MEASUREMENT OF RADON, THORON AND THEIR PROGENY CONCENTRATIONS IN MIZORAM WITH SPECIAL REFERENCE TO AIZAWL, CHAMPHAI AND KOLASIB DISTRICTS

Thesis submitted in fulfillment of the

requirements for the degree of

Doctor of Philosophy

in Physics

By

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Registration No and Date: MZU/Ph. D/ 329/10.06.2010

To

Department of Physics
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September 2012

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Certificate

This is to certify that the thesis entitled *'Measurement of Radon, Thoron and their progeny concentrations in Mizoram with special reference to Aizawl, Champhai and Kolasib Districts'* submitted by Shri Lalmuanpuia Vanchhawng, for the degree of Doctor of Philosophy of the Mizoram University, Aizawl, embodies the record of original investigations carried out by him under my supervision. He has been duly registered and the thesis presented is worthy of being considered for the award of the Ph. D. degree. This work has not been submitted for any degree of any other university.

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Certificate

This is to certify that the thesis entitled *'Measurement of Radon, Thoron and their progeny concentrations in Mizoram with special reference to Aizawl, Champhai and Kolasib Districts'* submitted by Shri Lalmuanpuia Vanchhawng, for the degree of Doctor of Philosophy of the Mizoram University, Aizawl, embodies the record of original investigations carried out by him under my joint supervision. He has done his training in BARC, Mumbai for two weeks during 14th – 27th March, 2008 as a JRF under a coordinated Research Project of Govt. Zirtiri Residential Science College, Aizawl and BARC, Mumbai. He has been duly registered and the thesis presented is worthy of being considered for the award of the Ph. D. degree. This work has not been submitted for any degree of any other university.

(Dr. B.Zoliana)

Jt. Supervisor

Declaration of the Candidate

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I, Lalmuanpuia Vanchhawng, a Ph.D. scholar in Physics Department, Mizoram University, Aizawl, do hereby solemnly declare that the subject matter of this thesis is the record of the work done by me. I have duly worked on my Ph. D. thesis under the supervision of Prof. R. K. Thapa, Department of Physics, Mizoram University (Supervisor) and Dr. B.Zoliana, Department of Physics, Govt. Zirtir Residential Science College, Aizawl (Joint supervisor). This is being submitted to the Mizoram University for the degree of Doctor of Philosophy in Physics and that I have not submitted this work to any other University or Institute for any other degree.

I also declare that the present investigations relate to bonafide research works undertaken and the title of the thesis is **'MEASUREMENT OF RADON, THORON AND THEIR PROGENY CONCENTRATIONS IN MIZORAM WITH SPECIAL REFERENCE TO AIZAWL, CHAMPAI AND KOLASIB DISTRICTS'.**

Dated: 14th September, 2012 **(LALMUANPUIA VANCHHAWNG)**
Candidate

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Dated: 14th September, 2012

Department of Physics,

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CONTENTS

I would like to dedicate my thesis to my late grand father,

Saisanga Sailo.

He made everlasting impression on my soul through his smile, his support, encouragement, love, strong opinions and safe hands. He was such a great man, and such a wonderful grandfather.
His love and support meant the world to me.

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CHAPTER 1

Introduction

1.1 Natural and Artificial Radiation

Organisms have been continuously exposed to radiation since time immemorial. Radiation is the process of release of energetic particles or energy or waves from unstable nuclei. Radiation can be classified into ionizing and non-ionizing radiation. As the name indicated, ionizing radiation refers to the type of radiation with sufficiently high energy which has the capability to ionize atom. Non-ionizing radiations are that with lower energy sufficient only to change the rotational, vibrational or electron valence configurations of atoms. In this work, we draw more attention to ionizing radiation, which is again divided into two types, natural and artificial radiation.

Radiation from naturally occurring nuclei is called Natural Radiation, whereas radiation from man-made or induced unstable nuclei is called Artificial Radiation. The main sources of natural radiation are Cosmic rays and Terrestrial radiation. Man-made sources or artificial sources of radiation include medical sources, industrial sources, nuclear sources, occupational sources and consumer products, etc. Some environmental radiation is of importance to life even though high levels of radiation are definitely harmful to organisms. And hence it is clear that contemporary life have adjusted or are doing so to all features and limitations of the environment, including the natural background radiation. Cosmic rays are radiation of extraterrestrial origin, to which the earth is continuously exposed. These rays are highly penetrating radiation that impinged upon the earth from space, rather than emanating from the earth. Radionuclides produced

from cosmic rays are ^{7}Be, ^{10}Be, ^{14}C, ^{36}Cl, ^{38}Cl, ^{39}Cl, ^{3}H, ^{22}Na, ^{27}Na, ^{32}P, ^{33}P, ^{35}S, ^{38}S and ^{32}Si. Among these, ^{39}Cl has the shortest half life of 55 min. Terrestrial radiation includes radiation emanating from the earth itself and not from outer space.

Among the primordial radionuclides, which have been come into existence at the time of formation of the earth, Potassium-40, Uranium-238 and Thorium-232 are of overwhelming significance. Among the radionuclides in the decay chain of U-238 and Th-232, the present study pays most concentration to Radon (^{222}Rn), Thoron (^{220}Rn) and their progeny.

1.2 Radon and thoron

Radon, thoron and their progeny, which is a topic of public health concern, has been found to be a ubiquitous indoor air pollutants in homes to which all persons are exposed. Annual exposure due to these nuclei imparts the major contribution to the inhalation dose. Therefore, it is fundamental and justified to make a quantitative assessment of their concentrations in dwellings. In view of the fact that radon, thoron and their progeny concentrations contribute the most to the natural radiation dose to general populations, large scale and long-term measurement of radon, thoron and their progeny concentrations has been receiving considerable attention (Mayya *et al.,* 1998).

Since radon is produced continuously from the α-decay of radium isotopes in rocks and minerals, there are three natural isotopes of this radioelement in the environment – ^{222}Rn (radon), ^{220}Rn (thoron), and ^{219}Rn (actinon) originated from the so-called decay series of ^{238}U (uranium), ^{232}Th (thorium), and ^{235}U (actinium), respectively. Fig. 1.1 and Fig. 1.2 show the detailed listing of ^{238}U and ^{232}Th decay series respectively.

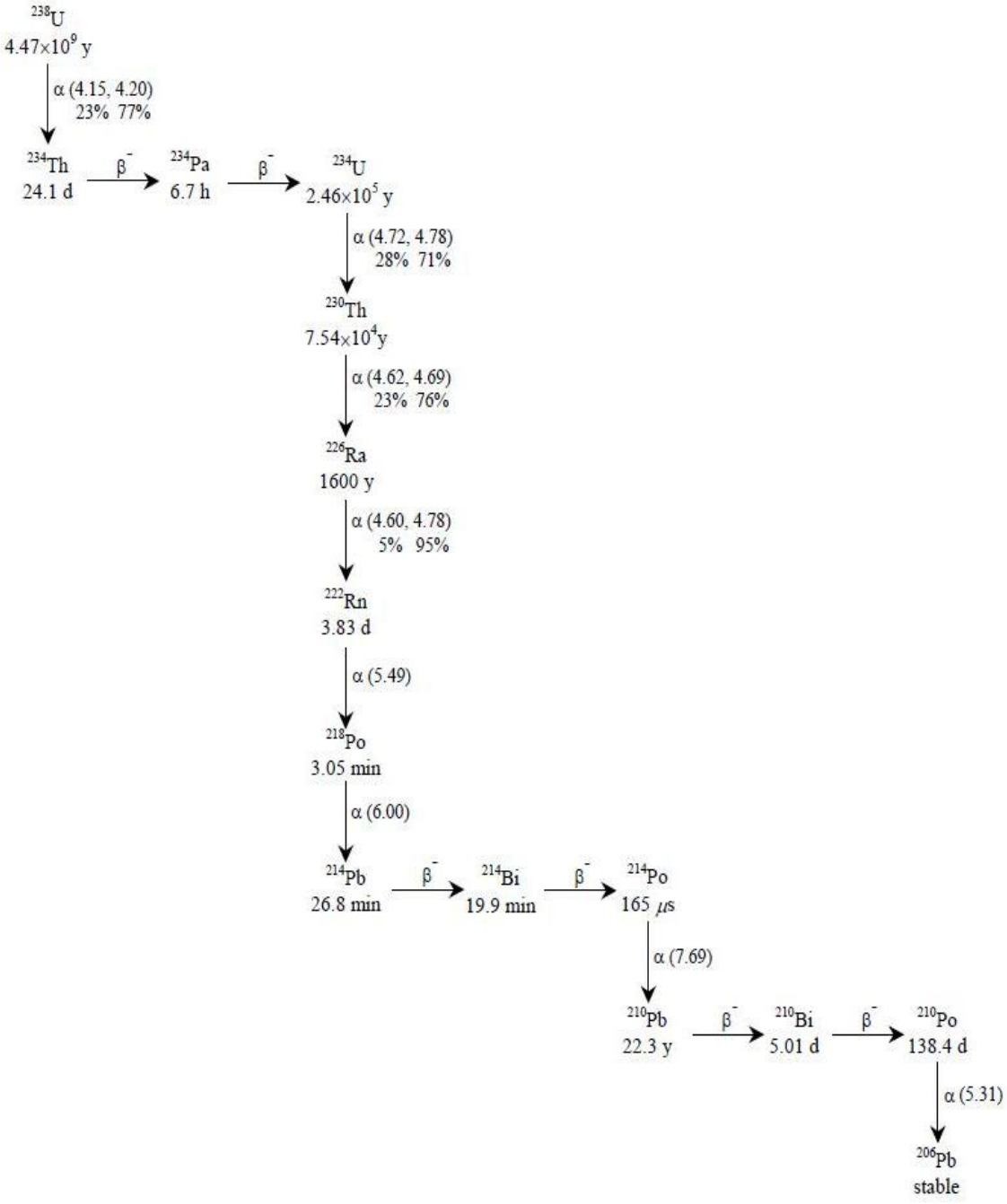

Figure 1.1 Decay diagram of ^{238}U series with the half-life of each radionuclide and the energies of α-emissions expressed in MeV.

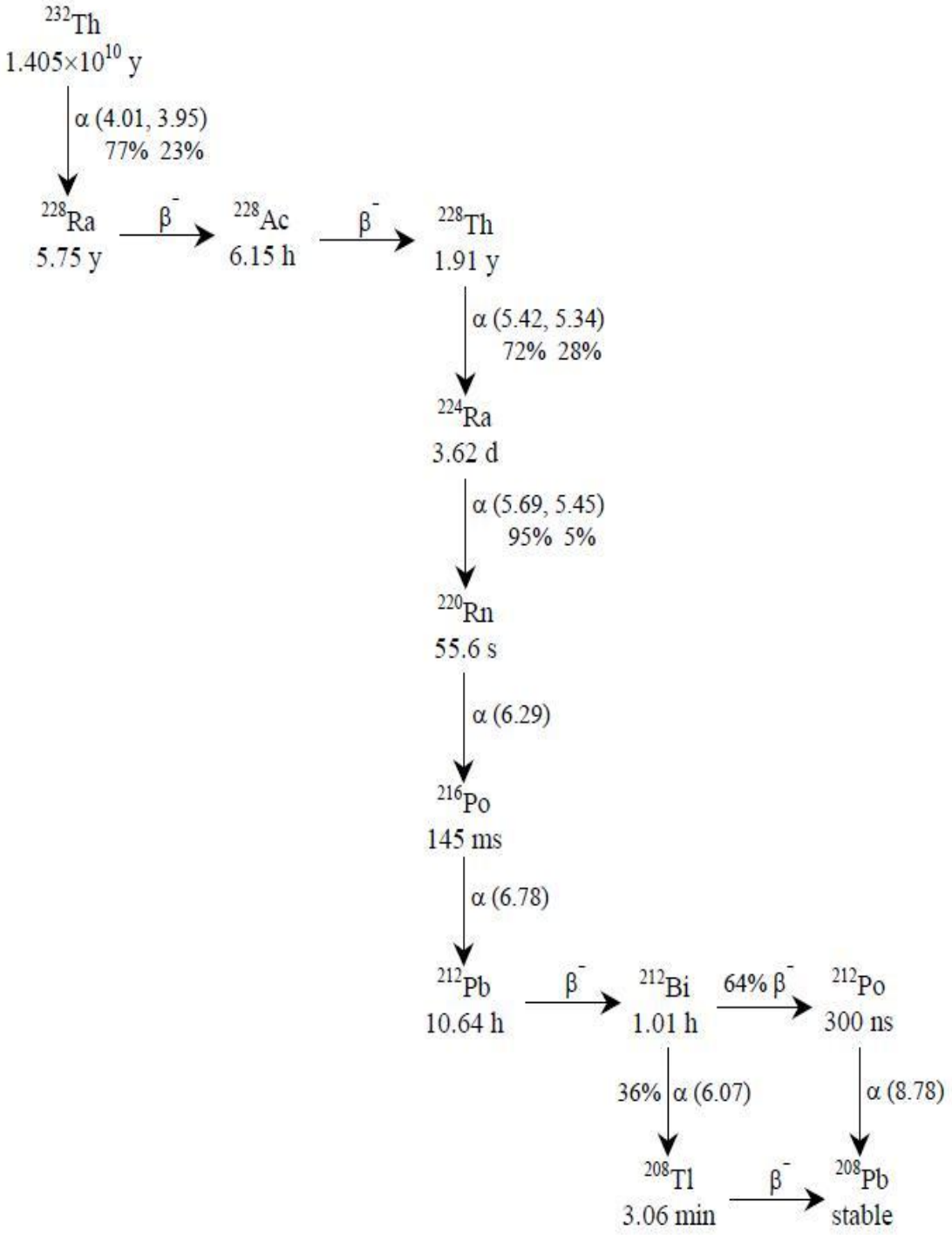

Figure 1.2 Decay diagram of ^{232}Th series with the half-life of each radionuclide and the energies of α-emissions expressed in MeV.

Radon was discovered by Friedrich Ernst Dorn in 1900 after the discovery of Radium by Marie Curie and Pierre Curie in 1898 (Bentor *et al.,* 2006). It was the fifth discovered radioactive element after uranium, thorium, radium and polonium. Rutherford established that thorium compounds also show similar emanation properties like radon. The name "radon" was chosen by the International Union of Pure and Applied Chemistry (IUPAC) in the year 1923. The presence of radon in the free atmosphere was first noted by Elster and Geitel around 1901 (Elster *et al.*, 1901).

Radon is a natural radioactive gas that occurs ubiquitously throughout the world. It is the decay product of radium and is produced in any material containing radium. Radon is a colourless, odourless, tasteless and radioactive noble gas that generally lacks activity towards other chemical agents. The atomic number of radon is 86 and mass number is 222. It is the heaviest member of the rare gas group (~100 times heavier than hydrogen and ~7.5 times heavier than air) and has a half life of 3.82 days. It is denoted by ^{222}Rn. The density of radon is 9.73 kg/m^3, it has a freezing point of 202K (- 71.15 ºC; - 96.07 ºF) and a boiling point of 211.3K (- 61.85 ºC; - 79.1 ºF) at 1 atmospheric pressure. The heat of fusion of radon is 3.247kJ/mol and heat of vaporization is 18.10 kJ/mol. It has a critical temperature of 105ºC and critical pressure of 62 atm. Since the electrons in the outer valence shell are tightly bound, the first ionization energy of radon is as high as 1037 kJ/mol. The atomic radius of radon is 1.82 Å. Radon has a lower electronegativity than xenon. It is sparingly soluble in water but more soluble than lighter inert gases. It is more soluble in organic solvents but the solubility of radon decreases with rise in temperature. Radon can be oxidized by a few powerful oxidizing agents such as fluorine. It has a low volatility. Upon condensation, when cooled below its freezing point, radon

has brilliant phosphorescence which turns from yellow to orange-red as temperature decreases. The property of radon that it is readily absorbed on activated charcoal (Kolthoff and Philip, 1966) helps in separating radon from a mixture gases. Atmospheric radon concentration is usually measured in Becquerel per cubic meter (Bq/m^3). This is the SI derived unit. In USA, it is measured in picocuries per liter (pCi/L) with 1 pCi/L = 37 Bq/m^3.

