Chapter 2

Theoretical formalism and methodology

In this chapter, we will discuss the theory, theoretical formulae used in the research work and a complete methodology. This chapter will include the detail description of detectors, instruments and theory of calibration of the instruments used in the present study. Detector used in the present study is a cellulose nitrate film mounted inside a twin cup dosimeter. Recently developed Direct progeny sensors (DPS) are used in determining the progeny concentrations. Equilibrium factors and inhalation doses are calculated from the obtained experimental data. RAD-7 is used for radon flux measurement and NaI (Tl) detector with 1K MCA is used to measure the radioactivity content of soil samples and building materials collected. Classification of measurements is also included in this chapter. The necessary procedures and formulae involved in measuring the concentrations of radon, thoron and their progeny, the radioactivity content of soil samples and building materials along with the calculations of equilibrium factor and inhalation doses are given in this chapter.

2.1 Dosimeter

For measurements of indoor radon/thoron concentrations, Solid State Nuclear Track Detector (SSNTD) based pin-hole dosimeters have been used. This detector has been manufactured by Kodak under the trade name LR-115. It consists of thin films of cellulose nitrate \((\mathrm{C}_6\mathrm{H}_{10}\mathrm{O}_5)n\) coloured deep red and coated on a 100µm thick polyester backing. LR-115 type II film is commonly used for radon measurements (Alter and Fleischer, 1981; Tommasino et al., 1990 and Furlan, 1993). It is. The thickness of the sensitive layer of detector, LR-115 films (Type II) is 12 µm. These films are not sensitive to electrons and electromagnetic radiations and they can be handled without risk wherever such radiations are present, nevertheless, care should be taken to avoid any
abrasion on the films (Azimi-Garakani et al., 1981). These detectors are kept inside a twin cup dosimeter, a cylindrical plastic chamber divided into two equal compartments (Nambi et al., 1994), each having an inner volume of 135 cm$^3$ and height 4.5 cm. The two equal compartments on both sides are filter and pinhole compartments. There is one small compartment at the external middle attached to it which is used for bare mode exposure.

![Figure 2.1 BARC type twin cup dosimeter.](image)

The detector films are then inserted at the three compartments. These detectors register tracks produced by the alpha particles emitted by radon as well as thoron. In the filter cup, filter paper is used to cover the entry point of the compartment blocking the entry of the progeny while it allows both radon and thoron gas to pass through (Eappen, 2005). In the pinhole side, we have a pinhole (0.4 mm diameter and 5 mm thick) in which radon gas only pass through. This is a modification from the earlier twin-cup dosimeter system (Eappen, 2005). This pin hole is designed in size and thickness of cap so as to block thoron from entry inside by considering the diffusion length and half life of thoron. One filter paper is used to cover the entry point to block the progenies. In bare mode, as is clear from its name, the film is being exposed barely to the environment and tracks on it are due to radon gas, thoron gas and their progenies. With the development of DPS recently, bare mode of this twin cup dosimeter is not used in the present work.
Dosimeters are hanged indoor overhead on the ceiling for a minimum of 90 days. The exposed dosimeters are taken for analysis and replaced with new ones for the next deployment. The exposed films are then etched in an etching bath using 2.5N NaOH solution at 60 °C for 90 mins. Etching of the film helps in obtaining a clear visibility of the tracks produced on the films which is necessary for counting. The tracks recorded in this SSNTD films are then counted using a spark counter, which is an electronic counter operating on high voltage.

2.1.1 Standardization of bulk etching rate

As mentioned above, LR-115 film when dipped into 2.5N NaOH (Sodium Hydroxide) solution is being chemically etched. Etching of the film is necessary because the tracks produced on the films due to radon, thoron and their progeny are visible for counting only after etching. Etched films are then counted by spark counter. Bulk etching rate is the rate of etching of the film (LR-115) per unit time.

