CHAPTER III

EXPERIMENTAL PROCEDURE
AND CALCULATION
3.1. INTRODUCTION:

The "Particle track analysis" method using SSNTDs, described in the previous chapter has been used for the estimation of radon and thoron concentrations in dwellings. A brief description of the various types of materials and instruments used in the present study and also the various stages of the experimental procedure are given below.

3.2. MATERIALS AND INSTRUMENTS USED IN THE PRESENT STUDY:

3.2.1. Solid State Nuclear Track Detectors:

In the present study special track detectors CR-39 and LR-115 (type-II) have been used as passive detectors of alpha particles from radon, thoron and their daughters. A brief description of these detectors is given below.

Detectors like LR-115 and CR-39 used for indoor radon study are durable, simple, stable and not fogged by exposure to sun light. Fading of the damaged trajectory is also not observed even with moderate heating. These advantages of SSNTDs are suitable for remote studies of environmental radiations like cosmic rays in air craft, alpha exposures due to $^{222}$Rn and $^{220}$Rn in indoors as compared to other devices. Characteristics of the alpha sensitive track detectors used in radon dosimetry and their threshold limit of detection are given in Table 3.1 and Table 3.2.

Track density registered on SSNTDs depend on the properties of the detector material and the characteristics of the environment.
Table 3.1: Characteristics of detectors used in $^{222}$Rn dosimetry
(Ramachandran, 1998)

<table>
<thead>
<tr>
<th>Detector Composition</th>
<th>Density (gm/cc)</th>
<th>Trade Name</th>
<th>Proposed Etching Condition</th>
<th>$V_g$ (µm/h)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cellulose Nitrate ($C_6H_8O_5N_2$)</td>
<td>1.52</td>
<td>CN85 LR115 Type II</td>
<td>10% wt. NaOH, 60°C same</td>
<td>3.2</td>
</tr>
<tr>
<td>Allyldiglycol carbonate</td>
<td>1.33</td>
<td>CR 39</td>
<td>20% wt. NaOH, 70°C</td>
<td>1.3</td>
</tr>
</tbody>
</table>

Table 3.2: Typical limits of detectable alpha-particle energies for these detector materials (Mishra et al., 1995)

<table>
<thead>
<tr>
<th>Type of detector</th>
<th>E (Min) in MeV</th>
<th>E (Max) in MeV</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cellulose Nitrate</td>
<td>0.1</td>
<td>4 - 6</td>
</tr>
<tr>
<td>Allyldiglycol Carbonate</td>
<td>0.1</td>
<td>&gt; 20</td>
</tr>
</tbody>
</table>

Table 3.3: Recommended conditions for chemical etching and typical bulk etch (Ramachandran, 1998)

<table>
<thead>
<tr>
<th>Detector</th>
<th>Etchant</th>
<th>Temperature (°C)</th>
<th>Time (hr)</th>
</tr>
</thead>
<tbody>
<tr>
<td>LR - 115</td>
<td>2.5 N NaOH</td>
<td>60</td>
<td>1.5</td>
</tr>
<tr>
<td>CR - 39</td>
<td>6.25 N NaOH</td>
<td>70</td>
<td>6.5</td>
</tr>
</tbody>
</table>
besides the etching conditions (Table 3.3). CN and polycarbonate film are very thin and flexible while allyldiglycol polycarbonate is in the form of a thicker and unbendable plate. It is necessary to calibrate the system before its use in the field because the sensitivity of the detector material used depends on the dosimeter material and its design besides its variations with time and storage.

The cellulose nitrate \((\text{C}_6\text{H}_8\text{O}_9\text{N}_2)\) LR-115 type–II (strippable) film, manufactured by Kodak, Pathe, France has been used for the present study. LR-115 can easily register alpha particle tracks, which can be made observable by chemical etching. The type–II film is thin enough for the penetration of majority of the incident alpha particles to form perforated tracks and also thick enough to make well etched visible tracks (Fleischer et al., 1975).

3.2.2. Dosimeter Cup:

Actual design of SSNTD based dosimeters is based on parameters like

i) the thoron discrimination,

ii) need for aerosols or particulates,

iii) time of exposure etc.

