

![Decay scheme of $^{137}\text{Cs}$ radioactive source.](image)

Fig. 3.2 (a): Decay scheme of $^{137}\text{Cs}$ radioactive source.
3.2.1 Radioactive sources and their housing

The experimental set-up, in scattering geometry, for the study of industrial samples is shown in Fig. 3.3. The radioactive source $^{137}$Cs, emitting gamma rays...
of energy 662 keV, is in the form of pellets of CsCl sealed in an aluminium can of
diameter 27 mm and length 80 mm. The thickness of this aluminium can is
sufficient to absorb all the β-particles and 32 keV K X-rays emitted due to
internal conversion process. The source is placed in the cavity of a rectangular
lead container of dimensions 200 mm x 160 mm x 160 mm especially prepared
to enclose the source. Keeping in mind the biological effects of radiation, a
cylindrical beam collimator consisting of a brass pipe (80 mm in length and 28
mm in diameter) and having aluminium windows on both ends is fitted in a
rectangular block of lead. This collimator could be filled with a column of mercury
and is used to close the beam incident on the target (sample) when desired. The
fine beam collimator has an opening of 8 mm diameter in a cubic block of lead of
each side 80 mm. The opening is lined with aluminium from inner side and
provides a narrow beam of gamma rays. The source housing, cylindrical beam
collimator and fine beam collimator are placed adjacent to each other so that the
three are coaxial. This arrangement is further shielded by additional lead bricks.
The complete source assembly, rectangular in shape and shown in marked
block of Fig. 3.3 having dimensions 480 mm x 320 mm x 320 mm with a
cylindrical opening of 8 mm is placed at a height of 380 mm on an aluminium
table fixed to one side of the scattering table to avoid scattering of radiation from
the scattering table. This table is placed in the centre of the room to minimize the
scattering from the walls of the room. When the cylindrical beam collimator is
filled with a column of mercury, the background near the assembly comes to
natural background level, thus confirming the proper shielding of the radioactive
source, which is one of the essential requirements in nuclear spectroscopy. The
source-sample assembly is aligned in such a way that the incident photon beam

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is confined to sample only. The shielding arrangement for 220 mBq $^{137}$Cs radioactive source, employed for measurements in transmission geometry, is similar to that of $^{241}$Am described in next paragraph.

The radioactive source $^{241}$Am is placed at the end of a cylindrical cavity of length 25 mm and diameter 23 mm fabricated in a lead shielding of 3 mm thickness. Figure 3.4 shows a typical set-up with $^{241}$Am as a radioactive source and an HPGe detector at a scattering angle of 110° for investigation of a sample of medical interest. Fig. 3.5 shows experimental set-up to observe transmitted and scattered gamma-ray flux. In transmission, the radioactive source $^{241}$Am and NaI(Tl) detector are positioned at opposite sides of each other with respect to the sample to be studied. In scattering measurements the detector has been displaced by desired angle (90° in Fig. 3.5) with respect to the source axis.

![Fig. 3.4: Experimental set-up with $^{241}$Am as a radioactive source.](image)
3.2.2 Gamma ray detector assembly

In the present study two gamma ray detectors have been employed for non-destructive testing of various samples. The one, a NaI(Tl) scintillation detector having dimensions of 51 mm in diameter and 51 mm in thickness. This crystal is sealed in an aluminium can (0.508 mm thick) and optically coupled to ORTEC photo-multiplier tube. To avoid the contribution due to background radiations (like cosmic rays, radiations from week radioactive sources present in the laboratory) the detector is shielded with cylindrical lead shielding of length 140 mm, thickness 27.5 mm and internal diameter of 60 mm. The gamma ray detector assembly used has an integral low noise pre-amplifier, (Model 276) a PMT base with voltage divider network, and a focus control for optimum performance in scintillation detector applications. The operating voltage to the photomultiplier tube is adjusted at 800 Volts. The unit provides two outputs one the pre-amplifier output for energy analysis and other the anode output for either timing or auxiliary energy analysis. The Model 276 is powered from power supply unit (Model 556) and its output is fed to ORTEC main amplifier (Model 572 A).
The other gamma ray detector used for the present measurements is a closed-end coaxial HPGe semiconductor gamma detector (GC1518, Canberra, U.S.A) of dimensions 56.4 mm in diameter and 29.5 mm in length with active volume 73.7 cm$^3$. The field of view of HPGe detector is confined to the target under investigations. For this purpose, a suitable cylindrical collimator is placed in front of gamma detector. The HPGe detector is properly shielded by a cylindrical lead shielding having inner side covered with 2 mm thick iron and 1 mm thick aluminium, with iron facing lead to absorb K X-rays emitted by lead shielding. It has been checked that radiation scattered from source collimator opening do not reach directly the active volume of HPGe detector. The detector is biased with a stabilized high voltage power supply of 3000 Volts D.C. with positive polarity.