The importance of radon as an environment source of radiation depends mainly on the concentrations of the parent – radium – isotopes, on the physical characteristics of its source medium, and on its mean life. Actinon has limited capacity to migrate into air environment because of its half-life of only 3.96 s. Similarly, due to the lower relative abundance of ^{235}U by weight in natural uranium – ~ 0.711% (Amgarou *et al.*, 2001) – this radioelement is extremely rare in the atmosphere and can generally be neglected in radon dose considerations.

The first major studies of the health concern occurred in the context of uranium mining, first in the Joachimstal region of Bohema and then in the Southwestern United States during the early Cold War. Because radon is a product of uranium, uranium mines may have high concentrations of radon and its highly radioactive daughter products. Many uranium miners in the Four Corners region contracted lung cancer and other pathologies as a result of high levels of exposure to radon in the mid-1950s. The danger of radon exposure in dwellings was discovered in 1984 with the case of Stanley Watras, an employee at the Limerick nuclear power plant in Pennsylvania (Nazarof, 1988).

Thoron is an isotope of radon having the same atomic number as radon (86) but different mass number of 220. Thoron has a half life of 55.6 seconds (Pillai and Paul,

1999). It is denoted by ^{220}Rn. It is a natural decay product of the most stable thorium isotope (^{232}Th). The main characteristic of ^{222}Rn and ^{220}Rn among other natural radioactive elements is the fact that their behaviour is not affected by chemical processes (Nazarof, 1988). Formed as a result of the natural radioactive series in the earth's crust they are free to move through soil pores and rock fractures; then to escape into the atmosphere. Radon and thoron decay with the emission of alpha particles and produce daughter nuclei – polonium, lead and bismuth. These daughter nuclei emit alpha or beta particles. Among the daughter nuclei of radon, ^{218}Po has a half life of 3.1 min while ^{214}Po has a half life of 0.164 μs. In case of thoron, the daughter nuclei ^{216}Po has a half life of 0.16 sec and ^{212}Po has a half life of 0.3 μs. Among all the other progenies of radon as well as thoron, these short lived progenies are under consideration.

The probability of decay of thorium is smaller compared to Uranium. However, it is more abundant in the earth's crust, as a result, the production ratio of ^{222}Rn and ^{220}Rn in the soil are roughly the same. Since ^{220}Rn has a short half-life, which is less than a minute, most of its atoms decay before reaching the earth's surface. The mean diffusion length of ^{220}Rn, which is proportional to the square root of the mean life τ, is expected to be lower than that of ^{222}Rn by a factor of 77. An effective source for ^{220}Rn entering the atmospheric environment, indoors or outdoors is just a small thickness of soil or building material. ^{222}Rn constitutes the major concern as a health hazard in the environment as compared to ^{220}Rn because of its higher dominance in indoor air. Considering a uniform entry rate from soil and building materials, the only removal process of the indoor concentration of ^{220}Rn is by decaying, while ^{222}Rn may also be reduced by ventilation.

Hence, the possible health significance of ^{220}Rn is not to be ignored, and, indeed, its concentration must be taken into account (Albarracin *et al*., 2002).

^{222}Rn and ^{220}Rn are free to move through soil pores and rock fractures and then to escape into the atmosphere since they are formed from the natural radioactive series in the earth's crust. In presence of dwellings, they may migrate into this structure and accumulate indoors in sufficient quantities to pose a health hazard (Amgaraou, 2001). In addition to the fact that the behavior of radon (^{222}Rn) and thoron (^{220}Rn) is not affected by chemical processes, their concentration levels depend strongly on geological and geophysical conditions, as well as on atmospheric influences.

1.2.1 Emanation and Exhalation

Emanation is the process of transfer of radionuclides into the air-filled pores beneath the soil surface. Exhalation is the transportation of radon and/or thoron from the air-filled pores inside the soil surface to the open atmospheres. As radon and thoron originated from the radioactive decay of radium isotopes in the earth's crust, their indoor concentrations depend on the abundance of their parent radionuclides and on their access to building interiors. Soils and rocks under or surrounding the dwellings are the main source of radon as well as thoron to which people are exposed (Nazaroff *et al*., 1988a; UNSCEAR, 2000). Building materials are the second sources of significance (Nazaroff *et al*., 1988a; Stranden, 1988; UNSCEAR, 2000). Both soil and building materials can be divided into two major volume fractions: solid and porous fractions. Solid fraction consists mainly of mineral grains of a wide range of sizes including a small amount of organic matter. Porous fraction is usually occupied by moisture content (water) and gas, generally in similar composition to air. The porosity increases with decrease in the solid

grain size (Nazaroff *et al*., 1988a). It is the fraction of the bulk volume of the considered soil matrix constituting the pore volume.

A soil or a building material is saturated when the moisture content equals its porosity. There is a substantial concentration gradient between such materials and indoor air because soil and most earth-based materials have approximately 100 times higher ^{222}Rn and/or ^{220}Rn concentration than the atmosphere. This gradient is permanently maintained by the generation of the ^{238}U and ^{232}Th series, from the long-lived parent radionuclides, and is responsible for a continuous flux of the radon isotopes. Fig. 1.3 shows a schematic illustration of radon and thoron emanation, transport and entry mechanisms from soil or buildings materials into indoor air.

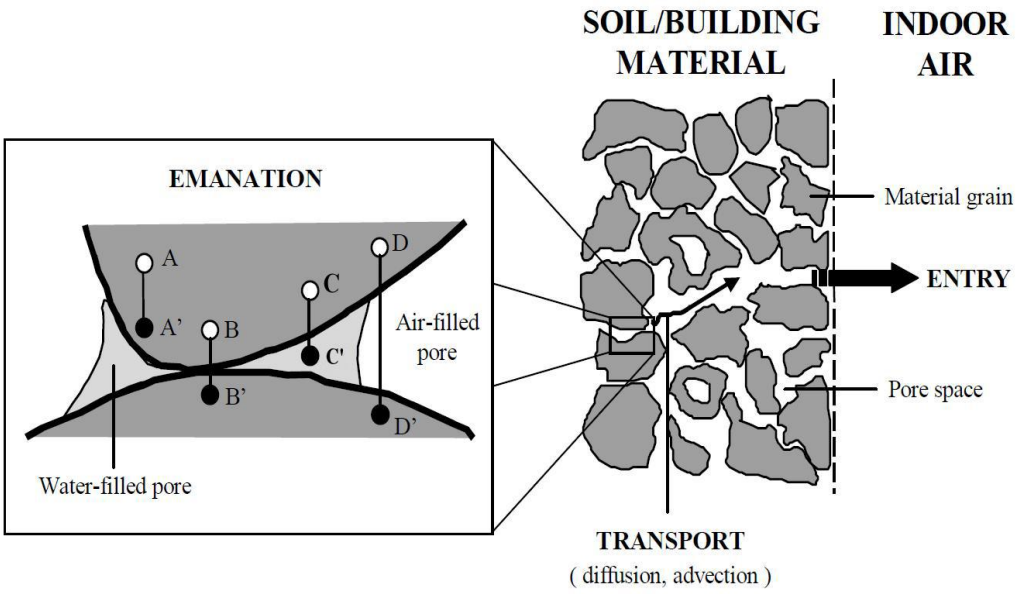

Figure 1.3 Schematic illustration of ^{222}Rn and ^{220}Rn emanation, transport and entry mechanisms from soil and buildings materials into indoor air – adapted from Knutson (1988).

From the figure, it is clear that ^{226}Ra (^{224}Ra) atom (indicated by open circles) decays producing an α-particle and a ^{222}Rn (^{220}Rn) atom, which may end its recoil path at the point indicated by the solid circle. In case of atoms present at A the parent atom is too deeply embedded within the grain for ^{222}Rn or ^{220}Rn atom to escape. But for locations at B and D the recoiling atom possesses sufficient energy after escaping the host to penetrate a neighbor grain. At C the ^{222}Rn or ^{220}Rn atom terminates its recoil in the pore water and, from there; it is readily transferred to the air-filled pore.

The resulting atoms of ^{222}Rn and ^{220}Rn from the decay of radium isotopes, the material grains possess kinetic energies of 86 keV and 103 keV respectively. The newly formed atom travels from its site off generation until its recoil energy is transferred to the material. A fraction of these atoms may reach the fluid-filled pore space when the site of generation is close to the grain surface as shown clearly in Fig. 1.3. This fraction is known as the emanation coefficient and is considered to have two components: recoil and diffusion. The main component of the emanation coefficient is contributed mainly by the recoil fraction stopped in the pore volume.

Due to the lower recoil range for ^{222}Rn and ^{220}Rn in water (~723 Å and ~807 Å, respectively) than in air (~65 μm and ~76 μm, respectively) the concentration of ^{222}Rn and ^{220}Rn in the air-filled pore volume increases with the soil moisture. A radon atom entering a pore that is filled or partially filled with water has a high probability of being stopped in the liquid phase without reaching another material grain. From there, it is readily transferred to the air-filled pore (Nazaroff *et al*., 1988a).

1.2.2 Radon/thoron entry into dwellings from soil

A schematic illustration of the radon and/or thoron entry routes from soil into a dwelling is shown in Fig. 1.4. It should be noted that the presence of a dwelling may alter the soil underneath changing its porosity, serve as an umbrella to rain so that the soil moisture content is generally minimal, and may also generate a small under-pressurization between indoor air and the soil underneath but high enough to provide all the radon needed to give the actual indoor levels.

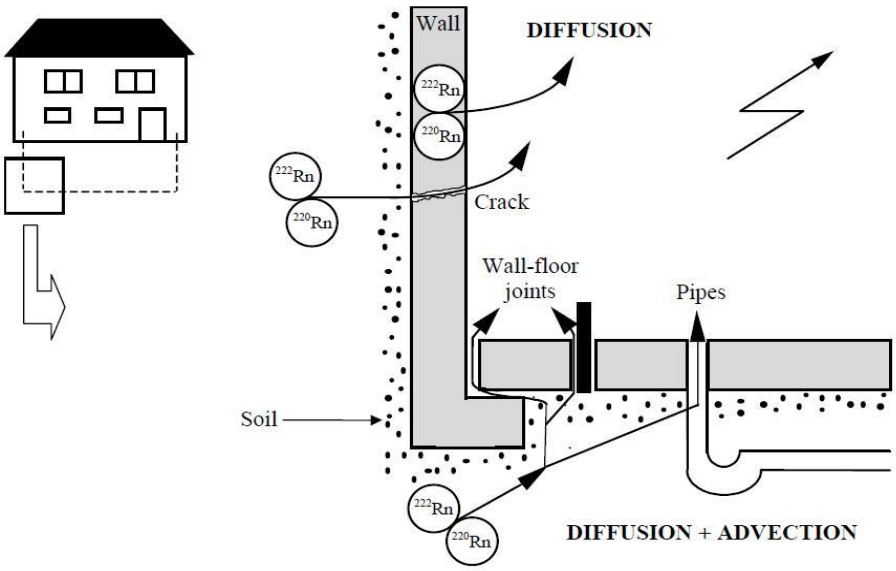

Figure 1.4 Schematic illustration of the 222Rn and/or 220Rn entry routes from soil into a house – adapted from Font (1997).

Besides, the soil underlying characteristics of the dwellings may be quite different from the original land patterns depending on the gradation or manner in which the foundation of the building is constructed. A very common material used in the building substructure is concrete, which acts as an effective barrier in front of ^{222}Rn and/or ^{220}Rn coming from the soil underneath taking into account its low diffusivity compared to that

of soil (Rogers *et al*., 1995). The entry of ^{222}Rn and/or ^{220}Rn from the soil into an indoor air may be considerably increased by the presence of cracks, gaps, holes and other penetration mechanisms in the concrete slab. Therefore, direct measurements of the resulting entry rate which is depending strongly on the permeability of the underlying soil and on the under-structure characteristics of the building are not available. As a result, a theoretical prediction of this source term for specific dwellings, taking into account all these effects and considering both diffusion and advection processes, is not easy to perform. The possible contribution of radon and/or thoron entry from soil can only be estimated from the observed total entry rate, subtracting the measured contribution of the building materials (Albaracin *et al.*, 2002).

1.2.3 Accumulation of ^{222}Rn and ^{220}Rn in indoors

Indoor radon and thoron concentrations are affected only by two factors: the entry and the removal processes. Due to their lack of chemical activity with other air components, indoor radon/thoron acts as inert pollutants. The entry and removal processes are highly affected by the building design, the construction and operation characteristics, and the inhabitant behaviour as well.

Radon and thoron are the decay product of radium and thorium respectively, hence, are produced in any material containing radium and/or thorium. It is well known that building materials have been extracted from the naturally existing materials found in the earth; the process of exhalation also takes place from a building materials used in constructing dwellings. Radon and thoron present in outdoor and indoor air as they exhaled from soil and building materials. ^{222}Rn and/or ^{220}Rn exhaled from the earth's surface into the free atmosphere is rapidly dispersed and diluted by natural convection

and turbulence. These gases concentrate in indoor due to the fact that when a dwelling is present, exhaled gases from the soil have a much higher chance to migrate into this structure as compared to their dispersion process into the atmosphere. Besides, contribution of building materials may increase higher indoor concentration and accumulation of radon, thoron and their progenies which may further results in sufficient quantities to pose a health hazard. This phenomenon of heightened concentration in indoor was discovered by chance in 1985. Air circulation rate of the building with the outside environment, called the 'ventilation rate', also plays a vital role in the accumulation of indoor radon, thoron and their progeny. Higher the ventilation rate, lower will be the indoor concentration and vice versa.

Building materials' radon exhalation rate has been studied by The Nuclear Engineering Section of the National Technical University of Athens (Petropoulos *et al*., 2001), Investigation of the influences of atmospheric condition on the variability of radon and progeny in buildings has been done in Northampton, UK (Marley, 2001) and Particle deposition onto surfaces of building materials has also been studied (Lai, 2004). In Japan, work has been in progress for the study of thoron chamber and interference of thoron on radon measurements (Tokonami, 2008). The concentrations of radon, thoron and progeny deviate from place to place and depend on the building material in case of indoor concentration. In India, Ramu *et al*. (1990) had initiated indoor radon measurements in some dwellings of 15 towns which were specially selected on the basis of high uranium content in the soil. Radon Monitoring has been done in Haryana by Kant and Chakravarti (2004) and found indoor radon levels in dwelling of Harayana to be 40 – 134 Bq/m^3 in Cemented House. Studies of radon and thoron levels in Mysore City have also been done

and radon concentrations were found within 33 Bq/m^3 in more than 50% of the dwellings studied (Chandrashekara and Paramesh, 2008). In Mizoram, measurement of radon, thoron and their progeny concentrations were done only in 17 dwellings (Ramachandran *et al.*, 2003).