Such type of dosimeters are classified into three categories viz.,

i) diffusion sampler,

ii) permeation sampler and

iii) bare detector dosimeter.

Diffusion sampler is a tube type dosimeter with the detector placed at one end. Other end of the tube is open. Length of the tube is made such
a way that complete thoron decay is possible during the diffusion to the effective zone area near the detector. Portability and easy handling of the use of it as a personal dosimeter are the attractive features of this arrangement. This is suitable only for long term measurements.

Permeation sampler differs from the diffusion sampler. In this type of dosimeter, the open end of the tube is closed by a semi permeable membrane that delays the entry of thoron and discriminates between $^{222}\text{Rn}$ and thoron (Ward et al., 1977).

Bare detector mode used in the measurements consists of a detector affixed on to a rectangular card which is facing the atmosphere to be monitored. This mode of exposure is generally suspected to suffer from interference due to dust deposition on the film. It has been observed that dust loading above 0.30 mg cm$^{-2}$ for a period of exposure 90 days could affect $^{222}\text{Rn}$ progenies (Subba Ramu et al., 1993). Different types of $^{222}\text{Rn}$ dosimeters used by different workers is shown in a tabular form (Table 3.4). While designing the dosimeter, the following points are taken in to consideration viz.

i) dosimeter cup,

ii) detector position,

iii) alpha energy range and

iv) source geometry (Jha, 1987).

Different types of dosimeters used for $\text{Rn}^{222}$/Thoron and their progeny measurements are shown in table 3.4.
Table 3.4: Different types of Dosimeters used for $^{222}$Rn /Thoron and their progeny measurements

<table>
<thead>
<tr>
<th>Dosimeter</th>
<th>Dimensions</th>
<th>Uses</th>
</tr>
</thead>
<tbody>
<tr>
<td>Radon dosimeter (RDD)</td>
<td>Internal diameter of 5.9 cm and a volume of 100 ml with open mouth covered with a suitable semi permeable membrane</td>
<td>$^{222}$Rn only</td>
</tr>
<tr>
<td>Twin chamber (TW)</td>
<td>The unit comprises a plastic cylindrical vessel open at both the ends. There is a plastic dividing wall in the middle, which divides the whole cylinder into two chambers. Detectors can be attached on both sides of this wall. Detectors can also be attached to the outer surface of the cylinder in a fixed position and exposed to radiation. The open ends are covered by perforated sheets. This type of dosimeter cups are used in the present study. Therefore, details of the dosimeter is discussed in this chapter.</td>
<td>$^{222}$Rn/thoron gas along with their daughters.</td>
</tr>
<tr>
<td>Bare detector</td>
<td>It is a rectangular type one with the detector affixed on it. It is also used for some areas in the present study and the details of the method is also discussed in this chapter.</td>
<td>$^{222}$Rn daughters</td>
</tr>
</tbody>
</table>
3.2.2.1. Details about Plastic Twin Chamber Dosimeter Cup

Method Used in the Present Study:

In the present study Plastic Twin-Chamber dosimeter cups (BARC-type) were used to determine the concentrations of radon, thoron and their progenies. The detectors were exposed in three different modes: 1) bare mode, 2) cup with filter paper, and 3) cup with filter paper and mylar. The schematic diagram of a Plastic Twin-Chamber dosimeter cup with detector positions is shown in Fig. 3.1.

It is a plastic cylindrical vessel of 11 cm. length and 7 cm. diameter and opened at both the ends. There is a plastic dividing wall at the middle, which divides the whole cylinder into two chambers each of length 5.5 cm. Detectors can be attached on both sides of this wall at the middle. On the outer surface of the cylinder in a fixed position, the detectors can also be attached and exposed to radiation. Open ends are covered by perforated sheets. From these three modes the concentrations of radon and thoron gas in Bq/m³ and the potential alpha energy concentration of individual progenies in terms of Working Level Units (WL) are measured.