3.2.3 Mechanical system for motion of samples

The sample plateform (Fig. 3.3) has the provision of horizontal and vertical motions with the help of two levers [$L_H$ and $L_V$]. Step wise motion for scanning of samples is performed with this mechanical system having precision of 1 mm for change in position. $S_H$ and $S_V$ are two scales for distance measurements in horizontal and vertical direction respectively.

3.3 Electronic assembly

The output signal from gamma ray detector, corresponding to interaction of each of the incident photons with detector material, is a pulse. Electronics play an important role in shaping and suitable pulse-height amplification desired for analysis and registration of detected events. The block diagram of the electronic set-up used for the present measurements of non-destructive testing of samples is shown in Fig. 3.6. It consists of the following units:
In general, the gamma ray detector is located at some distance from the linear amplifier and the rest of the electronic modules comprising of signal processing and counting system. A long detector-amplifier cable tends to attenuate the pulse amplitude, introduces reflected pulses and picks up noise. To avoid this noise, the pre-amplifier is mounted near the gamma detector. Pre-amplifier's main function is to convert the charge produced in the active volume of the detector to a proportional voltage pulse compatible with the main amplifier input. It also provides an optimal coupling between detector and counting system by matching the high output impedance of detector to the low input impedance of the amplifier.

The long-tailed output pulses from the preamplifier are not suitable for subsequent analysis. These are shaped and amplified using a linear amplifier to
a suitable level before feeding to the analysis units. The primary function of the linear amplifier is to amplify the detector signal, while introducing as little noise and non-linearity as possible. The secondary function includes pulse shaping and impedance transformation. Nuclear spectroscopy may be carried out using a single channel (SCA) or multi-channel pulse-height analyzer. SCA is capable of recording only those pulses falling within a single channel, while all other pulses are rejected. In that sense it is a very slow and laborious process. But multi-channel analyzer (MCA), measurements of counting rates can be made simultaneously for all channels, is capable of recording every pulse from an energy spectrum as the pulse occurs. One of the basic functions of the MCA is pulse-height analysis by which pulses are sorted according to their heights and stored in different channels. In the present experiment, the data is accumulated on a PC-based ORTEC Maestro-32 MCA. The stability and sensitivity of the system is checked frequently, and adjustments are made if required.

### 3.4 Calibration and energy resolution of detectors

The calibration of spectrometer is essential for linear relation between the incident energy and pulse-height distribution. The energy spectra of the NaI(Tl) gamma ray detector and HPGe detector are recorded by placing each of the calibration sources, $^{133}$Ba(81 and 356 keV), $^{22}$Na(511 keV), $^{137}$Cs(662 keV) and $^{54}$Mn(834 keV), at the sample’s position. The observed full energy peaks along with the linearity curve of the detectors are shown in Fig. 3.7 (a) and 3.8 (a). Ideally, one would like to observe a sharp delta function by recording a spectrum. But, in reality, we observe a peak structure with a finite width, usually Gaussian in shape and this width arises due to the fluctuations in the number of ionization and excitation produced in the detection material.
Fig 3.7 (a): Observed full energy peaks and calibration curve of NaI(Tl) detector.

Fig 3.7 (b): Energy resolution of NaI(Tl) detector.
Fig. 3.8 (a): Observed full energy peaks and calibration curve of HPGe detector.

Fig. 3.8 (b): Energy resolution of HPGe detector.
The energy resolution of detector is usually given in terms of the full width at half maximum of the peak (FWHM). Energies that are closer than this interval remain unresolved by a detector. Energy resolution can be calculated from FWHM measurements and is given by following relation

\[
\text{Percent resolution} = \frac{\text{FWHM}}{\text{Energy}} \times 100
\]  \hspace{1cm} (3.3)

The energy resolution of both the detectors, NaI(Tl) and HPGe, are studied independently and are shown in Fig. 3.7 (b) and 3.8 (b) respectively. The solid curve provides a best-fit curve through the observed data points. It is observed that, in range of ~100 – 900 keV, energy resolution values for NaI(Tl) detector are from ~6 to 10% while it remains less than ~1% for HPGe detector.