1.3 Progenies of radon and thoron

Radon and thoron atoms decay producing isotopes of polonium, lead, and bismuth. These elements are heavy metals chemically very active, which may exist briefly as ions and/or free atoms before forming molecules in condensed phase or attached to airborne dust particles, typically to those with a sub-micron range of sizes, forming radioactive aerosols. A variable proportion remains unattached to airborne dust particles and is referred as the airborne-unattached fraction. This fraction may be inhaled and deposited in the respiratory tract, in which they release all their α-emissions. These emitted alpha particles are used to calculate the actual concentration of the parent atom. The dose to airways is influence by the particle size distribution of the aerosol-attached fraction in the inhaled air because particles of different sizes deposit preferentially in different areas of the respiratory tract. ^{222}Rn decay products are divided into two groups, namely, the short-lived (^{218}Po, ^{214}Pb, ^{214}Bi, and ^{214}Po) and the long-lived (^{210}Po, ^{210}Pb, and ^{210}Bi) daughters. For the first group, the whole sequence of decays can be completed before the human clearance processes can sweep them away because even the longest-lived element has a half-life of less than 27 min. In the second group, the long-lived radon progeny contributes relatively little to lung exposure because they are utterly removed from the body before decaying (Amgarou *et al.*, 2001).

Since there are no long-lived group in its daughter, ^{220}Rn decay chain has a different case. The most important radionuclide in its chain is the lead isotope ^{212}Pb, which has a relatively long half-life of 10.64 h. However, a considerable fraction of this radionuclide deposited in the bronchial epithelium can be absorbed into blood; so that it may be carried to other organs and may produce a large biological impact (Amgarou *et al.*, 2001).

1.4 Factors governing environmental radon and thoron

There have been many factors affecting radon, thoron and their progeny concentrations in the environment. As already mentioned, geological and geophysical conditions, temperature, atmospheric pressure, climate, relative humidity, day/night, etc. plays important role in exhalation rate, dispersion and diffusion in the environmental atmosphere as well as indoor accumulation and concentration of radon, thoron and their progeny.

The rate of escape or the exhalation of radon and thoron from the soil depends on the abundance of the parent nuclei inside the soil, local geological and meteorological conditions, soil porosity, soil moisture, soil grain size, and conditions of the soil surface (Porstendorfer, 1994). For example, in fault region the exhalation rate is expected to be higher due to the loose binding of the soil particles due to often movement of the layers of the earth's crust. The climatic effects of environmental radon, thoron and their progeny concentrations are also considerable, since with increase in temperature, the exhalation of radon increases. Besides, in case of indoor environment, increases in temperature will results in high ventilation rate due to longer duration of open windows and doors in

dwellings. Also, after a heavy rain, indoor radon levels will rise when the gas flow is diverted toward the unsaturated soil near the structure of the dwellings.

Construction type and types of building materials used for construction also become an important factors governing indoor radon, thoron and their progeny concentrations. Building materials containing more radium and/or thorium will lead to higher exhalation of their daughter radon and/or thoron nuclei, which will result in higher indoor concentrations and vice versa. Recalling the decay chain, higher radium means higher Uranium-238. Construction type of dwellings varies considerably taking into account the air exchange rate with the environment. More air exchange rate will result in less accumulation of the radon in indoor while radioactivity content of the building materials as well as soil and exhalation rate greatly affects indoor thoron levels.

1.5 Measurement of the focused radionuclides

Even though measurement of radon, thoron and their progeny concentrations was done over the past 50 years in many countries, with the improvement of experimental apparatus and technical formulation, the same is going on till today. With these improvements, monitoring of radon, thoron and their progeny concentrations are also well correlated with the prediction of earthquakes (Ramachandran *et al.*, 2004). As for the correlation with earthquakes, by continuous monitoring of radon concentration in a specific area, there has been a high deviation on the concentration of radon before or after the earthquake. Radon anomalies were observed prior to earthquakes in California in 1979, in Japan at Kobe in 1995, in China at Tangshan in 1976, etc (Ramachandran *et al*., 2004). In India, Guru Nanak Dev University, Amritsar and Palampur Station, Himachal Pradesh which has continuously monitored radon concentrations reported that their data

recorded shows 25 anomalies correlated to earthquakes in the region (Virk, 1994). Both Chamobi and Bhuj earthquake that occurred in March 29, 1999 and January 26, 2001 respectively were postdicted by correlation of radon anomalies recorded at Palampur in the soil-gas and ground water (Ramchandran *et al*., 2004).

Several techniques are in use to measure the radon/thoron levels in air. This includes their collection on a filter paper and subsequent alpha counting. Several personnel dosimeters employing tracks detectors have also been developed. These techniques have been increasingly used for the measurement of radon or thoron in soil gas, uranium exploration, earthquake predictions and geological studies. The nuclear track detector technique is the most reliable method for the integrated and long-term measurement of indoor radon activity (Ramu *et al*., 1992). Frank and Benton (1977) studied the improvement of two-detector devices, where one detector is placed open, and the other is placed inside the chamber closed with an inlet filter. By this method they propose the possibility to determine the equilibrium factor. Twin cup dosimeter was developed, in which membrane is use to filter the inlet of radon chamber.

Eappen (2005) comes out with the improvement of twin cup dosimeter, where membrane filter was replaced by a pinhole cap of the radon chamber. In this, one pinhole is used to block the entry of radioactive nuclides other than radon. In 2009, this pinhole cap was again improved by replacing it with 4 holes. For the correct choice of the design of a radon and thoron measuring device using track detectors, it is necessary to have information about the response of the detector to radon and its progeny. The mathematical basis for calculation of these dependencies was first developed by Fleischer and Mogro Campero (1978). Several theoretical papers, based on various calculation

techniques to obtain the response of detectors and elements of design, have been reported.

In India, measurements of these concentrations have been done for the past many years which were undertaken by Environment Assessment Division (EAD), Bhabha Atomic Research Center (BARC), Mumbai (Ramachandran *et al.,* 2003). With these results conditions of some places, mines, etc. can be studied well. Although there exist a wide range of study for this kind of work in global level with different approach to various conditions, very little has been done in Mizoram. In North-East India, in spite of its geological and seismic characteristics the radon data remained almost unrepresented (Dwivedi and Ghosh, 1991).

The present study tries to explore the concentrations of radon, thoron and their progeny in Mizoram with special reference to Aizawl, Champhai and Kolasib Districts which will supplement the mapping of concentration of these gases in Mizoram. This area covers the northern part of the State of Mizoram. This thesis will reflect the actual abundance of the studied radionuclides in the study area based on the results of the experimental measurements. In this experimental work, indoor concentrations are measured using solid state nuclear track detector (SSNTD). The activities of the source radioactive elements viz., uranium and thorium for the considered gases in soil and building materials are measured using NaI(Tl) detector link with 1K Multichannel Analyzer. This will be used to understand the deposition of the mentioned radioactive elements in Mizoram and can be well correlated with the concentrations of radon and that of thoron in dwellings. Solid-state nuclear track detector (SSNTD) based pin-hole dosimeters have been used to obtain the time integrated concentration levels of indoor

radon and thoron. The progenies were measured by deposition based Direct Progeny Sensors (DPS) in bare modes. Simultaneous measurement of background gamma radiation level at the spot was done indoor and outdoor at a height of 1 metre from the ground and on the ground level using Survey Meter.

The chapters in this thesis are organized in the following manner:

Chapter 2 will contain the theoretical formulae used in the research work. A complete methodology will also be given in this chapter.

In chapter 3, we will present the experimental calibration and determination of operating points of the instruments used which will be followed by the details of results obtained from the experimental determination of indoor radon, thoron and their progenies concentration carried out in the present study. Calculation of equilibrium factors and annual inhalation doses for radon as well as thoron and discussion will also be included.

Chapter 4 will present the experimental measurements of surface radon flux, radioactivity content of collected soil samples and building materials and finally the background gamma radiation measurements. Possible and even critical discussion along with comparison on the results obtained in the present investigation will also presented.

In chapter 5, we will discuss the conclusion of the whole results and summary of the entire work will be included.

This will be followed by references, appendices, etc.

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 $\{(C_6H_{10}O_5)n\}$ 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.

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

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

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

$$\Delta W = w_f - w_i \tag{2.2}$$

Bulk Etching Rate is given by

$$V_B = \frac{\Delta W}{\Delta t \times \rho \times A} \tag{2.3}$$

where Δt 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

$$T = kCt \tag{2.4}$$

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

$$k_{R(P)} = \frac{T_{R(P)}}{tC_{R(P)}} \tag{2.5}$$

$$k_{T(F)} = \frac{T_{T(F)}}{tC_{T(F)}} \tag{2.6}$$

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. $T_{R(F)}$ 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.

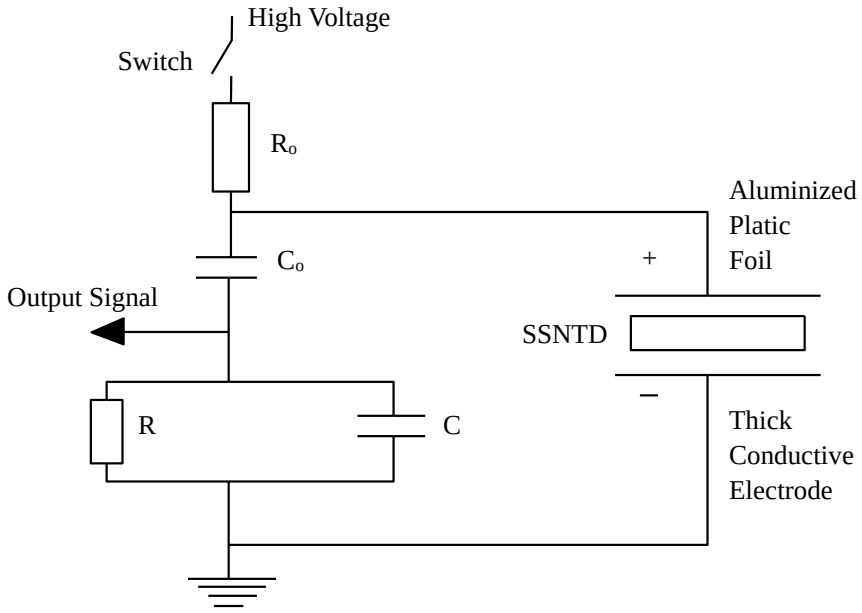

Figure 2.2 Schematic diagram of a spark counter.

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.

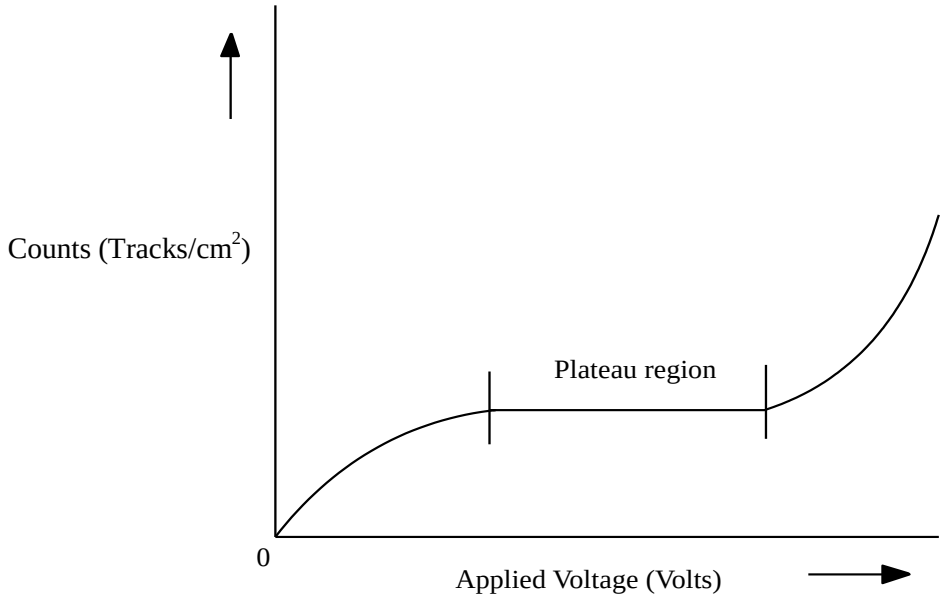

Figure 2.3 Applied Voltage vrs Count showing the plateau region.

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

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

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.

$$C_T\ (Bq/m^3) = \frac{T_F - T_P}{Calibration\ \ factor \times Exposure\ \ period\ \ (days)} \qquad (2.8)$$

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 (α energy 8.78 MeV) and ^{214}Po (α energy 7.69MeV) 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 60ºC 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, α 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

Equivalent Equilibrium Thoron Concentration

$$EETC\ (Bq/m^3) = \frac{T_{DTPS}}{Calibration\ \ factor \times Exposure\ \ period\ \ (days)} \qquad (2.9)$$

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

Equivalent Equilibrium Radon Concentration

$$EERC\ (Bq/m^3) = \frac{T_{DRPS} - T_{DTPS}}{Calibration\ \ factor \times Exposure\ \ period\ \ (days)} \qquad (2.10)$$

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

$$F_R = \frac{EERC\ (Bq/m^3)}{C_R(Bq/m^3)} \tag{2.11}$$

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

$$F_T = \frac{EETC\ (Bq/m^3)}{C_T(Bq/m^3)} \tag{2.12}$$

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 (μSv/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:

$$D = [(0.17 + 9\ F_R)\ C_R + (0.11 + 40\ F_T)\ C_T] \quad (2.13)$$

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.

Average concentration levels of radon, thoron and their progeny in air and corresponding annual effective doses*							
Radionuclide	**Location**	**Concentration ($Bq.m^{-3}$)**		**Effective dose equivalent ($nSv/Bq.h.m^{-3}$)**		**Annual effective dose (μSv)***	
		Gas	**EEC+**	**Gas**	**EEC**	**Gas**	**EEC**
Radon	Outdoor	10	6	0.17	9	3	95
	Indoor	40	16	0.17	9	48	1009
Total (numerical)							**1155**
Thoron	Outdoor	10	0.1	0.11	40	2.0	7.0
	Indoor	10	0.3	0.11	40	8.0	84
Total (numerical)							**101**
Total Annual Effective dose equivalent due to radon and thoron (μSv)							**1256**

+ 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).

$$C(t) = \frac{J_s A}{V\lambda_e}\left(1 - e^{-\lambda_e t}\right) + C_o e^{-\lambda_e t} \tag{2.14}$$

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); λ_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

$$Y(x) = Y_o + A_1 e^{-x/t_1} \tag{2.15}$$

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_o) present in the accumulator 'J_s' should be obtained from the fitting parameter 'Y_o' i.e.

$$J_s = \frac{Y_o V}{t_1 A} = \frac{Y_o}{t_1} H \qquad (2.16)$$

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 $m^{-2}s^{-1}$.

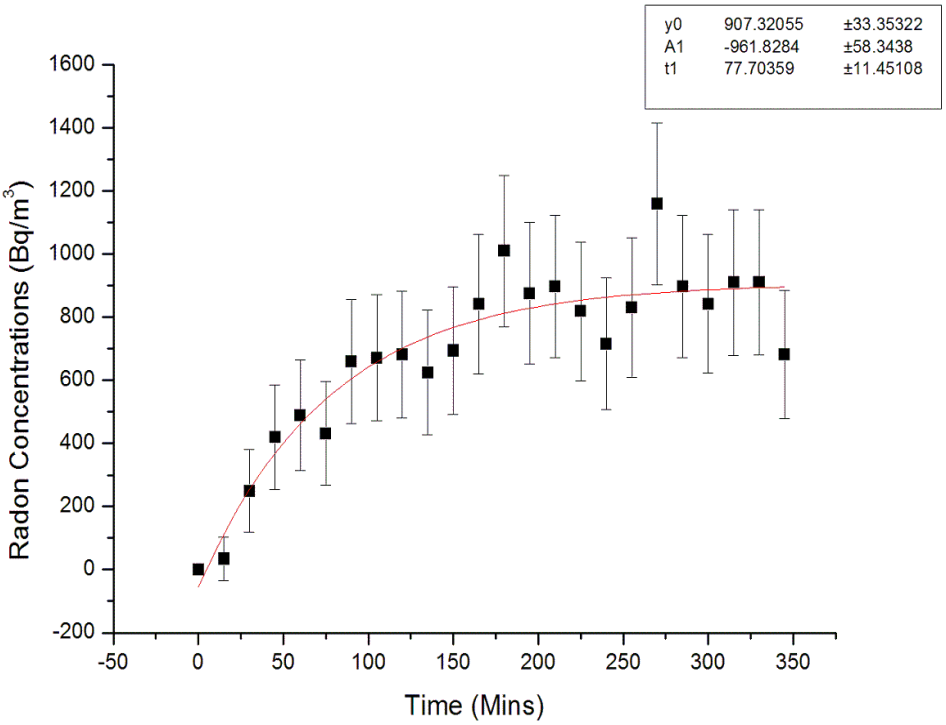

Figure 2.4 Building up of radon concentrations with time inside the accumulator.