Let $W$ be the weight of the film in grams, $A$ be the area in cm$^2$ and $\rho$ be the density in gram/cm$^3$. Then, the thickness of the film can be calculated by using the equation

$$Thickness = \frac{W}{A \times \rho} \text{ (cm)}$$  \hspace{1cm} (2.1)

If the initial weight be $w_i$ and final weight be $w_f$, then change in weight after etching is given by

$$\Delta W = w_f - w_i$$  \hspace{1cm} (2.2)

Bulk Etching Rate is given by

$$V_B = \frac{\Delta W}{\Delta t \times \rho \times A}$$  \hspace{1cm} (2.3)

where $\Delta t$ is the time of etching in seconds.

By using Eq. 2.3 the bulk etching rate can be easily calculated.
2.1.2 Calibration factor

Calibration factors (CFs) are the quantities, which are used for converting the observed track density rates to the activity concentrations of the species of interest.

If \( T \) denotes the track densities observed on a SSNTD due to exposure in a given mode to a concentration \( C \) of given species for a time \( t \), it is obvious that

\[
T = kCt
\]  

(2.4)

where, we define \( k \) as the calibration factor (Eappen and Mayya, 2004).

In the cup mode, only radon or thoron or both enter the cup and the progeny species from the environment will be filtered out. Hence, the total tracks formed on the SSNTD placed inside the cups will be uniquely dependent on the gas concentrations only. In the twin-cup dosimeter used in the present study, there exists two compartments (i.e. pinhole and filter compartments) in which detectors are mounted. Hence, the corresponding calibration factors may be defined as

\[
k_R(P) = \frac{T_R(P)}{tC_R(P)}
\]  

(2.5)

\[
k_T(F) = \frac{T_T(F)}{tC_T(F)}
\]  

(2.6)

where, \( k_R(P) \) is the calibration factor of radon in pinhole cup and \( k_T(F) \) is the calibration factor of thoron in the filter cup. \( C_R \) is the gas concentration of radon in Bq/m\(^3\) and \( C_T \) is the gas concentration of thoron in Bq/m\(^3\). \( T_R(P) \) is the tracks recorded for radon on the detector in tr/cm\(^2\) and \( T_T(F) \) is the tracks recorded for thoron on the detector in tr/cm\(^2\). The subscript \( P \) and \( F \) denote the compartments in the dosimeter. \( P \) represents pinhole compartment and \( F \) represents the filter compartment.
2.2 Spark counter

The spark counting technique, which is the most successful and widely used technique for counting etched tracks in plastic track detectors was first invented by Cross and Tommasino (1970) and has been developed and discussed in a number of publications (Somogyi et al., 1978; Azimi-Garakani et al., 1981; Tommasino et al., 1986, Durrani and Bull, 1987). When the plastic track detector is chemically etched, the through holes are produced along the tracks. Spark counter is an instrument used to count the number of tracks on the films. The thin etched detector, which is an insulating material, is placed between two electrodes of the spark counter forming a capacitor and covered with an aluminized plastic foil (a very thin layer of aluminium evaporated onto a Mylar backing). The aluminized side of the plastic foil is in contact with the thin detector. The thick conductive electrodes of a spark counter are commonly made of brass. It is sometime necessary to put a relatively heavy weight on top of the plastic foil to have an intimate contact between the thin detector and the electrodes. With application of a high voltage across the capacitor C, an electrical discharge or spark takes place through a track-hole. The voltage pulse produced across the resistor, R, can easily be counted electronically by a scalar (Azimi-Garakani et al., 1981).

The spark passing through a track hole has enough energy to evaporate the thin layer of aluminium coating and produces a much larger hole in the aluminium electrode. Because of the evaporation of the aluminium there exist a short-circuit in the electrode, and hence second spark cannot occur in the same track hole. As a result the spark is stopped, the capacitor C is charged again. Consequently, the spark shifts randomly from one track hole to another until all track holes are counted. The evaporated spot on the aluminium, which have the diameter of about 100 µm are equal to the number of sparks
and hence to the number of track holes in the plastic track detector. The aluminium replica can easily be counted by an optical microscope or a microfiche reader. The schematic diagram of a spark counter is given below.