### 3.5 Photo-peak efficiency of gamma ray detectors

Photo-peak efficiency is another important parameter for quantitative measurements while making use of scintillation and semiconductor detectors for gamma spectroscopy. The photo-peak efficiency of a detector is the product of intrinsic efficiency (the probability of detecting a radiation falling) and peak-to-total ratio (photo-fraction). The photo-peak efficiency largely depends on the type of detector, crystal dimensions, geometrical set-up and the incident energy of the gamma photons used in the experiment.

If \( N_o \) is the rate of emission of photons from a source and \( N \) the counting rate recorded in the scintillation detector subtending a solid angle \( \Omega \) at the source then

\[
N = N_o \varepsilon \Omega
\]  \hspace{1cm} (3.4)

where \( \varepsilon \) is the detection efficiency. The intrinsic efficiency of a NaI(Tl) detector can be calculated from the knowledge of gamma ray attenuations coefficients for the
scintillator. The intrinsic (crystal) efficiency \[78\] values of 51 x 51 mm NaI(Tl) cylindrical detector are mathematically calculated using the formula

\[
\varepsilon_i(E) = 1 - e^{-\mu_{\text{tot}}(E) t}
\]  

(3.5)

Here \(\mu_{\text{tot}}(E)\) is the attenuation coefficient for NaI(Tl) at energy E and \(t\) is the crystal thickness. The peak-to-total ratio \[78\] values are calculated for different mono-energetic pulse height distributions ranging from 0.145 to 1.12 MeV for NaI(Tl) detector (used in present measurements). The fitted intrinsic (crystal) efficiency and fitted peak-to-total ratio values of the detector are given by curves “a” and “b” respectively in Fig. 3.9. The product of peak-to-total ratio, \(\varepsilon_p\), and intrinsic (crystal) efficiency values will provide the photo-peak efficiency of the NaI(Tl) detector, as shown by following equation

\[
\varepsilon = \varepsilon_i \varepsilon_p
\]  

(3.6)

Fig. 3.9: Photo-peak efficiency curve for 51 mm x 51 mm NaI(Tl) detector.
The maximum value of the intrinsic peak efficiency at very low energy is unity and of peak-to-total ratio is less than unity, but with the increase in energy of incident radiation both the intrinsic peak efficiency and peak-to-total ratio becomes less than unity. Their product shows a decrease in the photo peak efficiency with increase in incident energy.

Some correction factors related to the absorption of low energy gamma rays in the aluminium window (of thickness 0.508 mm), absorption in air present between the target and the detector, and iodine escape peak at lower gamma energies are also considered to modify the photo-peak efficiency obtained by the product of the intrinsic efficiency and peak-to-total ratio of the detector. In the lower energy range there is significant probability for escape of K X-rays of 29.2 keV of iodine from the NaI(Tl) scintillation crystal following a photoelectric interaction with iodine atom [79]. So in the energy range extending from K-shell binding energy of 33.2 keV of the iodine atom up to 150 keV, iodine escape peak correction (curve-c) is significant. It is clear from the Fig. 3.9 that for energies more than 150 keV there is no significant contribution from iodine escape peak correction. The absorption of gamma rays (curve-d) in air column between target and the detector is negligible owing to the high energy photon flux involved in the present measurements but for achieving the high accuracy it has been calculated using numerical values taken from data given by Hubbell [80]. The aluminium window correction (curve-e) is calculated by using the Lambert-beer’s law through the aluminium window of thickness 0.508 mm of NaI(Tl) detector by using the known values of absorption coefficients [81]. The product of peak-to-total ratio and intrinsic (crystal) efficiency values corrected for the stated correction factors will provide the photo-peak efficiency (curve-f) of NaI(Tl) detector.
The data for photo-peak efficiency of HPGe detector is taken from the manual provided with the detector (supplied by Canberra inc. USA) and is plotted in Fig. 3.10. It is clear that photo-peak efficiency of both the detectors decreases with increase in energy in the region of interest for present measurements. The decrease in efficiency with increase of energy is due to higher penetration of gamma radiations without interacting with detector medium. The efficiency is higher for NaI(Tl) detector in comparison to HPGe detector. It can be up to ~90% in case of NaI(Tl) (due to higher value of atomic number, Z = 53, for iodine) but can not be more than ~10% in case of HPGe (due to lower value of atomic number, Z = 32, for Germanium).

![Fig 3.10: Photo-peak efficiency curve for HPGe detector.](image)

3.6 Evaluation of self-absorption correction factor

Non-destructive testing at different angular positions can be performed by using one of the following two types of geometries:

(i) Reflection (Backscattering) geometry

(ii) Transmission geometry
In these two types of geometries, a fraction of incident and scattered photons may be absorbed in the target (sample) thus implying that the actual thickness of the target must be replaced by effective thickness. The ratio of the effective thickness to actual thickness is called self-absorption correction. The details for absorption correction in two geometries are written in following section:

### 3.6.1 Backscattering (Reflection) geometry

This type of geometry is used for large scattering angles. To find the effective thickness $t_{\text{eff}}$ of the target, the actual thickness of the target (sample) is assumed to be made up of a number of small segments, each of thickness $dx$ as shown in Fig. 3.11.