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 γ-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 γ-spectrometry of the ^{232}Th content

considering the peaks of the intermediate γ-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.

$$Activity = \frac{Net\ Peak\ Area\ /_{Counting\ Time}}{\eta}\ (Bq/g) \qquad (2.17)$$

where η 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}Rn from the surfaces of building materials and infiltration of ^{222}Rn from external atmosphere coupled with air exchange rate inside a room govern the concentration of ^{222}Rn inside a dwelling. The basic parameters governing the ^{222}Rn potential from building materials are: (i) its radioactive content, (ii) ^{222}Rn emanation rate and (iii) diffusive length of ^{222}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.

Chapter 3

Experimental determination of indoor radon, thoron and their progeny concentrations in Aizawl, Champhai and Kolasib Districts

In this chapter, we present the experimental determination of indoor radon, thoron and their progeny concentrations in Aizawl, Champhai and Kolasib Districts. Instrumental calibrations and detailed measurements are also included.

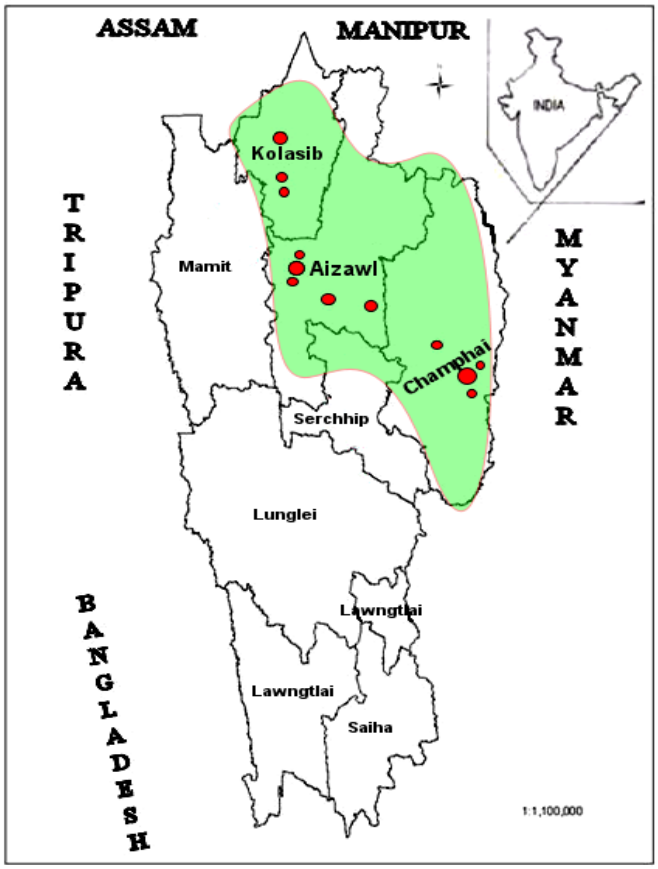

Figure 3.1 A map of Mizoram showing the sampling sites covering Aizawl, Champhai and Kolasib Districts.

This will be followed by the details of results obtained from the experiments carried out in the present study and include the possible and even critical discussion on

the results obtained in the present investigation. The results obtained will also be compared with the global and national average level whenever possible.

3.1 Indoor radon and thoron measurements

In measuring indoor radon and thoron concentrations, Solid State Nuclear Track Detector (SSNTD) based pin-hole dosimeters have been used. The dosimeter system is of BARC type which is a cylindrical plastic chamber divided into two equal compartments. Cellulose nitrate films (LR-115 type II) are used as detectors. Dosimeters are hanged indoor overhead on the ceiling at the height of minimum 1.5 m from the floor and at least 10 cm away from any surface for a minimum of 90 days. The exposed dosimeters are taken for analysis and replaced with new ones for the next deployment. In this study each exposed dosimeters are replaced three times in a year to have seasonal variations in concentrations of these gases particularly during rainy, winter and summer seasons in the study area.

The exposed films are then etched in an etching bath using 2.5N NaOH solution at 60ºC for 90mins. 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.

3.1.1 Calibration of dosimeter

Calibration of this type of dosimeter is done personally at the Environment Assessment Division (EAD), BARC, Mumbai by the author. The detail of experimental calibration is as shown in Appendix – I. In this experiment calibration chamber used is a 1 m^3 capacity chamber. Inside it there are small fan, dosimeter mounting bar, inlets,

outlets and a tube light. Radon and thoron source can be kept inside the chamber and their activity concentrations can be measured continuously using RAD-7 as shown in Fig. 3.2 below. In this experiment, radium is used as radon source and thorium nitrate is used as thoron source. The activity concentrations of the gases are continuously monitored using RAD-7.

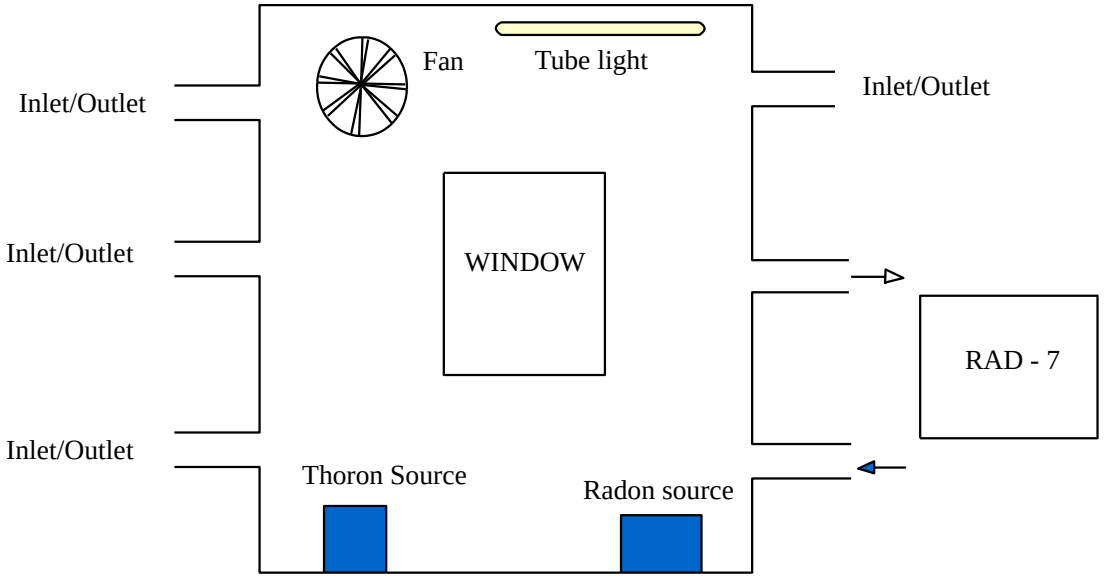

Figure 3.2 Block diagram of the calibration chamber for calibrating twin cup dosimeter.

Four observations have been taken within 8.17 days, from which the calibration factors have been calculated. From the experimentally obtained data, the calibration factor for radon was found to be ~ 0.02 which is very near to standard value, 0.023 (Eappen *et al.*, 2004). But in case of thoron, the experiment was unsatisfactory and the obtained value was unacceptably small as compared to the standard value, 0.016 (Eappen *et al*., 2005).

3.1.2 Standardization of etching rate

Bulk etching rate is the amount of thickness etched away with time. After exposing the detector films using twin cup dosimeter, the film requires etching before counting. Experimental determination of the standard etching rate of the LR-115 film has been performed by the author in BARC, Mumbai. The details of experiment are shown in Appendix – II(a) and Appendix II(b). The average etching rate calculated using the data obtained from the two sets of experiments is 3.9 µm/h without stirring. This value is in good agreement with previously experimentally obtained standard value, which is 4µm/h (Eappen, 2005). The standard parameter set for the above experiment is 90 min etching at constant 60ºC without magnetic or any other stirring device.

3.1.3 Operating voltage of a Spark counter

The importance of finding out the operating voltage of the spark counter is that even with a slight fluctuation of the applied voltage the counts (track density) obtained by the device is not altered. Since, the actual applied voltage can vary to a small extend due to some limitation of the device even though the preset voltage remains the same hence, to have an accurate result, the operating voltage of each spark counter should be experimentally determined.

This experiment has been done with the specific spark counter used in the present study. The determination of operating voltage of a spark counter is as shown in Appendix – III. The average value for the operating voltage of the specific spark counter, which is used in the present study, obtained from five sets of observations was found to be ~ 450V.

The graph plotted between applied voltage and counts is shown in Fig. 3.3 below.

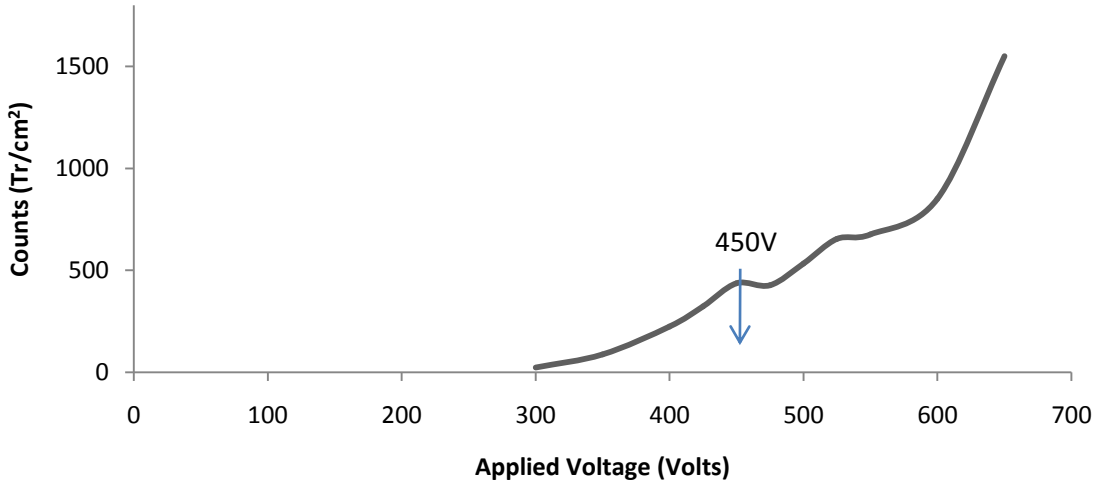

Figure 3.3 Operating voltage of the spark counter used in the present study.

Slight difference has been discovered in the obtained track densities from the same exposed detector when compared with the spark counter at BARC, Mumbai. Hence, with the help of scientist from BARC, careful calibration has been done for the operating voltage of the spark counter used in this study. The calibrated value is 500V.

3.1.4 Results and discussion

Measurement using GPS in the study area shows that the average altitude of Aizawl District is 940m, Champhai District is 1331m and Kolasib District is 890m above sea level. In Aizawl District, Aizawl (District Headquarters), Hlimen, Saitual, Seling and Sihphir were selected for measurements. In Champhai District, Champhai (District Headquarters), Khawzawl, Zote and Zotlang were selected. In Kolasib District, Kolasib (District Headquarters), Kawnpui and Bualpui were selected.

Among the selected dwellings in which dosimeters were exposed, measurements have been done successfully in a total of 138 dwellings within Aizawl, Champhai and Kolasib Districts in Mizoram for a complete one year. In Aizawl District, dosimeters were exposed successfully in 63 dwellings, in Champhai District, 37 dwellings and in Kolasib District, 38 dwellings. Dwellings for deployment of the dosimeters were selected such that the data obtained from them could be as scattered and as best as possible to be evenly distributed in the region. The exposure period starts from May 2008 and ends in April 2009. This whole period was classified into three seasons viz., rainy season (May – August, 2008), winter season (September, 2008 – January, 2009) and summer season (February – April, 2009). The concentrations obtained in this work show no significant radiological risks and lies in the range covered by nationwide survey result (Ramu *et al.,* 1992) as well as the ICRP regulations (ICRP, 1993).

The experimentally determined value of annual average concentration of radon in the study area ranges from 26.91 Bq/m^3 to 84.81 Bq/m^3 with a geometric mean (GM) of 48.69 Bq/m^3 and geo-standard deviation (GSD) of 1.23. In case of thoron, the annual average concentration in the whole study area ranges from 8.56 Bq/m^3 to 66.35 Bq/m^3 with geometric mean of 23.06 Bq/m^3 and GSD 1.54. The study area has higher average indoor concentrations of radon and thoron as compared to average global level of 40 Bq/m^3 and 10 Bq/m^3 as well as national level of 42 Bq/m^3 and 12.2 Bq/m^3 respectively (Mishra *et al*., 2009; UNSCEAR, 2000).

Geographical (District-wise) comparison and seasonal variation

The annual average concentrations of radon and thoron in Aizawl, Champhai and Kolasib Districts are shown in Table 3.1 and Table 3.2 respectively. Minimum observed value (Min), maximum (Max) and geometric mean (GM) along with geometric standard deviation (GSD) are shown.

Table 3.1 Annual average concentrations of radon in Aizawl, Champhai and Kolasib Districts.

Radon (Bq/m^3)			
	Aizawl District	**Champhai District**	**Kolasib District**
Min	26.91	24.72	21.16
Max	84.81	90.51	93.54
GM	**47.56**	**50.6**	**48.76**
GSD	1.26	1.22	1.2

Table 3.2 Annual average concentrations of thoron in Aizawl, Champhai and Kolasib Districts.

Thoron (Bq/m^3)			
	Aizawl District	**Champhai District**	**Kolasib District**
Min	8.77	3.44	3.02
Max	56.94	67.38	93.92
GM	**22.65**	**22.13**	**24.74**
GSD	1.58	1.43	1.58

Champhai District has the highest average concentration of radon while Kolasib District and Aizawl District have lower average concentrations of radon. Among many factors, the main factor which seems to influence the variation in indoor radon concentrations among the three districts is the pseudo-ventilation rate which depends strongly on annual average temperature of the area. As a whole Champhai District has minimum average temperature as compared to Aizawl and Kolasib Districts.

Consequently, ventilation rate of the dwellings is lower in Champhai District which results in slightly higher indoor concentrations. In case of thoron, ventilation rate does not affect the indoor thoron concentration hence, the variation becomes different. Maximum average indoor thoron concentration has been observed in Kolasib District and minimum in Champhai District.

In Aizawl District, during rainy season, indoor radon concentrations vary from a minimum of 17.7 Bq/m^3 to a maximum of 101.56 Bq/m^3 with geometric mean (GM) of 45.94 Bq/m^3 and geo-standard deviation (GSD) 1.41. During winter season, it ranges from 19.57 Bq/m^3 to 130.8 Bq/m^3 with GM 47.4 Bq/m^3 and GSD 1.46. Likewise, during summer season, indoor radon concentrations range from 15.13 Bq/m^3 to 86.32 Bq/m^3 with 43.38 Bq/m^3 GM and 1.5 GSD.