Three pieces of LR-115 (type II) detectors of size 3 cm x 3 cm were placed in proper positions of the dosimeter cups. The bare detector, mounted on the outer side of the cup, views a hemisphere of air of radius at least 9.1 cm, the range of ²¹²Po alpha in air or 6.4 cm, the range of ²¹⁴Po alpha [Durrani and Bull, 1998]. It records all the tracks due to radon, thoron and their progenies. In the cup with filter paper mode, the detector was fixed on the dividing wall within the dosimeter cup and the mouth of the
FIG 3.1: SCHEMATIC DIAGRAM OF PLASTIC TWIN-CHAMBER DOSIMETER CUP USED FOR THE MEASUREMENT.
chamber on its side was covered with a filter paper. In the other chamber of the cup, the detector was fixed on the other side of the same wall and the mouth of the chamber on this end was covered with a filter paper, a mylar, then a filter paper. Filter paper and mylar do not permit the solid daughter products of thoron to pass through them and partly reduces the rate of diffusion of thoron gas itself due to its short half-life. It has been estimated that 98% of radon penetrates, but thoron does not enter the cup [Jojo, 1993; Mayya et al., 1998].

3.2.2.2. Details about the Method by Using Bare Mode Detector:

Monitoring of radon and its decay products were carried out by Bare Mode detector at the initial stage of the present study. This method employs assessment of radon and progeny concentrations from the alpha tracks registered on Solid State Nuclear Track detectors. In the Bare Mode small pieces of CR-39 detector of suitable size (2.5 cm × 2.5 cm) was mounted on a rectangular card such that it views a hemisphere of air of radius 6.9 cm., the range of 214Po alpha. No surface should be closer than this range as the daughter deposition would then add an interminate alpha particle source. An undetermined number of tracks are formed due to plateout of radon daughters on surfaces. Submicron aerosols of size 0.2 mm diameter and concentration (1.5 × 10^4 cm^-2 ), comparable to the ambient indoor values, are also needed for the attachment of radon daughters to keep them air-born. Otherwise most of the radon daughters will be lost on the walls of the chamber and as a result the calibration factor obtained will vary widely. The track-etch reading of a bare detector configuration will be a function not only of radon but also of the degree of
equilibrium of radon with its daughters. The bare detector mode of exposure is therefore, a measure of the total potential alpha energy exposure expressed as WL units. The bare detector configuration gives an average calibration factor of 1504 tracks cm\(^{-2}\) d\(^{-1}\) per WL and shows that it is necessary to calibrate the detector over a wide range of radon levels to obtain an accurate sensitivity factor. The detector is already calibrated by the method as given by Jojo et al. (Jojo et al., 1994).

In the bare mode exposure dust is generally deposited on the film. It has been reported that on an average about 0.3 mg/cm\(^2\) of dust load could effect the radon progeny estimates (Orzechowski et al., 1982). Dust collected over a three month period of exposure has been found to be less than 0.05 mg/cm\(^2\). The bare mode of exposure in the plane vertical to the ground reduce the dust deposition.

The card with the detector was suspended inside a room such that no wall or other surface (like ceiling and roof) was closer than 10 cm. from the detector. The detector was exposed to ambient radiation for a period of 90-100 days after which they were retrieved. After retrieving, the detectors were etched.

3.2.3. Selection of Sites and Installation of the Dosimeter Cups:

The following criteria are applied to select the location for placing the dosimeter with detector within a room.

A position is selected where the detector will not be disturbed during the observation period and where there is adequate room for the
device. Care is taken not to place the dosimeter in any of the room where there is possibility of air currents. Locations near excessive heat, such as fireplaces or in direct sunlight and areas of high humidity are also avoided (Homer and Miles, 1986)

The location should not be within 90 centimeters (about 3 feet) of windows or other potential openings in the exterior wall. The dosimeter is hung at an appropriate place within a room of the house in such a way that the dosimeter is not disturbed by inhabitants during the observation period. All dosimeters in the present study are suspended at a height of 2 to 2.5 meters (about 6 to 8 feet) from the floor.

The Plastic Twin-Chamber dosimeter cups with detectors were installed in such a way that no wall or other surfaces (like ceiling and roof) is closer than 10 cm. from the detector. The choice of the house was random one and one room in each house was selected for the measurement. Generally drawing rooms, bedrooms of a house are selected for suspending the dosimeters. The cups were exposed for about 90–95 days after which they were retrieved.

After retrieval, the exposed detectors were taken out from the dosimeter cups and the exposed detectors were immediately kept in a specially designed container. These were chemically etched within 24 hours after retrieval.