![Schematic diagram of a spark counter](image)

**Figure 2.2** Schematic diagram of a spark counter.

### 2.2.1 Operating voltage of a Spark counter

Operating voltage of a Spark counter is that specific voltage by which the counting of tracks should be done. When graph is plot between applied voltages and counts, a plateau region is produced. The corresponding middle voltage of this plateau is taken as the operating voltage for that Spark counter. This plateau region shows that even with a small change in the applied voltage the number of tracks count by the counter remains constant. Hence, with the fluctuation of the applied voltage, the counts will remain the same.
The graph plotted between applied voltage and counts is shown in Fig. 2.3 below.

![Graph showing the plateau region](image)

**Figure 2.3** Applied Voltage vrs Count showing the plateau region.

### 2.3 Concentrations of radon and thoron

The track density obtained from the spark counter is then used to calculate the concentration of that particular gas producing the α-emissions using the following formulae.

The formula used for calculating radon concentration is given as

$$C_R \ (Bq/m^3) = \frac{TP}{Calibration \ factor \times Exposure \ period \ (days)} \ (2.7)$$

where $C_R$ is the radon concentration in Bq/m$^3$ and $T_P$ is the track density of films (Tracks/cm$^2$) in pin hole compartment. Calibration factor is the quantity, which is used for converting the observed track density rates to the activity concentrations of the species of interest.
For calculating thoron concentration the following formula was used.

\[
C_T \left( \frac{Bq}{m^3} \right) = \frac{T_F-T_P}{\text{Calibration factor} \times \text{Exposure period (days)}}
\]  

(2.8)

where \( C_T \) is the thoron concentration, \( T_F \) is the track density of films in filter compartment and \( T_P \) is that for pinhole compartment (Mayya et al., 1998).

The concentrations obtained using the above formulae are in Bq/m\(^3\).

### 2.4 Equivalent Equilibrium Radon Concentration (EERC) and Equivalent Equilibrium Thoron Concentration (EETC)

The concentrations of progenies are determined through Equivalent Equilibrium Concentrations of radon as well as thoron (EERC & EETC) respectively. EERC and EETC were measured by deposition based Direct Progeny Sensors (DPS) in bare modes (Mishra et al. 2009). This DPS system uses absorber-mounted nuclear track detectors (LR-115 type II) which selectively register the tracks due to alpha emissions from \(^{212}\)Po (\(\alpha\) energy 8.78 MeV) and \(^{214}\)Po (\(\alpha\) energy 7.69 MeV) from the deposited atoms of thoron and radon progeny species, respectively. These are termed as DTPS (Direct thoron progeny sensor) and DRPS (Direct radon progeny sensor).

The track density is obtained using a spark counter after etching the detector film with 2.5N NaOH at 60°C for 90 mins. In calculating the progeny concentrations, the track density obtained using DTPS can be used directly in calculating EETC. But, in case of EERC, since we have a mixed radon and thoron progeny environment, \(\alpha\) energy of \(^{212}\)Po (thoron progeny) is higher as compared to that of \(^{214}\)Po (radon progeny). So, the track density obtained using DTPS should be used to eliminate the interference on the DRPS by \(^{212}\)Po. This is done by simple subtraction method. Formulae used to calculate EETC (Mishra et al., 2008) and EERC (Mishra et al., 2009) are given as follows
Chapter 2

**Equivalent Equilibrium Thoron Concentration**

\[ EETC \ (Bq/m^3) = \frac{T_{DTPS}}{\text{Calibration factor} \times \text{Exposure period (days)}} \]  

(2.9)

where \( T_{DTPS} \) is the track density obtained by counting tracks in the etched film of the DTPS.

**Equivalent Equilibrium Radon Concentration**

\[ EERC \ (Bq/m^3) = \frac{T_{DRPS} - T_{DTPS}}{\text{Calibration factor} \times \text{Exposure period (days)}} \]  

(2.10)

where \( T_{DRPS} \) and \( T_{DTPS} \) are the track densities obtained by counting tracks in the etched film of the DRPS and DTPS respectively.