In Champhai District, indoor radon concentrations range from 23.76 Bq/m^3 to 111.37 Bq/m^3 with GM 50.99 Bq/m^3 and GSD 1.37 during rainy season. During winter season, the concentrations vary from a minimum of 20.94 Bq/m^3 to a maximum of 121.74 Bq/m^3 with GM 59.69 Bq/m^3 and GSD 1.44. And during summer season, it varies from 19.61 Bq/m^3 to 63.3 Bq/m^3 with GM 37.71 Bq/m^3 and 1.37 GSD.

In Kolasib District, indoor radon concentrations range from a minimum of 28.19 Bq/m^3 to a maximum of 85.06 Bq/m^3 with GM 45.75 Bq/m^3 and GSD 1.32 during rainy season. The concentrations range from 22.88 Bq/m^3 to 133.38 Bq/m^3 with GM 68.61 Bq/m^3 and 1.43 GSD during winter season. During summer season, concentrations of indoor radon vary from 12.5 Bq/m^3 to 61.99 Bq/m^3 with GM 26.53 Bq/m^3 and 1.46 GSD.

In case of indoor thoron concentrations, in Aizawl District, indoor radon concentrations vary from 1.15 Bq/m^3 to 63.16 Bq/m^3 with 13.7 Bq/m^3 GM and GSD 2.4

during rainy season. The concentration ranges from 2.12 Bq/m^3 to 136.68 Bq/m^3 with GM 22.65 Bq/m^3 and GSD 2.2 during winter season. During summer season, it ranges from 5.5 Bq/m^3 to 71.89 Bq/m^3 with 22.03 Bq/m^3 GM and 1.98 GSD.

In Champhai District, indoor thoron concentrations range from 1.31 Bq/m^3 to 93.38 Bq/m^3 with GM 12.45 Bq/m^3 and GSD 2.63 during rainy season. During winter season, the concentrations vary from a minimum of 3.21 Bq/m^3 to a maximum of 94.02 Bq/m^3 with GM 27.11 Bq/m^3 and GSD 2.1. And during summer season, it varies from 5.72 Bq/m^3 to 75.28 Bq/m^3 with GM 14.29 Bq/m^3 and 1.78 GSD.

In Kolasib District, during rainy season, indoor thoron concentrations range from a minimum of 1.54 Bq/m^3 to a maximum of 106.48 Bq/m^3 with GM 16.92 Bq/m^3 and GSD 2.7. The concentrations range from 5.64 Bq/m^3 to 126.95 Bq/m^3 with GM 31.93 Bq/m^3 and 2.05 GSD during winter season. During summer season, concentrations of indoor thoron vary from 1.88 Bq/m^3 to 48.41 Bq/m^3 with GM 12.23 Bq/m^3 and 2.21 GSD.

Calculating the annual average from the experimentally obtained data within the whole study area, during rainy season, indoor radon concentrations vary from a minimum of 17.7 Bq/m^3 to a maximum of 111.37 Bq/m^3 with GM 47.57 Bq/m^3 and GSD 1.39. During winter season, it ranges from 19.57 Bq/m^3 to 133.38 Bq/m^3 with GM 56.99 Bq/m^3 and GSD 1.5. Likewise, during summer indoor radon concentrations range from 11.94 Bq/m^3 to 92.69 Bq/m^3 with 35.54 Bq/m^3 GM and 1.57 GSD.

Annual average indoor concentrations of thoron vary from 0.5 Bq/m^3 to 106.48 Bq/m^3 with GM 13.74 Bq/m^3 and GSD 2.68 during rainy season. During winter season, the concentrations vary from a minimum of 2.12 Bq/m^3 to a maximum of 136.68 Bq/m^3

with GM 26.03 Bq/m^3 and GSD 2.18. During summer season, it varies from 1.88 Bq/m^3 to 75.28 Bq/m^3 with GM 16.3 Bq/m^3 and 2.07 GSD.

Fig. 3.4 shows the concentrations of indoor radon in Aizawl, Champhai and Kolasib Districts as well as whole study area which is obtained by combining the mentioned three districts, for a complete one year. It shows the variation of indoor radon levels during rainy season (2008), winter (2008-2009) and summer (2009) along with annual average. The height of the marker represents the concentrations of radon in Bq/m^3. In the entire three districts as well as whole study area, indoor radon level is highest during winter and lowest during summer as expected.

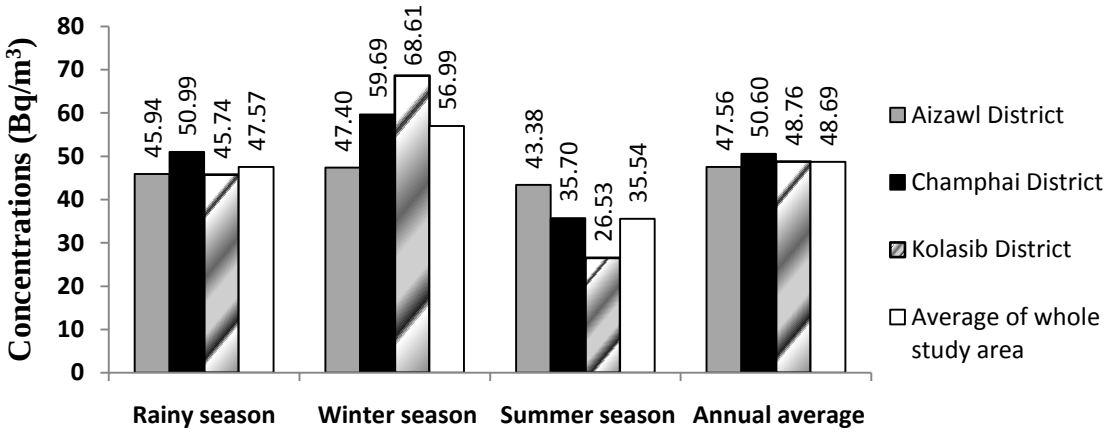

Figure 3.4 Indoor radon concentrations in each district along with the whole study area for different seasons including the annual average.

In Aizawl District, the ratio of winter (maximum average) to summer indoor radon level (minimum average) is 1.09. Comparing rainy season and summer, the level of radon are almost equal but with slightly lower level during summer. In Champhai District, the level of radon during rainy season is in between the other two seasons but close to the winter level as compared to that of summer readings. The ratio of winter to

summer radon level is 1.67. In Kolasib District, the level of radon during rainy season is almost in the middle level between that of winter and summer seasons. The ratio of winter to summer radon level is 2.6. The ratio of winter to summer radon level of the whole study area from the combination of the three districts is 1.6. The difference in radon level comparing summer and rainy season with rainy season and winter are almost similar as a whole.

Maximum ratio of winter to summer levels has been observed in Kolasib District, this may be due to hotter summer season of Kolasib District as compared to other districts. In Champhai District, winter season is very cold and summer season is not so hot as compared to other districts. As a result, the ratio of winter to summer levels has been lower than Kolasib District. In Aizawl District, the differences in radon level during the three seasons are very less; this may be due to moderate temperature of the area as compared to other areas. The temperature does not vary much during the whole year. Hence, ventilation rate is also high and almost same during a year. However, it is clear from the data that there exist differences in the air exchange rate during these seasons with the observation of different radon levels.

From the data obtained from each districts, the concentration was found to be highest in winter season and lowest in summer. In winter, the temperature was lowest among the three seasons and hence ventilation rate was also lowest as windows and doors were closed for more duration. Consequently, air exchange rate of indoor with the outdoor environment was low which result in high concentration of the gas in indoor. Whereas in summer, because of high temperature, ventilation rate was high as doors and windows were opened regularly and also ceiling fan, table fan, etc. were used as comfort

for the occupant. As a result, the concentrations of the gas were found to be minimum during this particular season. And in rainy season, the temperature in Mizoram is in between summer and winter, with the result that radon concentrations also were in between that of winter and summer.

The ratio of indoor radon level in winter (maximum level) and summer (minimum level) are low. This is due to overall low concentration of radon in the environment (David *et* al., 2008; Khan *et al*, 1993; Kumar *et al*., 1994; Gupta *et al.*, 2010; Ramu *et al*., 1992; EPA, 1993). Since the radon level in the environment is low, the rate of indoor accumulation is low even in winter season. This results in low ratio of radon level comparing winter and summer.

Fig. 3.5 shows the indoor thoron concentrations in Aizawl, Champhai and Kolasib Districts as well as whole study area for a complete one year along with annual average.

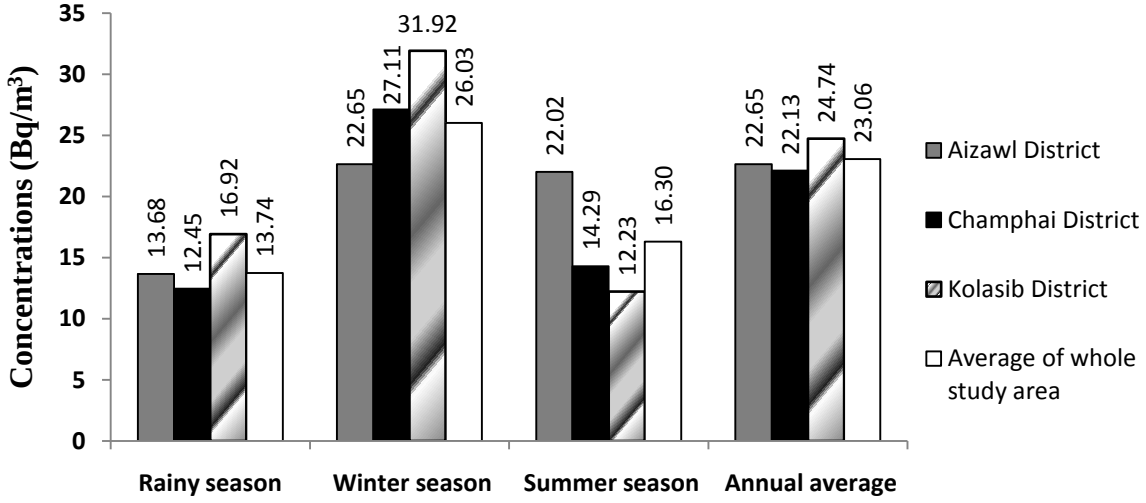

Figure 3.5 Indoor thoron concentrations in each district along with the whole study area for different seasons including the annual average.

In case of indoor thoron concentrations, the seasonal variation is different as compared to that of indoor radon levels. This is due to the fact that ventilation rate does not affect indoor thoron levels because of its short diffusion length due to its short half life. Even then, during winter, the maximum concentration of indoor thoron is observed in each district as well as combining the whole study area. But, summer readings are higher than rainy season readings. The same variation has been observed in houses of Garhwal Himalayas. Perhaps this behaviour may be due to low emanation of thoron during rainy season. It may be possible that due to low half-life, thoron cannot escape easily from the capillaries of soil, which are mostly occupied by water during the rainy season (Ramola, 2011).

House type comparison

In this study, comparison of indoor radon as well as thoron concentrations has been done with different types of dwellings depending on the materials used for construction of buildings. As already mentioned in section 2.9, types of houses are classified into two main groups, which are then sub-divided into a total of five types depending on the building materials, namely, Complete RCC (Reinforced Cement Concrete), RCC with GI sheet roof, Assam type with bamboo/wooden walls, Assam type with asbestos walls and Assam type with GI sheet walls.

Table 3.3 shows the detail experimental observations and classifications of measured indoor radon and thoron concentrations for each for the selected different house types in Aizawl, Champhai and Kolasib Districts along with compilation of the whole study area.

Table 3.3 Indoor radon and thoron concentrations for different house types in the three districts along with the whole study area.

Complete RCC

	Aizawl District		Champhai District		Kolasib District		Whole study area	
	Radon (Bq/m^3)	Thoron (Bq/m^3)	Radon (Bq/m^3)	Thoron (Bq/m^3)	Radon (Bq/m^3)	Thoron (Bq/m^3)	Radon (Bq/m^3)	Thoron (Bq/m^3)
Min	28.66	6.72	38.37	22.88	44.3	19.93	28.66	6.72
Max	77.27	42.7	66.55	39.54	69.57	47.71	77.27	47.71
GM	50.17	17.66	51.94	29.51	55.5	32.97	51.98	23
GSD	1.24	1.54	1.19	1.21	1.13	1.3	1.21	1.59

RCC with GI sheet roof

	Aizawl District		Champhai District		Kolasib District		Whole study area	
	Radon (Bq/m^3)	Thoron (Bq/m^3)	Radon (Bq/m^3)	Thoron (Bq/m^3)	Radon (Bq/m^3)	Thoron (Bq/m^3)	Radon (Bq/m^3)	Thoron (Bq/m^3)
Min	39.53	10.09	31.54	12.59	40.52	10.98	31.54	10.09
Max	62.21	35.92	71.89	25.38	67.45	66.35	71.89	66.35
GM	51.07	17.32	50.52	18.7	50.31	21.51	50.65	18.95
GSD	1.17	1.62	1.27	1.22	1.19	1.84	1.22	1.57

Assam type with bamboo/wooden walls

	Aizawl District		Champhai District		Kolasib District		Whole study area	
	Radon (Bq/m^3)	Thoron (Bq/m^3)	Radon (Bq/m^3)	Thoron (Bq/m^3)	Radon (Bq/m^3)	Thoron (Bq/m^3)	Radon (Bq/m^3)	Thoron (Bq/m^3)
Min	29.38	6.58	42.54	15.34	30.36	13.87	29.38	6.58
Max	64.14	29.64	66.97	31.12	55.56	57.82	66.97	57.82
GM	46.03	15.36	51.12	22.69	42.44	26.29	45.38	20.79
GSD	1.22	1.57	1.17	1.3	1.18	1.52	1.21	1.61

Assam type with asbestos walls

	Aizawl District		Champhai District		Kolasib District		Whole study area	
	Radon (Bq/m^3)	Thoron (Bq/m^3)	Radon (Bq/m^3)	Thoron (Bq/m^3)	Radon (Bq/m^3)	Thoron (Bq/m^3)	Radon (Bq/m^3)	Thoron (Bq/m^3)
Min	26.91	6.59	38.63	10	39.4	8.6	26.91	6.59
Max	84.81	34.69	71.48	44.82	52.32	30.25	84.81	44.82
GM	45.13	16.27	52.16	24.89	46.45	17.51	47.38	18.72
GSD	1.28	1.55	1.23	1.49	1.1	1.43	1.25	1.58

Assam type with GI sheet walls

	Aizawl District		Champhai District		Kolasib District		Whole study area	
	Radon (Bq/m^3)	Thoron (Bq/m^3)	Radon (Bq/m^3)	Thoron (Bq/m^3)	Radon (Bq/m^3)	Thoron (Bq/m^3)	Radon (Bq/m^3)	Thoron (Bq/m^3)
Min	33.55	8.91	33.66	11.97	41.17	12.09	33.55	8.91
Max	62.46	37.04	55.52	27.16	69.61	23.64	69.61	37.04
GM	45.38	19.61	47.35	17.3	51.36	17.74	47.32	18.16
GSD	1.27	1.71	1.16	1.35	1.25	1.33	1.22	1.49

It is clear from the table that RCC type of buildings has the maximum indoor radon as well as thoron concentrations with only one exceptional case each for radon in Champhai District where Assam type with asbestos walls have the maximum indoor levels and for thoron in Aizawl District where highest indoor thoron concentration has been observed in Assam type building with GI Sheet roof. However, looking at the data of the whole study area, taking the three districts as a whole, the maximum concentrations of indoor radon and thoron have been observed in RCC type of buildings.

Fig. 3.6 shows a chart plotted using the geometric mean of indoor radon and thoron concentrations with the construction type of buildings in Aizawl District.