For each sampling site, a protocol containing necessary parameters for indoor radon/thoron concentrations are enlisted so that data interpretation and comparison can be made (Annexure-I).
3.2.4. Duplicate Measurements:

As a measure of cross checking the results of measurements, extra dosimeters are placed at the same room in some cases and radon concentrations for both dosimeters compared. In the present study duplicate measurements were made in at least 10% of the total number of locations.

3.2.5. Background measurements:

Unexposed detector may contain few tracks because of radon impinging on it during its transportation and storage for a long period at a place other than the selected site. Background measurements are necessary for getting accurate track density value at the location where the dosimeter is placed. We measured the background of a statistically significant number of unexposed detectors from each batch for the entire measurement system. Finally the background count is subtracted from the field sample results.

3.2.6. Etching apparatus:

Chemical etching is the important step to make tracks in solid state nuclear track detectors observable by optical microscope. By the method of etching using a suitable chemical etchant, the latent tracks can be enlarged to microscopically visible size. The transformation of a latent track to a visible track is determined by the simultaneous action of two etching processes: a) chemical dissolution along the path of the alpha particle at a faster rate, b) chemical dissolution of the bulk material at a slower rate.

In the present study the exposed films of CR-39 are exposed in 6N NaOH for 6 hours at (70±1)°C temperature and LR-115 films are etched in 2.5 N NaOH solution at (60±1)°C for 90 minutes. The solution is kept in a
glass beaker of 1000 ml. Now to suspend the detectors in the solution a straw of length 2 cm is taken. In this straw a fine incision is made by a sharp razor blade and in this incision one edge of the detector piece is inserted. This straw is allowed to float in the solution. When the straw floats, the detector inserted in it remains suspended vertically as shown in the Fig. 3.2. Normally 6 to 9 detectors are etched at a time in this manner. To ensure uniform etching of the films the solution is subjected to very mild stirring using a magnetic stirrer. The arrangement for etching the detectors is shown in Fig. 3.2.

After etching, the films are taken out from the solution and thoroughly clean in a jet of distilled water. Then the films are allowed to dry slowly and after that kept in a Desicator. Using an optical microscope performs the measurements of optically visible tracks.

3.2.7. Optical microscope:

An optical microscope (Olympus-BH-2) was used to scan the chemically etched tracks. Various magnifications could be made by using different combinations of objectives and eyepieces. Magnification used for the track density measurement in the present study was 200X. The eye piece was fitted with a square graticle which was used to count the tracks randomly all over the detector surface, for 100 fields of view to obtain a representative value. The area of each field of view was 0.004225 cm².

3.3. WORKING FORMULA:

3.3.1. FOR BARE MODE DETECTOR:

The measured track density (Tracks cm⁻² d⁻¹) was converted into radon progeny concentration in WL and the Equivalent Equilibrium Radon
FIG. 3.2: SCHEMATIC DIAGRAM OF ETCHING APPARATUS
concentration $EEC_{\text{radon}}$ in Bq.m$^{-3}$ by using the following formulae (3.1) and
(3.2) respectively (Jojo et al., 1994).

\[ WL = \text{Tracks cm}^{-2} \text{d}^{-1} / 1504 \]  
\[ EEC_{\text{radon}} = WL \times 3700 \]  

where 1504 tracks cm$^{-2}$ d$^{-1}$ (WL)$^{-1}$ is the calibration factor for the
detector and WL is a measure of the total potential alpha energy exposure
from 3700 Bq.m$^{-3}$ (Khan et al., 1990).

**3.3.2. FOR PLASTIC TWIN-CHAMBER DOSIMETER CUP:**

Let $T_1$ and $T_2$ be the track densities registered in membrane
and filter mode exposure (as observed through microscope), d is the
exposure days, $C_R$ and $C_T$ be the concentrations of radon and thoron in
Bq.m$^{-3}$, $K_R$ and $K_T$ be the sensitivity factors for radon and thoron gas. Then
(Dwivedi et al., 2001)

\[ C_R = \frac{T_1}{dK_R} \]  
\[ C_T = \frac{(T_2-T_1)}{dK_T} \]

where $K_R = 0.020$ Tcm$^{-2}$d$^{-1}$/Bq.m$^{-3}$ and $K_T = 0.019$ Tcm$^{-2}$d$^{-1}$/Bq.m$^{-3}$ for radon
and thoron gas in the membrane and filter compartments.