2.5 **Equilibrium factors (Sensitivity factors) for radon and thoron**

The equilibrium factor or the sensitivity factor for the radon (\( F_R \)) and thoron (\( F_T \)) are the quantity of ultimate interest in passive dosimetry applications. In the literature on inhalation dosimetry, it is conventional to express \( F_T \) as the track density expected for 1-day exposure to an environment containing 1 Bq/m\(^3\) of EETC (Mishra et al., 2008). Likewise, \( F_R \) represents the track density expected for 1-day exposure to an environment containing 1 Bq/m\(^3\) of EERC after subtracting the track density expected from 1 Bq/m\(^3\) of EETC. Direct progeny sensors viz., direct radon progeny sensor (DRPS) and direct thoron progeny sensor (DTPS) are used to monitor the progeny concentrations and are used to find the equilibrium factor. The following formulae are used to obtain the sensitivity factor (equilibrium factor) of radon and thoron respectively (Mishra et al. 2009).
**Equilibrium Factor for radon is calculated as**

\[
F_R = \frac{EERC \ (Bq/m^3)}{C_R \ (Bq/m^3)}
\]  

(2.11)

where \(C_R\) is the concentration of radon calculated using track density from pinhole compartment and \(EERC\) is the Equivalent Equilibrium Radon Concentration.

**Equilibrium Factor for thoron is calculated as**

\[
F_T = \frac{EETC \ (Bq/m^3)}{C_T \ (Bq/m^3)}
\]  

(2.12)

where \(C_T\) is the concentration of thoron calculated using track densities from pinhole and filter compartment and \(EETC\) is the Equivalent Equilibrium Thoron Concentration.

**2.6 Inhalation dose of radon and thoron**

Annual inhalation dose rate is the amount of radon and/or thoron inhaled per annum (\(\mu\)Sv/yr) by individuals living in dwellings. Inhalation dose can be calculated using the obtained concentrations of the parent nuclei and the progenies. The dosimeters along with the DPS (DTPS and DRPS) were exposed simultaneously in different selected houses for a period of at least 3 months. After the stipulated time of exposure, the detectors were chemically processed and the track densities were obtained using spark counter. The track densities were converted into radon, thoron and their progeny concentrations using appropriate calibration factors.

Several models have been developed to assess the inhalation dose rates to the population due to radon, thoron and their progeny (Ramu *et al*., 1992). Lung dose distribution assessment carried out by different agencies right from 1956 to 2000 given in details in UNSCEAR reports (UNSCEAR, 2000) shows a large variation in dose conversion factors.
The estimated dose conversion factors varied drastically based on the breathing rate as well as the target tissue. Based on these, the dose conversion factors were derived, which has been used for the compilation of the inhalation dose rate (D) as shown below:

\[
D = [(0.17 + 9 F_R) C_R + (0.11 + 40 F_T) C_T]
\]  

(2.13)

where numerical numbers are the dose conversion factors for gas and progeny concentrations (UNSCEAR, 2000). \(F_R\) and \(F_T\) represent the equilibrium factor of radon and thoron respectively. \(C_R\) and \(C_T\) represent the radon and thoron concentration respectively. Table 2.1 demonstrates the inhalation dose estimate from global averaged radon and thoron concentration.