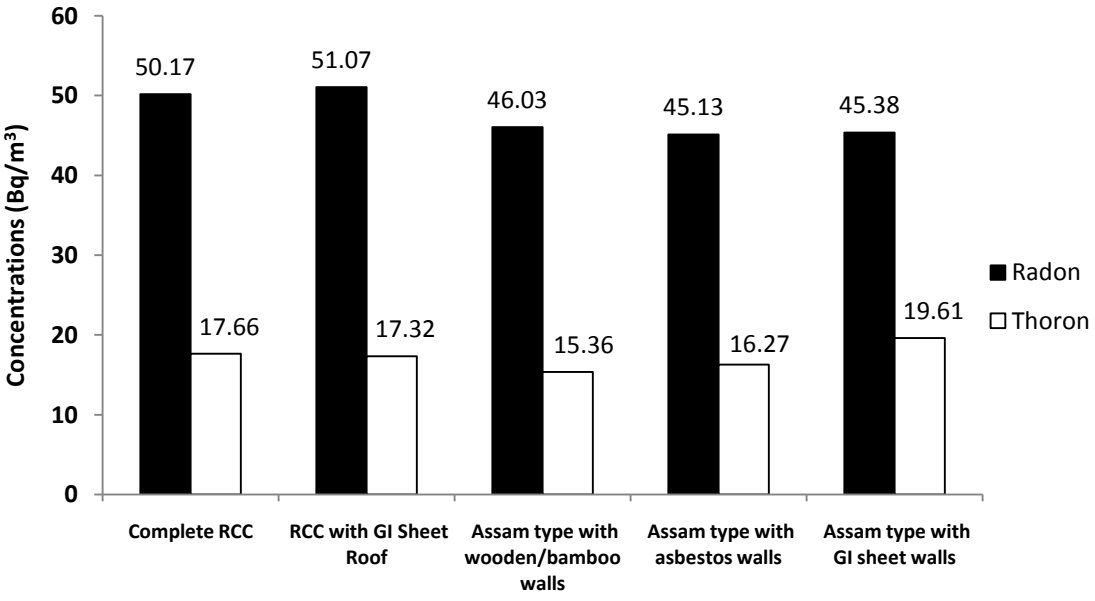

Figure 3.6 Indoor radon and thoron concentrations of different types of buildings in Aizawl District.

Hence, it is clearly seen from the figure that in Aizawl District, the RCC with GI Sheet roof type of building has the highest average concentration of indoor radon and Assam type with GI sheet walls has the highest average indoor thoron level.

A chart plotted using the geometric mean of indoor radon and thoron concentrations with the construction type of buildings in Champhai District is shown in Fig. 3.7. From the chart, in Champhai District, Assam type building with asbestos walls has the maximum indoor radon concentrations while Complete RCC type has the maximum indoor thoron concentrations. It is clear that even though highest indoor radon level is observed in Assam type building with asbestos walls, the difference in its concentration of indoor radon is not much high as compared to Complete RCC type building.

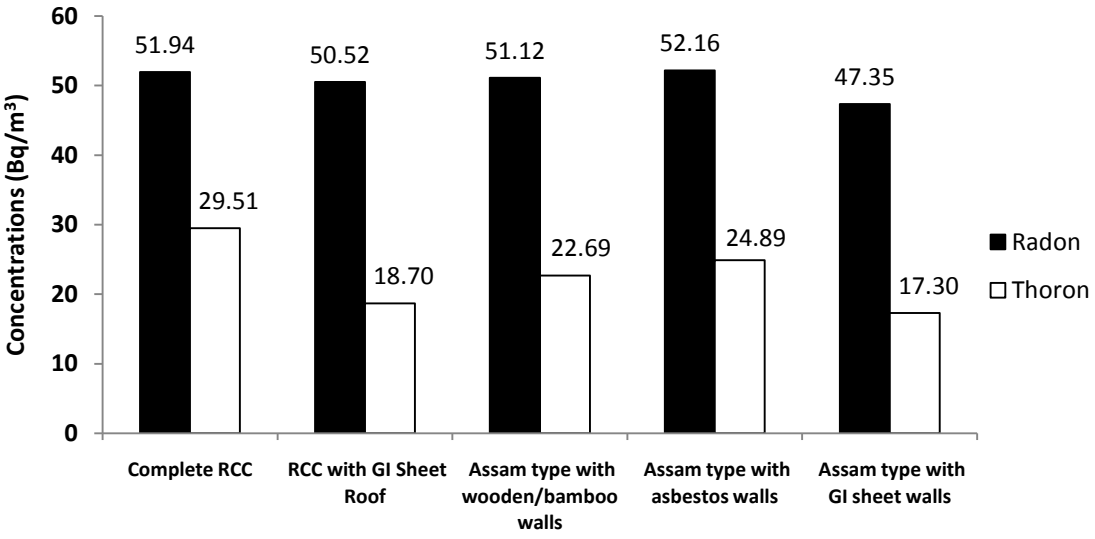

Figure 3.7 Indoor radon and thoron concentrations of different types of buildings in Champhai District.

In Fig. 3.8, a chart plotted using the geometric mean of indoor radon levels as well as indoor thoron concentration with the construction type of buildings in Kolasib District is displayed. The chart shows clearly that the Complete RCC type of building has the maximum average indoor radon and thoron concentrations, while Assam type

building with wooden walls has the minimum average indoor radon levels and Assam type with asbestos walls has the lowest average indoor thoron level.

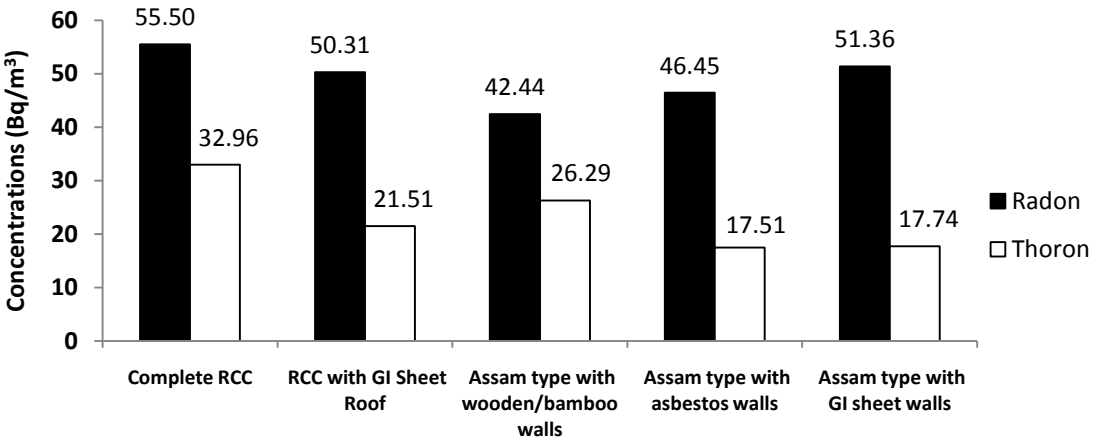

Figure 3.8 Indoor radon and thoron concentrations of different types of buildings in Kolasib District.

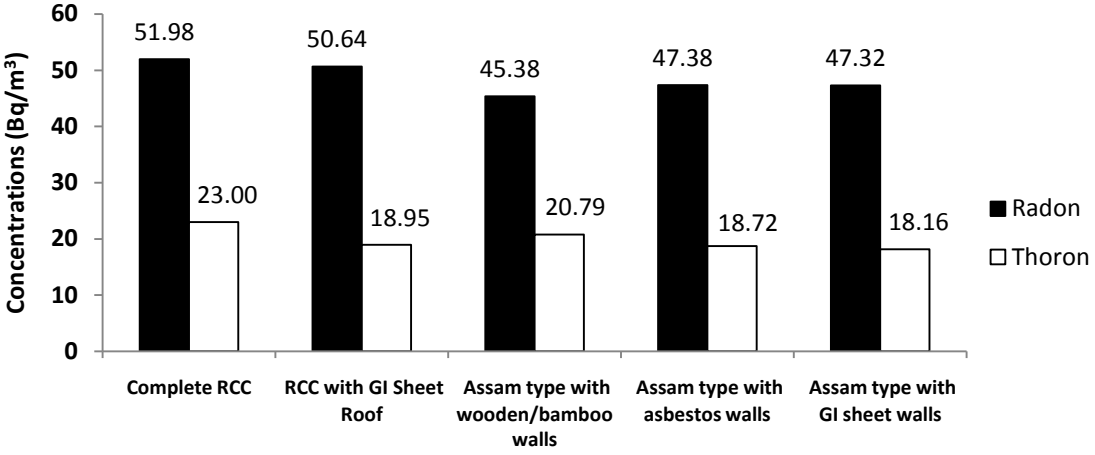

Figure 3.9 Indoor radon and thoron concentrations of different types of buildings in the whole study area.

Fig. 3.9 shows a plot between the geometric mean of indoor radon and thoron concentrations and the construction type of buildings in the whole study area. From the figure, it is clear that the Complete RCC have the maximum average indoor radon and thoron concentrations. Besides, RCC type with GI Sheet roof building has the next

highest average concentration of indoor radon level. Hence, RCC type of building has higher values of indoor radon as well as thoron levels as compared to other types in the whole study area.

The RCC type of construction having materials of higher natural radioactivity content (Menon *et al*., 1987) has higher radon/thoron concentrations as expected compared to Assam type buildings. In Assam type also, it has been observed that those buildings with asbestos walls have high average indoor radon level which could be attributed due to the higher natural activity content of asbestos material (Porstendorfer, 1994). The detail comparison of indoor concentrations of radon and/or thoron with the natural radioactivity content of the building materials will be discussed in the next chapter.

Geological conditions

The comparison of indoor radon and thoron concentrations has also been done with different geological conditions in the study area. The compilation of the whole study area regarding the comparison of the measured concentrations among the selected geological conditions has also been accomplished. In this particular study, the study area is divided into three regions as follows.

a) **Fossils area** where there are fossils. In the whole study area, there has been found only one location where fossils are present. This area is in Hlimen Stone Quarry in Aizawl District.

b) **Fault Region** where faults are observed. This area covers Armed Veng, Ramthar, Dinthar and Hunthar Localities in Aizawl District. These places are located using the available geological mapping of the state.

c) **Dwelling area** where no geological distinctiveness like fault or fossils regions are indicated and they may be treated as having normal soil. It is also mention as *Unrepresented areas*.

With limited availability of the geologically divided regions in the study area, this particular study regarding measurements of indoor radon and thoron concentrations depending on the geological conditions has been done in Aizawl District only. In fossil area, annual average of indoor radon concentrations ranges from a minimum of 36.25 Bq/m^3 to a maximum of 66.99 Bq/m^3 with GM 47.33 Bq/m^3 and 1.22 GSD. In fault region, the annual average concentration range from 32.9 Bq/m^3 to 84.81 Bq/m^3 with GM 48.85 Bq/m^3 and 1.28 GSD. In dwelling (unrepresented) area, annual average concentrations of indoor radon vary from 26.91 Bq/m^3 to 77.27 Bq/m^3 with GM 47.48 Bq/m^3 and 1.26 GSD.

In case of thoron, in fossil area, annual average indoor thoron concentrations range from 10.95 Bq/m^3 to 44.7 Bq/m^3 with GM 25.81 Bq/m^3 and 1.66 GSD. In fault region, the annual average concentrations vary from a minimum of 0.83 Bq/m^3 to a maximum of 56.94 Bq/m^3 with GM 19.36 Bq/m^3 and GSD 2.36. And in unrepresented area, it varies from 8.77 Bq/m^3 to 49.38 Bq/m^3 with GM 22.27 Bq/m^3 and 1.53 GSD.

Comparison of the annual average of indoor radon and thoron levels among each of the selected geological areas are represented in Fig. 3.10 and Fig. 3.11 respectively. From Fig. 3.10, it can be seen that among the three areas, annual average of indoor radon concentration is maximum in fault region as expected but with only slightly higher values as compared to other areas. In case of thoron, maximum annual average indoor concentration is observed in fossil area. The reason that fossil and/or fault region has

higher radon and/or thoron concentrations lies in the fact that in these regions the exhalation of these gases is expected to be higher as compared to unrepresented or dwelling areas due to frequent movements of the layers of the earth's crust.

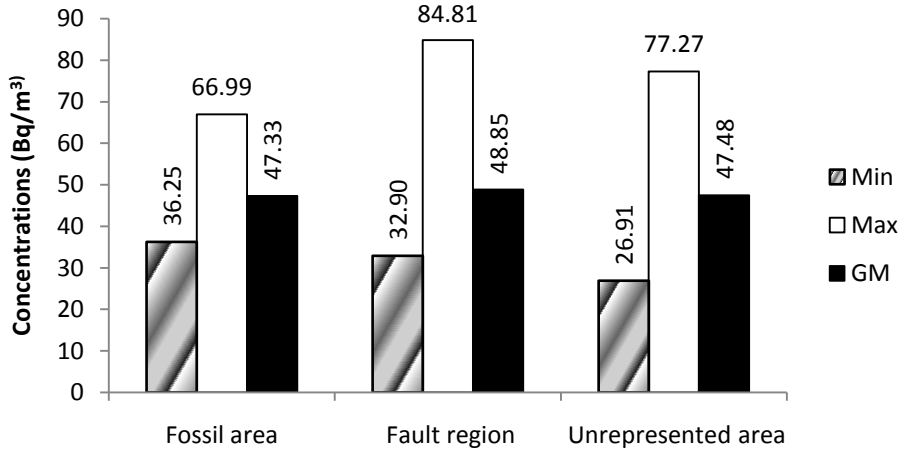

Figure 3.10 Annual average concentration of indoor radon in different areas.

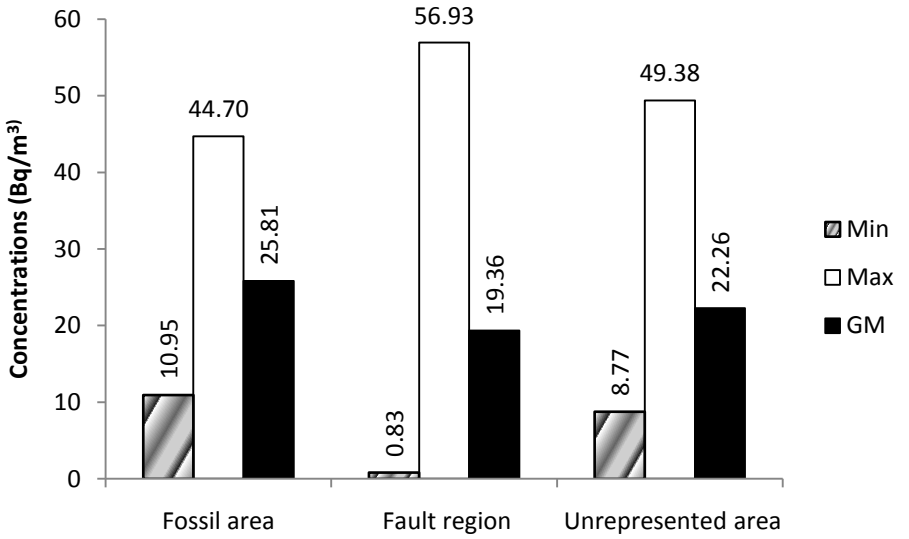

Figure 3.11 Annual average concentration of indoor thoron in different areas.

In case of thoron, the geometric mean of the annual average concentrations in fault region is lower than unrepresented area which is in contradictory to the expected one. There are many factors influencing the indoor concentrations, among which

ventilation rate or air exchange rate and the materials used for construction of building seems to be the main factor affecting it. However, experimental determination of the particular reason for this result is beyond the present study.