![Backscattering geometry](image)

Fig. 3.11: Backscattering geometry.

The incident photon is scattered from the target electron in the sample segment $dx$ at a depth $x$ and is detected only if

(a) The incident photon reaches the segment $dx$ without any interaction

(b) After interaction at a depth $x$ in the segment $dx$, the scattered gamma ray comes out of the target for detection.

The gamma ray beam of intensity $I_0$ is incident upon the target at angle
\( \theta_i \), with the normal to the surface. The intensity \( I_i \) of gamma rays reaching the segment \( dx \) will be

\[
I_i = I_0 e^{-\mu_i AB} = I_0 e^{-\mu_i \left\{ \frac{x}{\cos \theta} \right\}} \quad (3.7)
\]

Here \( \mu_i \) is the linear absorption coefficient of the incident gamma ray in the target.

The incident gamma rays interact with the target electrons and as a result gamma rays are scattered with degraded energy of intensity

\[
I_2 = I_1 \sigma n_e \, dx \quad (3.8)
\]

Where \( \sigma \) is the interaction cross-section and \( n_e \) is the number of electrons per \( \text{cm}^3 \) of the target material.

The intensity \( I_3 \) of scattered gamma rays coming out of the target is

\[
I_3 = I_2 e^{-\mu_e BC} = I_2 e^{-\mu_e \left\{ \frac{x}{\cos \theta} \right\}} \quad (3.9)
\]

Where \( \theta_2 \) is the angle, which the scattered gamma ray makes with the normal to the surface and \( \mu_e \) is the linear absorption coefficient of scattered gamma rays in the target material. Therefore,

\[
I_3 = I_2 e^{-\mu_e \left\{ \frac{x}{\cos \theta} \right\}} = I_1 \sigma n_e e^{-\mu_e \left\{ \frac{x}{\cos \theta} \right\}} \, dx
\]

\[
I_3 = I_0 \sigma n_e e^{-x \left[ \left\{ \frac{\mu_i}{\cos \theta_1} \right\} + \left\{ \frac{\mu_e}{\cos \theta_2} \right\} \right]} \, dx \quad (3.10)
\]

Overall probability of the scattering process to occur in the segment \( dx \) is

\[
dP = \frac{I_3}{I_0} = \sigma n_e e^{-x \left[ \left\{ \frac{\mu_i}{\cos \theta_1} \right\} + \left\{ \frac{\mu_e}{\cos \theta_2} \right\} \right]} \, dx \quad (3.11)
\]

Therefore, the total probability of interaction of gamma rays for a target of
actual thickness, \( t \), is obtained by integrating the above equation from 0 to \( t \).

\[
P = \int_{0}^{t} \sigma n_{e} e^{-\left[ \left( \mu_{l} / \cos \theta_{l} \right) + \left( \mu_{s} / \cos \theta_{s} \right) \right] t} \, dx
\]

\[
= \sigma n_{e} \left[ 1 - e^{-\left[ \left( \mu_{l} / \cos \theta_{l} \right) + \left( \mu_{s} / \cos \theta_{s} \right) \right] t} \right]
\]

Which implies that actual thickness, \( t \), is replaced by the effective thickness, \( t_{\text{eff}} \), and is equal to

\[
t_{\text{eff}} = \frac{1 - e^{-\left[ \left( \mu_{l} / \cos \theta_{l} \right) + \left( \mu_{s} / \cos \theta_{s} \right) \right] t}}{\left[ \left( \mu_{l} / \cos \theta_{l} \right) + \left( \mu_{s} / \cos \theta_{s} \right) \right] t}
\]

(3.12)

Thus, the self-absorption correction factor is given by

\[
\beta = \frac{t_{\text{eff}}}{t} = \frac{1 - e^{-\left[ \left( \mu_{l} / \cos \theta_{l} \right) + \left( \mu_{s} / \cos \theta_{s} \right) \right] t}}{\left[ \left( \mu_{l} / \cos \theta_{l} \right) + \left( \mu_{s} / \cos \theta_{s} \right) \right] t}
\]

(3.13)

When the target is placed symmetrically to the incident and scattered gamma rays (\( \theta_{l} = \theta_{s} = \theta \)), then the above equation becomes

\[
\beta = 1 - e^{-\left( \mu_{l} + \mu_{s} / \cos \theta \right) t}
\]

(3.14)

Thus \( \beta \) can be evaluated by using the known values of absorption coefficients for incident and scattered gamma rays, at a particular scattering angle.