### Table 2.1 Global averaged radon and thoron inhalation dose.

<table>
<thead>
<tr>
<th>Radionuclide</th>
<th>Location</th>
<th>Concentration (Bq.m(^{-3}))</th>
<th>Effective dose equivalent (nSv/Bq.h.m(^{-3}))</th>
<th>Annual effective dose ((\mu)Sv)*</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Gas</td>
<td>EEC*</td>
<td>Gas</td>
</tr>
<tr>
<td>Radon</td>
<td>Outdoor</td>
<td>10</td>
<td>6</td>
<td>0.17</td>
</tr>
<tr>
<td></td>
<td>Indoor</td>
<td>40</td>
<td>16</td>
<td>0.17</td>
</tr>
<tr>
<td>Total (numerical)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Thoron</td>
<td>Outdoor</td>
<td>10</td>
<td>0.1</td>
<td>0.11</td>
</tr>
<tr>
<td></td>
<td>Indoor</td>
<td>10</td>
<td>0.3</td>
<td>0.11</td>
</tr>
<tr>
<td>Total (numerical)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total Annual Effective dose equivalent due to radon and thoron ((\mu)Sv)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*It is the equilibrium equivalent concentration (EEC) of radon and thoron and calculated multiplying gas concentration with equilibrium factor (F). The equilibrium factor (F) has been taken as 0.6 for outdoor and 0.4 for indoor in the case of radon. In the case of thoron F is taken as 0.01 for outdoor and 0.03 for indoor. *The annual effective dose is calculated taking occupancy factor of 0.2 for outdoor and 0.8 for indoor (UNSCEAR, 2000).
2.7 Radon in soil (Surface Radon Flux)

The potential of radon emission over the soil surface is governed by the physical quantity called ‘radon flux’ and is used as a source term for the atmospheric radon dispersion modelling. Accumulator technique is used to measure the in-situ radon flux. This measurement can be carried out using a set up consisting of an accumulator in line connected to continuous radon monitor. In this study, accumulator connected RAD-7 is used to measure radon flux from the soil surface. Accumulator is fixed on the soil surface at the area of interest and the radon concentration is allowed to build up for a certain time. The time variation of the radon concentration inside the accumulator is monitored and related to the flux through growth kinetic equations (Sahoo, 2008).

\[ C(t) = \frac{J_s A}{V \lambda_e} \left( 1 - e^{-\lambda_e t} \right) + C_o e^{-\lambda_e t} \]  

(2.14)

where, \( C(t) \) is the radon concentration in the accumulator at time \( t \) (Bq m\(^{-3}\)); \( J_s \) is the radon flux from soil (Bq m\(^{-2}\)s\(^{-1}\)); \( V \) is the volume of the accumulator (m\(^3\)); \( \lambda_e \) is the effective time constant (h\(^{-1}\)) of \(^{222}\)Rn for the given set up and it is the sum of leakage rate, radon decay constant and back diffusion rate; \( A \) is the area of soil surface covered by accumulator (m\(^2\)) and \( C_o \), the radon concentration inside the accumulator at time \( t = 0 \).

Radon flux can be determined by fitting the exponential growth equation given in Eq. 2.14 to the concentration data inside accumulator obtained from the measurement set up. As the exact form of the equation is not available in the standard software for the fitting procedure, hence the available general growth equation is given by

\[ Y(x) = Y_o + A_1 e^{-x/t_1} \]  

(2.15)

where, \( Y_o, A_1 \) and \( t_1 \) are the fitting parameters.

Comparing Eq. 2.14 and Eq. 2.15,

\[ Y(x) = C(t), \quad Y_o = \frac{J_s A}{V \lambda_e}, \quad A_1 = \frac{-J_s A}{V \lambda_e} + C_o, \quad x = t \quad \text{and} \quad t_1 = \frac{1}{\lambda_e} \]
In order to avoid interference of initial radon concentration \( (C_0) \) present in the accumulator ‘\( J_s \)’ should be obtained from the fitting parameter ‘\( Y_0 \)’ i.e.

\[
J_s = \frac{V_{at}}{t_{1, A}} = \frac{Y_0}{t_{1, H}}
\]  

(2.16)

where \( H \) is the height of the cylinder accumulator (Sahoo, 2008).

The building up of radon concentration measured by RAD-7 is plotted using Origin Pro as shown in Fig. 2.4 from which the parameters \( Y_0 \) and \( t_{1} \) values are obtained. These values are inserted in Eq. 2.16 to calculate radon flux from soil in mBq m\(^{-2}\) s\(^{-1}\).