3.2 Progeny concentration measurement

The progenies of radon and thoron were measured by deposition based Direct Progeny Sensors (DPS) in bare modes (Mishra *et al*., 2009). This DPS system uses the same detector (LR-115 type II) which is used in dosimeter system. The detector selectively registers the tracks due to alpha emissions from ^{216}Po and ^{212}Po from the deposited atoms of radon and thoron progeny species, respectively. Direct radon progeny sensor (DRPS) and Direct thoron progeny sensor (DTPS) are used to register tracks from radon and thoron progenies respectively. Since the system is intended for use in the deposition mode, it is necessary to avoid uncontrolled static charges from affecting the deposition rates and hence aluminized side of the mylar is chosen to act as the deposition surface (Mishra, 2008).

The DPS are exposed along with the dosimeters in different selected houses in the study area 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. This experimental procedure is similar with the determination of indoor radon and thoron concentrations since the detector film used in both the measurements is LR-155 (Type-II) film, with only difference in exposure mode where bare mode exposure is used in DPS. The track densities were converted into progeny concentrations using appropriate calibration factors. Calibration factor used in calculating EERC is 0.09 and in EETC is 0.94 (Mishra *et al.,* 2008).

The progeny concentrations are given in terms of equivalent equilibrium concentration (EEC). EEC of a non-equilibrium mixture of short lived radon/thoron daughters in air is that activity concentration of radon/thoron, which would have been in equilibrium with this mixture. This value is essential in estimating the equilibrium factor for each of these gases respectively.

3.2.1 Results and discussion

Due to limited source of DPS, a total of 24 DPS were exposed in Aizawl District only for two seasons (2008 rainy season and 2009 summer season). Among these, 18 exposed DPS were retrieved undisturbed from the total of 24 DPS. The experimentally determined value of EERC varies from a minimum of 5.07 Bq/m^3 to a maximum of 24.48 Bq/m^3 with a geometric mean of 9.89 Bq/m^3 and 1.62 GSD during rainy season. It ranges from 2.46 Bq/m^3 to 47.88 Bq/m^3 with GM 7.28 Bq/m^3 and 2.08 GSD during summer season. The annual average value of EERC ranges from a minimum of 4.43 Bq/m^3 to a maximum of 36.18 Bq/m^3 with a geometric mean of 9.01 Bq/m^3 and GSD 1.71.

The obtained value of EERC becomes higher in rainy season as compared to summer season as in the case of parent radionuclide, radon. The main reason for this variation is mainly due to the higher average temperature in the study area during summer season. Consequently, air exchange rate of indoor with outdoor environment becomes higher during summer season, resulting in lower EERC value as compared to rainy season.

In case of thoron, EETC value varies from a minimum of 0.4 Bq/m^3 to a maximum of 5.7 Bq/m^3 with a geometric mean of 1.03 Bq/m^3 and 1.94 GSD during rainy season. It ranges from 0.37 Bq/m^3 to 2.44 Bq/m^3 with GM 0.76 Bq/m^3 and 1.6 GSD

during summer season. The annual average value of EETC ranges from 0.43 Bq/m^3 to 4.07 Bq/m^3 with a geometric mean of 0.91 Bq/m^3 and 1.75 GSD. The obtained value of EETC also becomes higher in rainy season as compared to summer which is similar to seasonal variation of indoor thoron concentrations.

Fig. 3.12 and Fig. 3.13 show the annual average value of EERC and EETC in the study area respectively. The variation of EERC with EETC values are not the same for each dwellings.

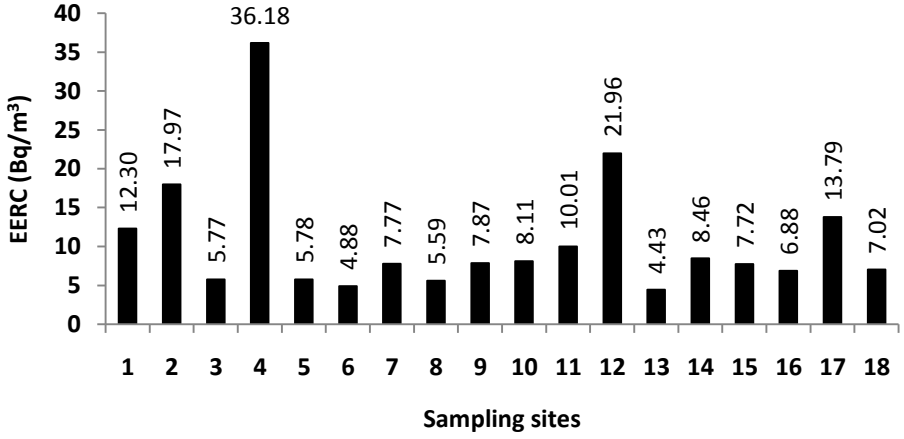

Figure 3.12 Annual average value of Equivalent Equilibrium Radon Concentration.

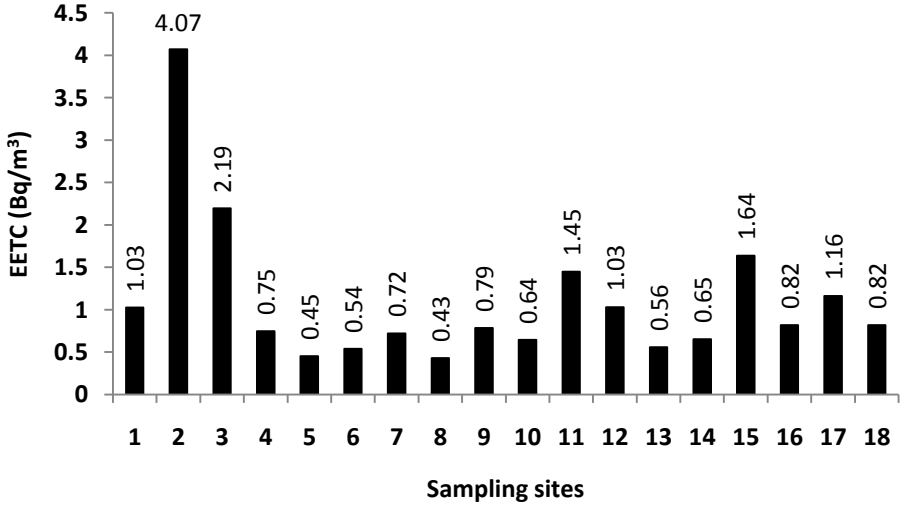

Figure 3.13 Annual average value of Equivalent Equilibrium Thoron Concentration.

3.3 Equilibrium factors or F-factor for Radon (F_R) and thoron (F_T)

In the past years, the equilibrium factor (which is also referred to as *F-factor*) for radon and thoron were globally assumed values and even the calculation of radon/thoron progenies were inferred using this value (UNSCEAR, 2000). These are understood as representative mean values in a global sense and might vary across countries and geographical locations. With the advent of passive detection techniques using solid state nuclear track detectors (SSNTDs), direct progeny sensor (DPS) has been developed. The value of equilibrium factor in the indoor air depends mainly on the pseudo-ventilation rates, which is the sum of the air exchange rate and the wall removal rate in the dwelling. These quantities are expected to vary from house to house as well as from time to time in a given house. In the present work, using dosimeters and direct progeny sensors, direct calculation of equilibrium factor becomes possible from the experimentally determined values of the progeny concentrations along with the concentrations of the parent radionuclides.

3.3.1 Results and discussion

The calculated value of equilibrium factor for radon ranges from a minimum of 0.08 to a maximum of 0.9 with a geometric mean of 0.45 and 1.79 GSD during rainy season. It varies from 0.10 to 0.8 with GM 0.28 and 1.86 GSD during summer season. The annual average value of equilibrium factor of radon ranges from a minimum of 0.10 to a maximum of 0.86 with a geometric mean of 0.32 and GSD 1.66. The obtained value of radon equilibrium factor becomes higher in rainy season as compared to summer season. This variation is in good correlation with the variation of measured EERC as well as indoor radon concentrations.

The value of Equilibrium factor of thoron varies from a minimum of 0.01 to a maximum of 0.46 with a geometric mean of 0.07 and 2.56 GSD during rainy season. It ranges from 0.004 to 0.09 with GM 0.03 and 2.35 GSD during summer season. The annual average value of Equilibrium factor of thoron ranges from 0.01 to 0.25 with a geometric mean of 0.05 and 2.34 GSD. The obtained value of thoron equilibrium factor is also much higher in rainy season as compared to summer season which is similar to seasonal variation of EETC as well as indoor concentrations of thoron.

The annual average value of equilibrium factors of radon and thoron in the study area are shown in Fig. 3.14 and Fig. 3.15 respectively. The observed annual average value of the measured equilibrium factor for radon is 0.32 and that for thoron is 0.05. The study area has slightly lower values of equilibrium factor for radon (F_R) but slightly higher for thoron (F_T) in comparison to average global level, which are 0.4 and 0.03 respectively (UNSCEAR, 2000).

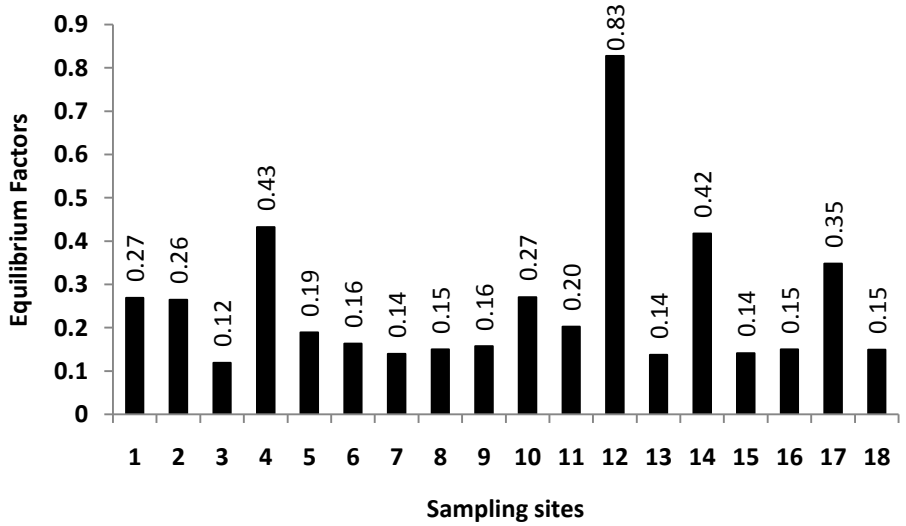

Figure 3.14 Annual average value of equilibrium factor of radon.

The study area has higher average indoor concentrations of radon, 48.69 Bq/m^3 as well as thoron, 23.06 Bq/m^3 as compared to average global level of 40 Bq/m^3 and 10 Bq/m^3 respectively (Mishra *et al*., 2009; UNSCEAR, 2000). Consequently, the obtained value of F_R is slightly low with respect to average global level. But, in case of thoron we obtain much higher EETC value, which is the numerator in the calculation and this results in higher calculated F_T value in this study.

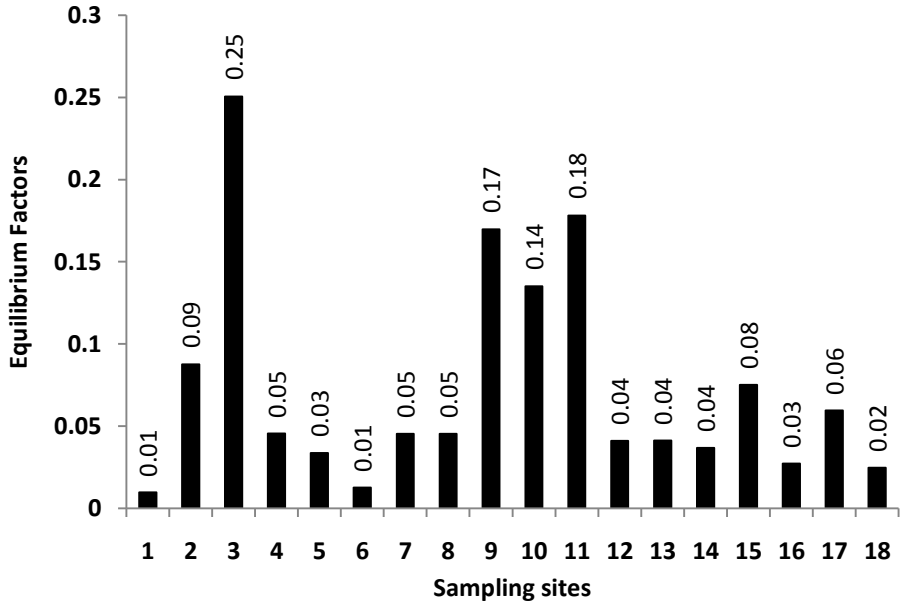

Figure 3.15 Annual average value of equilibrium factor of thoron.

The maximum annual average value of F_R has been observed in Assam type building with asbestos walls while minimum value has been observed in Complete RCC type of building. In case of F_T, highest annual average value has been observed in Complete RCC type of building whereas lowest annual average value has been observed in Assam type with asbestos walls and Complete RCC type. The variation of F_R in consideration of building type is in perfect correlation with the variation of EERC whereas variation of F_T is not in perfect but acceptable correlation with that of EETC.

3.4 Annual inhalation dose for radon and thoron

With the development of DPS system, progeny concentrations of radon and thoron can be obtained directly. In this study, inhalation doses are calculated directly each for radon and thoron using the experimentally obtained concentrations of the parent nuclei and the progenies. The minimum (Min), maximum (Max), geometric mean (GM) and geo-standard deviation (GSD) of the annual inhalation dose for indoor radon and thoron during rainy season and summer season along with the annual average is given in the table 3.4 below.

Table 3.4 Annual inhalation dose rate of radon and thoron.

	Radon inhalation dose (μSv/y)			**Thoron inhalation dose (μSv/y)**		
	Rainy Season	**Summer Season**	**Annual average**	**Rainy Season**	**Summer Season**	**Annual average**
Min	366.82	187	317.48	118.22	122.35	128.75
Max	1627.79	3130.54	2379.17	1646.92	704.97	1175.95
GM	681.89	517.3	624.89	304.8	241.43	278.75
GSD	1.57	2	1.67	1.91	1.58	1.72

As shown in the table, the geometric mean of annual average of radon inhalation dose rate is obtained to be 624.89 μSv/y with 1.67 GSD and that for thoron is 278.75 μSv/y with 1.72 GSD. Comparing the two seasons for radon as well as thoron, the geometric mean of inhalation dose has higher value during rainy season with respect to that of summer season.

Fig. 3.16 and Fig. 3.17 show the average of the inhalation doses per annum for radon and thoron at each sampling sites respectively.

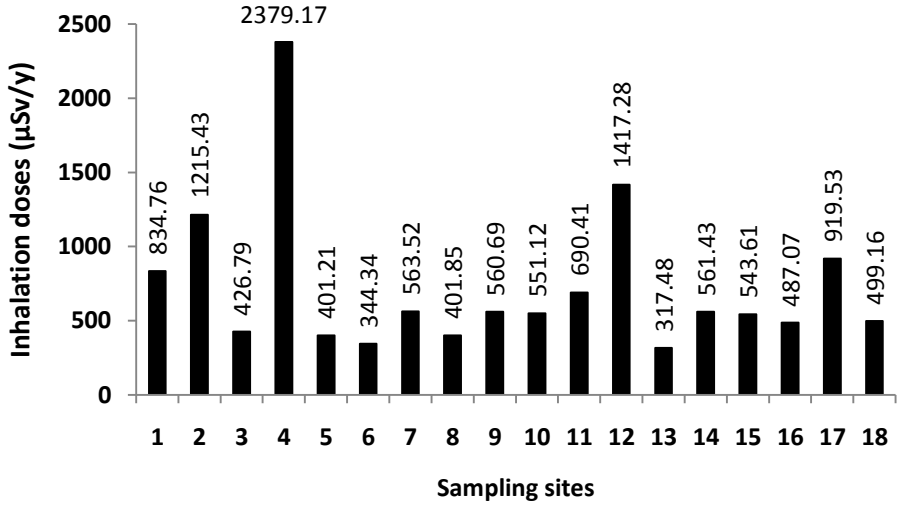

Figure 3.16 Average value of inhalation dose per annum for radon.