The progeny working levels are expressed in WL units. One WL is
a measure of the total potential alpha energy exposure of radon/thoron in
one litre of air which will result in the ultimate emission by them of $1.3\times10^6$
MeV of alpha ray energy. ICRP-65(1993) now defines the WL as $1.300\times10^6$
MeV.m$^{-3}$. It also corresponds to $2.08\times10^{-5}$ J m$^{-3}$ in S.I. units. The progeny
working levels can be estimated as
\[ WL_R = C_R F_R / 3.7 \] (3.5)

where

\[ F_R = (0.104 F_{R,A} + 0.518 F_{R,B} + 0.37 F_{R,C}) \] (3.6)

and

\[ WL_T = C_T F_T / 275 \] (3.7)

where

\[ F_T = 0.908 F_{T,B} + 0.092 F_{T,C} \] (3.8)

where \( F_R \) and \( F_T \) are the equilibrium factors for radon and thoron progeny respectively, corresponding to the extracted ventilation rate.

\[ F_{R,A} = D_{R,A} / \{ D_{R,A} + (U_{F_{R,A}} \times WLF) + (1 - U_{F_{R,A}}) \times WLC + V \} \] (3.9)

where, \( D_{R,A} \) is decay constant of RaA \((= 3.79 \times 10^{-3} \text{ s}^{-1})\) and \( U_{F_{R,A}} \) is the unattached fraction for RaA \((= 0.2)\), WLF is the wall loss rate for fine fraction \((= 10 \text{ h}^{-1})\) and WLC is the wall loss rate for coarse fraction \((= 0.1 \text{ h}^{-1})\).

\[ F_{R,B} = F_{R,B} D_{R,B} / \{ D_{R,B} + (U_{F_{R,B}} \times WLF) + (1 - U_{F_{R,B}}) \times WLC + V \} \] (3.10)

where, \( D_{R,B} \) is the decay constant of RaB \((= 4.3 \times 10^{-4} \text{ h}^{-1})\) and \( U_{F_{R,B}} \) is the unattached fraction for RaB \((= 0.025)\) and \( V \) is the ventilation rate.

\[ F_{R,C} = F_{R,B} D_{R,C} / \{ D_{R,C} + (U_{F_{R,C}} \times WLF) + (1 - U_{F_{R,C}}) \times WLC + V \} \] (3.11)

where, \( D_{R,C} \) is the decay constant of RaC\((^{214}\text{Bi})\) \((= 5.78 \times 10^{-4} \text{ s}^{-1})\) and \( U_{F_{R,C}} \) is the unattached fraction for RaC \((= 0.001)\).
\[ F_{T-A} = \frac{D_{T-A}}{D_{T-A} + WLC + V} \]  (3.12)

where \( D_{T-A} \) is the decay constant of ThA (\(^{216}\)Po) \( (= 1.82 \times 10^{-5} \text{ h}^{-1}) \).

\[ F_{T-C} = F_{T-A} \times \frac{D_{T-C}}{D_{T-C} + WLC + V} \]  (3.13)

where \( D_{T-C} \) is the decay constant for ThC (\(^{212}\)Bi) \( (= 1.91 \times 10^{-1} \text{ s}^{-1}) \).

Representative average thoron concentration denoted by \( C_T \),

\[ C_{T-B} = C_T \times F_{T-B} \]  (3.14)

\[ C_{T-B} = C_T \times F_{T-B} \]  (3.15)

Finally, the estimate of the inhalation dose is given by:

\[ D = \frac{(0.17 + 9F_R)C + (0.11 + 32F_T)C_T}{1000 \, \mu \text{Sv.h}^{-1}} \]  (3.16)

A computer program was developed in order to carry out these computations. With the help of this computer program we can calculate the radon, thoron and their progeny concentrations, equilibrium factors for radon and thoron, inhalation doses and ventilation rate.

Distribution of indoor radon levels follows a log-normal distribution, which means that there would be a long tail in the distribution where a very small fraction of the total would have very large values. The geometric mean and geometric standard deviation are appropriate for characterising this type of distribution.