![Figure 2.4 Building up of radon concentrations with time inside the accumulator.](image-url)
2.7.1 RAD-7

The DURRIDGE RAD-7 uses a solid state alpha detector that converts alpha radiation directly to an electrical signal. It has the ability to electronically determine the energy of each alpha particle which makes it possible to tell exactly which isotope (polonium-218, polonium-214, etc.) produced the radiation. The RAD-7 is immune to the buildup of lead-210.

The RAD-7’s internal sample cell is a 0.7 litre hemisphere, coated on the inside with an electrical conductor. A solid-state, Ionimplanted, Planar, Silicon alpha detector is at the center of the hemisphere. The high voltage power circuit charges the inside conductor to a potential of 2000 to 2500 volts, relative to the detector, creating an electric field throughout the volume of the cell. The electric field propels positively charged particles onto the detector (RAD-7 manual, http://www.durridge.com/products_rad7.shtml).

A radon-222 nucleus that decays within the cell leaves its transformed nucleus, polonium-218, as a positively charged ion. The electric field within the cell drives this positively charged ion to the detector, to which it sticks. When the short-lived polonium-218 nucleus decays upon the detector’s active surface, its alpha particle has a 50% probability of entering the detector and producing an electrical signal proportional in strength to the energy of the alpha particle. Subsequent decays of the same nucleus produce beta particles, which are not detected, or alpha particles of different energy. Different isotopes have different alpha energies, and produce different strength signals in the detector. The RAD-7 amplifies, filters, and sorts the signals according to their strength. In Sniff mode, the RAD-7 uses only the polonium-218 signal to determine
radon concentration, and the polonium-216 signal to determine thoron concentration, ignoring the subsequent and longer-lived radon daughters.

This device produces the radon and/or thoron concentrations along with errors, temperature, relative humidity and time, automatically after each pre-set time intervals through its LCD Display. The readings can also be printed instantly with the infra-red connected printer included along with it.

2.8 **Background Gamma Radiation Survey**

During deployment and retrieving of the dosimeters, background gamma radiation at ground level and 1m height inside and outside the house are measured using a Micro-R survey meter (Vanchhawng *et al*., 2009). This device manufactured by Nucleonix automatically displays the background gamma radiation values after each gate time of 8 seconds which is noted suitably as required. The variation of background gamma radiation helps in tracing the origin of these radiations viz., whether it is cosmic of terrestrial.

2.9 **Radioactivity content**

The radium content in soil and building materials is typically given as an activity per unit dry mass, ARa (Bq kg\(^{-1}\)). The most convenient and accurate method largely used for the determination of natural occurring radionuclides is by means of \(\gamma\)-spectrometry on individual samples previously dried, powdered and packed in small plastic containers with a given geometry (Nazaroff *et al*., 1988a; Ibrahim, 1999; Bojanowski *et al*., 2001). The amount of \(^{238}\)U present in the soil and building materials mainly determine the amount of \(^{226}\)Ra present in it. Since \(^{226}\)Ra is the parent nuclei of \(^{222}\)Rn, and hence knowing the amount of \(^{238}\)U present in the soil and/or building materials, the level of radon concentration can be predicted or assumed. A \(\gamma\)-spectrometry of the \(^{232}\)Th content
considering the peaks of the intermediate $\gamma$-emitters, $^{228}$Ra and $^{228}$Ac, is a good indicator of the rate of $^{220}$Rn production within the reference soil or building material because the intermediate radioelements in the $^{232}$Th series to $^{224}$Ra have relatively short half-life in terms of geological time scales and are not altered to any extent by natural physical and/or chemical processes.

For measuring the source radioactivity element content of soil, samples are taken from around the dwellings where dosimeters are hanged. These samples are then powdered into a small particle sizes and packed in a sealed container which are kept for at least 30 days in such a way to obtain secular equilibrium between radon and thoron with their parent nuclides before counting (Vanchhawng et al., 2011). The samples are placed inside the NaI(Tl) detector which is previously calibrated using standard radioactive sources. 1K MCA is used to monitor the content of uranium, thorium, potassium, etc. Monitoring of each sample is carried out as long as a minimum of 30,000 seconds. Spectrum obtained in the 1K MCA is used to obtain the net peak area for each nuclide. From this net peak area, the activity can be calculated using the following formula.

$$\text{Activity} = \frac{\text{Net Peak Area}}{\eta \cdot \text{Counting Time}} \, (Bq/g)$$  \hspace{1cm} (2.17)

where $\eta$ is efficiency obtained using standard source, counting time is in second.