**3.6.2 Transmission geometry**

This type of geometry is used for small scattering angles. The target is considered to make up of infinite number of small segments each of thickness \( dx \) as shown in fig. 3.12.
Fig. 3.12: Transmission geometry.

The intensity of incident gamma rays reaching the segment $dx$ is

$$I_1 = I_0 e^{-\mu_1 \left( \frac{x}{\cos \theta_1} \right)}$$  \hspace{1cm} (3.16)

After interaction, the scattered gamma rays travel a distance $(t-x)$ from the segment $dx$. The intensity of scattered gamma ray is

$$I_2 = I_1 e^{-\mu_1 \left( \frac{t-x}{\cos \theta_2} \right)}$$  \hspace{1cm} (3.17)

Where $\mu_1$ is linear absorption coefficient of scattered gamma rays.

$$I_2 = I_0 e^{-\mu_1 \frac{x}{\cos \theta_1} - \mu_1 \left( \frac{t-x}{\cos \theta_2} \right)}$$

$$= I_0 e^{-\mu_1 \frac{x}{\cos \theta_1} \left( \frac{t-x}{\cos \theta_2} \right)}$$  \hspace{1cm} (3.18)

Overall probability of the scattering process to occur in the segment $dx$ is given by

$$dP = \sigma n_e \frac{I_2}{I_0} = \sigma n_e e^{-\mu_1 \frac{x}{\cos \theta_1} \left( \frac{t-x}{\cos \theta_2} \right)}$$  \hspace{1cm} (3.19)

For the target placed symmetrically $(\theta_1 = \theta_2 = 0)$
\[ dP = \sigma n e^{-\left(\frac{\mu + \mu_i - \mu}{\cos \theta}\right) t} \]  

(3.20)

Thus, the overall probability of interaction of gamma rays for thickness, \( t \), of the target is given by

\[
P = \int_0^t \sigma n e^{-\left(\frac{\mu + \mu_i - \mu}{\cos \theta}\right) x} \, dx
\]

\[
= \sigma n e^{-\mu_i t} \left[ \frac{1 - e^{-\left(\frac{\mu_i - \mu}{\cos \theta}\right) t}}{\frac{\mu_i - \mu}{\cos \theta}} \right]
\]

(3.21)

Hence, the effective thickness is

\[
t_{\text{eff}} = e^{-\mu_i t} \left[ \frac{1 - e^{-\left(\frac{\mu_i - \mu}{\cos \theta}\right) t}}{\frac{\mu_i - \mu}{\cos \theta}} \right]
\]

(3.22)

Therefore, self-absorption correction is given by

\[
\beta = \frac{t_{\text{eff}}}{t} = e^{-\mu_i t} \left[ \frac{1 - e^{-\left(\frac{\mu_i - \mu}{\cos \theta}\right) t}}{\frac{\mu_i - \mu}{\cos \theta} t} \right]
\]

(3.23)

Using the known values of \( \mu_i, \mu, \theta \) and \( t \), the self-absorption correction factor \( \beta \) can be evaluated.

### 3.7 Summary

As experimentation is the most reliable lever enabling us to extract secrets from nature so it becomes equally important to know about the important components of experimental set-up employed. The desirable features of experimental set-up including source housing, sample platform, detector & electronic assemblies, and data accumulation unit (PC-based ORTEC Maestro-
32 multi-channel analyzer) have been described in the present chapter. Efficiency and resolution are two important factors for detectors which are designed to measure the energy of scattered radiation emerging from object. NaI(Tl) scintillation detector and HPGe detector are employed respectively where good efficiency and resolution are the characteristics of interest. Before using detectors, calibration and resolution (Fig 3.7 and Fig. 3.8) must be the essential part of study.

As absorption of low energy photons and use of low activity sources is unfavorable for precise measurements of gamma spectroscopy, so absorption corrections also play a vital role for the enhancement of intensity in the measurements. For the investigations of Rayleigh to Compton scattering intensity ratio technique, HPGe detector is employed in the present work. Also, various measurements (discussed in next chapters) are performed with NaI(Tl) scintillation detector for transmission as well as scattering geometry set-up. Although direct exposure of gamma radiations may cause injury to human cells but handling with care (not with fear) for radioactive sources is beneficial for the development of society. In present study, all the precautions are taken while handling the radioactive sources.