The same procedure is used for measuring the radioactivity of different building materials. Most building materials of terrestrial origin contain small amounts of Naturally Occurring Radioactive Materials (NORM), mainly radionuclide from the $^{238}$U and $^{232}$Th decay chains and the radioactive isotope of potassium, $^{40}$K (Gustavo Haquin). In this study, some of the commonly used building materials, viz., rocks, brick, asbestos and
wood in the study area were collected and analyzed with a special focus on indoor radon and thoron concentrations in dwellings.

2.10 Classification for measurements

Radon presents in indoor air as it had been exhaled from soil and building materials. The concentration of this gas varies widely depending on the meteorological and geographical conditions, pseudo-ventilation rate of the dwellings, emanation rate from the building material, etc. Exhalation of $^{222}\text{Rn}$ from the surfaces of building materials and infiltration of $^{222}\text{Rn}$ from external atmosphere coupled with air exchange rate inside a room govern the concentration of $^{222}\text{Rn}$ inside a dwelling. The basic parameters governing the $^{222}\text{Rn}$ potential from building materials are: (i) its radioactive content, (ii) $^{222}\text{Rn}$ emanation rate and (iii) diffusive length of $^{222}\text{Rn}$ in the sample matrix. The radiation exposure from building materials creates prolonged exposure situation as individuals spend more than 80% of their time indoors (ICRP, 1999).

Taking into consideration the different factors influencing the concentration of radon, thoron and their progeny, the following classifications of measurements are done for the present work.

2.10.1 Geographical (District-wise) classification and seasonal variation

Geographical comparison includes the comparison of results in the three districts viz., Aizawl, Champhai and Kolasib Districts. Indoor radon concentration is greatly influenced by the pseudo-ventilation rate. During different seasons the temperature varies, this change in temperature results in change in ventilation rate of dwellings. Hence seasonal variation of indoor radon as well as thoron has been monitored. In this study complete one year is divided into three seasons viz. rainy season (May – August), winter season (September – January) and summer season (February – April).
2.10.2 Geological conditions

Locations are selected carefully taken into consideration the geological conditions of the place/area which are then sub-divided as follows:

a) **Fault Region**

These are the region where faults are observed. These places are located using the available geological mapping of the state. Since outgassing of the interested gasses is expected to increase in the area where there is fault hence, the study of concentration of these gases in these areas will be important.

b) **Fossils area**

The other selected geographical condition is the areas where there are fossils. For example, in Aizawl District, fossils are found in Hlimen Stone Quarry.

c) **Dwelling area (Unrepresented area)**

The third selected areas are places where no geological distinctiveness like fault or fossils regions are indicated and they may be treated as having normal soil also referred to as unrepresented area. These areas covered mostly the habitats/dwellings in Mizoram.

2.10.3 Types of Houses

Another important factor that influences especially the concentrations of indoor radon, thoron and their progeny is the types of houses. As the building material contributes the indoor radon and thoron concentration, hence the materials used for roof, wall and floor of the buildings are considered for selection of different types of houses. The types of houses selected are categorized as follows:
a) **Reinforced Cement Concrete (R.C.C.)**

The building material used for this type is cement concrete reinforced using iron rod. Hence, roof and floors are all made up of the same, while wall material is usually of bricks plastered with cement. However, the construction of this type of building may not be fully concrete at all. In such cases, the type of material will be indicated clearly whether the roof, wall or floor material is made of different materials.

b) **Assam Type**

In this type of house, roofs are G.I. Sheets, walls are mostly made up of asbestos (tile) while some are wooden and bamboo or even G.I. Sheets. Floors are mostly concrete while some are wooden.