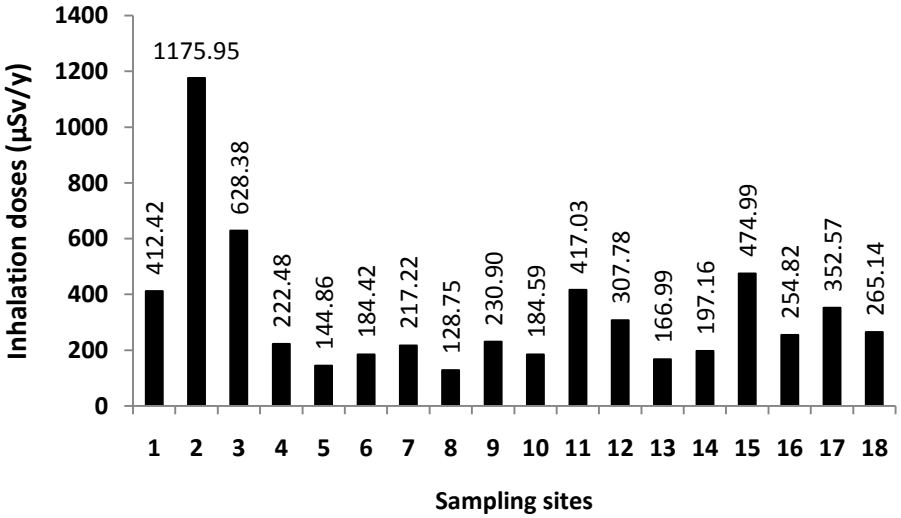

Figure 3.17 Average value of inhalation dose per annum for thoron.

As in the case of F-factor, annual indoor radon inhalation dose is found to be lower than the global average value which is 1009 µSv/y but, in case of thoron it is higher than global average which is 84 µSv/y (UNSCEAR, 2000). The measured total annual dose rate due to radon and thoron range from 484.47 µSv/y to 2601.65 µSv/y with GM 934.29 µSv/y and GSD 1.62, which is lower than the global average value of 1093 µSv/y.

Chapter 4

Experimental determination of surface flux, radioactivity content and background gamma radiation

In this chapter, experimental measurements of surface flux, radioactivity measurement of soil sample as well as building materials and background gamma radiation will be presented. The obtained results will be compared with the available previous findings in other areas, global and nation-wide whenever possible. The details of results obtained from the experiments carried out in the present study including the possible discussion will follow.

4.1 Surface radon flux

Radon flux is used as a source term for the atmospheric radon dispersion modelling. It governs the potential of radon emission over the soil surface. Measurement of radon flux is carried out using a set up consisting of an accumulator in line connected to RAD-7. The accumulator is a cylindrical cup of 17.5 cm height and diameter 15.5 cm which is placed on the surface of the soil in an inverted position and accumulates radon gas for a specified period of time (Zoliana *et al,*. 2011). Time variation of the radon concentration inside the accumulator monitored using RAD-7 is related to the flux through growth kinetic equations (Eq. 2.14). By fitting this exponential growth equation to the concentration data inside accumulator obtained from the measurement set up radon flux can be determined. Due to limitation of availability in the standard software (Origin

pro) for the fitting procedure, fitting with the exact form of the equation is not possible, hence, carefully slight calibration have been made for fitting purpose with the available general growth equation (Eq. 2.16). Surface radon flux is obtained from the fitting parameter Y_0 in order to avoid interference of initial radon concentration present in the accumulator (Sahoo, 2008). The accumulator technique takes care of two dimensional non-steady motion of both lateral and vertical diffusion of the trace gas emission into a chamber deployed at the surface of the soil matrix. This type of measurement provides an accurate method for interpreting the concentration data derived from surface deployed chambers without having to worry about insertion depth or deployment duration (Sahoo *et al.*, 2010).

The rate of radon concentration build up inside the accumulator is measured within each 15 min interval for a complete 5 hours using RAD-7. This concentration build up is plotted using Origin Pro from which the parameters Y_0 and t_1 values are obtained. These values are inserted in equation 16 to calculate Radon flux from soil in mBq $m^{-2}s^{-1}$. RAD-7 set up is as follows : Mode – *Sniff mode*, Cycle – *15 mins*, Recycle – *20*, Pump – *ON* and Thoron – *OFF*. With this set up, the device takes the reading of radon build up inside the accumulator for each 15 mins and stored in its inbuilt memory. After completing continuous 20 readings for a complete duration of exactly 5 hours, the stored data are printed out using the Infra-red connected printer device. A total of 20 locations have been selected in the study area depending on the geological conditions of the area.

Measurement of surface radon flux at BARC, Mumbai using the same instruments has been performed by the author in the year 2008. The detail of experiment has been shown in Appendix – IV. The result obtained in this experiment which is 35 mBq $m^{-2}s^{-1}$ is used for cross checking the result obtained in the present work in order to detect large deviation which may occur in the present study due to experimental errors.

4.1.1 Results and discussions

The calculated results obtained from flux measurement are presented in this topic. From the selected 20 locations, the measured radon flux value ranges from a minimum of 9.58 mBq $m^{-2}s^{-1}$ to a maximum of 74.79 mBq $m^{-2}s^{-1}$ with 22.63 mBq $m^{-2}s^{-1}$ geometric mean and 1.65 GSD. Each flux values are correlated with the indoor radon concentrations measured using dosimeters in dwellings at the vicinity of the surface flux measurements.

Fig. 4.1 shows the graph obtained by plotting the radon concentrations build up inside the accumulator with respect to time at one of the unrepresented area. Origin pro is

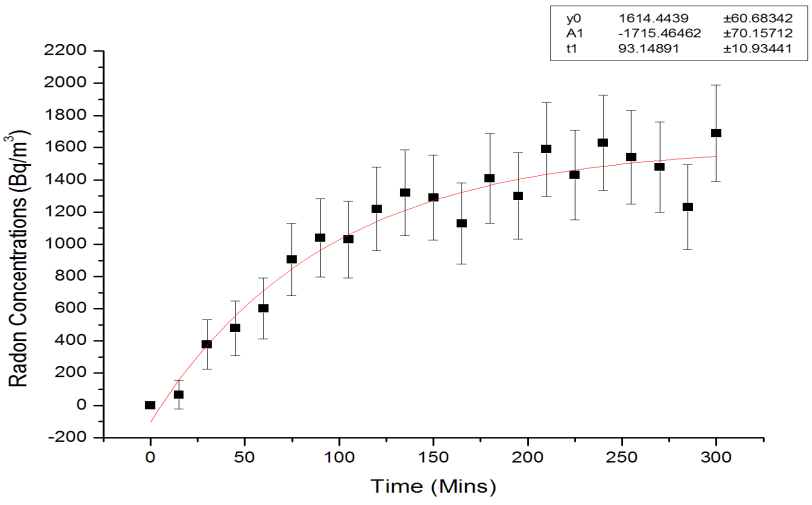

Figure 4.1 Concentrations of radon build up inside the accumulator plotted with respect to time in one of the unrepresented area.

used to plot this graph as well as in fitting and calculating the parameters Y_0 and t_1 which are then used to calculate the radon flux from the soil surface.

The correlation of flux and indoor radon levels at the sampling sites with the help of Excel software is shown in Fig. 4.2. Good correlations were observed between radon flux and the radon concentrations inside nearby dwellings. There exist a trend of increasing indoor radon levels with increasing radon flux which is shown by a line of equation $y = 0.524x + 29.6555$ with correlation coefficient (R^2) = 0.1605.

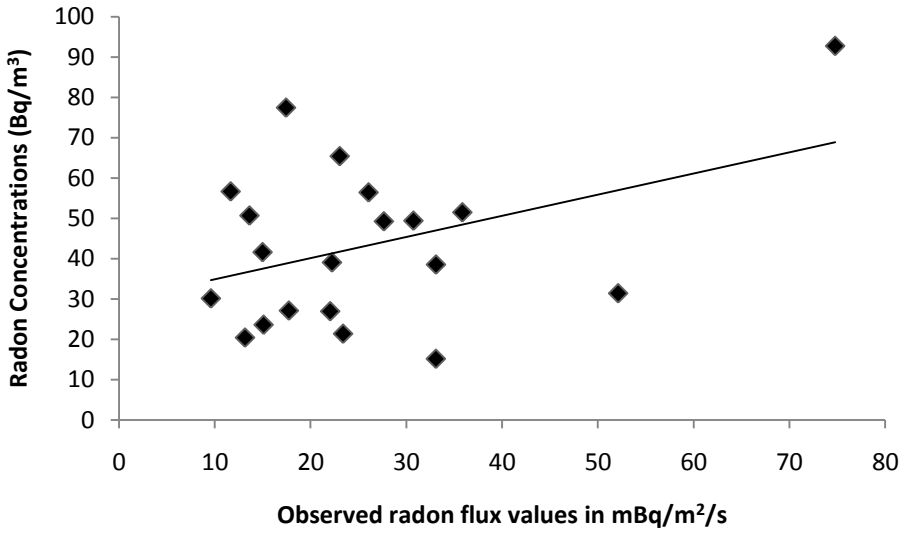

Figure 4.2 Correlation of radon flux with indoor radon concentrations.

Comparisons of flux values have also been done depending on the geological condition of the area of interest location, viz, fault region and unrepresented areas (dwelling areas). A total of 10 measurements each have been done in fault region as well as unrepresented area. In fault region, the value of surface radon flux varies from a minimum of 11.64 mBq $m^{-2}s^{-1}$ to a maximum of 74.79 mBq $m^{-2}s^{-1}$ with 25.9 mBq $m^{-2}s^{-1}$ geometric mean and 1.63 GSD. In an unrepresented area, measured surface radon flux

ranges from 9.56 mBq $m^{-2}s^{-1}$ to 52.12 mBq $m^{-2}s^{-1}$ with GM 19.77 mBq $m^{-2}s^{-1}$ and 1.61 GSD. The plot of measured surface radon flux in the two areas have been displayed in Fig. 4.3 showing minimum (Min), maximum (Max) and geometric mean (GM) values.

The geometric mean of radon flux is higher in fault region as compared to that observed in unrepresented area. The reason is that in fault region, there are many landslides and frequent movements of layers of the earth's crust. Cracks are also observed in many places in fault region where at some places the occupants left their houses due to probable landslide which can cause critical damage to the buildings and can even result in fatal destruction. It is clear that more exhalation of radon gases occurs in fault region as compared to unrepresented area. However, due to overall lower concentration of radon, the ratio of concentration between fault region and unrepresented area is still not very high, which is 1.3.

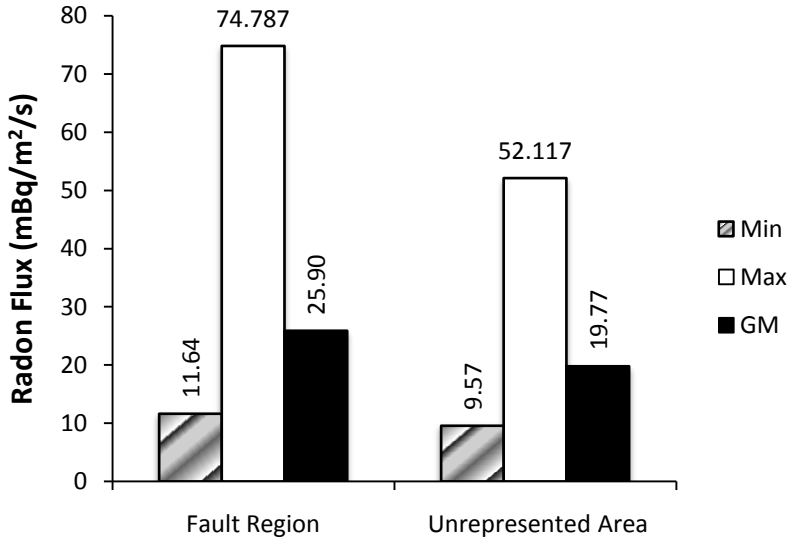

Figure 4.3 Comparison of radon flux in fault region and unrepresented area.

4.2 Radioactivity content

Measurements of radioactivity content were performed from collected soil samples and samples of building materials used for construction of dwellings using γ-spectrometer. At least small amounts of naturally occurring radioactive materials mainly radionuclide from the ^{238}U and ^{232}Th decay chains and the radioactive isotope of potassium, ^{40}K is contained by most building materials of terrestrial origin. Soil samples are collected from different parts of the area of interest within the study area. The collected samples were grinded into a powder size and sealed inside a container (250 ml) for a minimum of 30 days to attain equilibrium condition. The radioactivity content of the samples was then obtained using NaI(Tl) scintillation detector coupled with 1K Multichannel Analyzer. Samples were analyzed for duration of 30000 sec. The instrument had been manually calibrated for each measurement using known activity of standard sources. In this analysis, activity concentrations were determined for ^{238}U (Uranium), ^{232}Th (Thorium) and ^{40}K (Potassium) after removing the background radiation content. The sample weights were measured and the radioactivity content was obtained in Bq/kg for each samples.

4.2.1 Results and discussions

A total of 17 soil samples have been collected from different area of interest within the study area. From the analysis of these samples, the obtained activity for ^{238}U ranges within 61 Bq/kg and 459 Bq/kg with geometric mean of 243 Bq/kg and 1.47 GSD. In case of ^{232}Th, activity ranges from 53 Bq/kg to 346 Bq/kg with GM 239 Bq/kg and 1.45 GSD. For ^{40}K, the experimentally obtained activity varies from 93 Bq/kg to 318

Bq/kg with 147 Bq/kg GM and 1.44 GSD. In this study, ^{238}U and ^{232}Th are the main concern since these two radionuclides are the parent nuclei of radon and thoron respectively. Hence, ^{40}K activity can be neglected for the time being. The results obtained in this measurement is slightly higher which may be due to lower obtained efficiency of the particular instruments, experimentally determined using standard source provided from BARC, Mumbai.

Measurements of the radioisotopic content of collected building materials in the study area viz., brick, asbestos and rock has also been performed. In obtaining natural radioactivity content, available local samples were collected from material used for construction of buildings. Due to limited sources and equipments, samples were collected only from brick, rock and asbestos. From the analysis, in brick sample, 251 Bq/kg, 230 Bq/kg and 114 Bq/kg were obtained for ^{238}U, ^{232}Th and ^{40}K respectively. In rock sample, 260 Bq/kg, 261 Bq/kg and 253 Bq/kg were obtained for ^{238}U, ^{232}Th and ^{40}K respectively. In analyzing asbestos sample, 320 Bq/kg, 315 Bq/kg and 165 Bq/kg were obtained for ^{238}U, ^{232}Th and ^{40}K respectively. The natural radioactivity content obtained from the collected samples of building materials lies in normal range as compared to other data (Arman, 2007).

Fig. 4.4 shows the radioactivity content of collected building materials in Bq/kg. As is clear from the figure, asbestos samples have the highest uranium as well as thorium content; while lowest activity content for both uranium and thorium has been observed in brick samples. For potassium, highest content has been observed in rock samples while lowest content has been observed in brick samples.

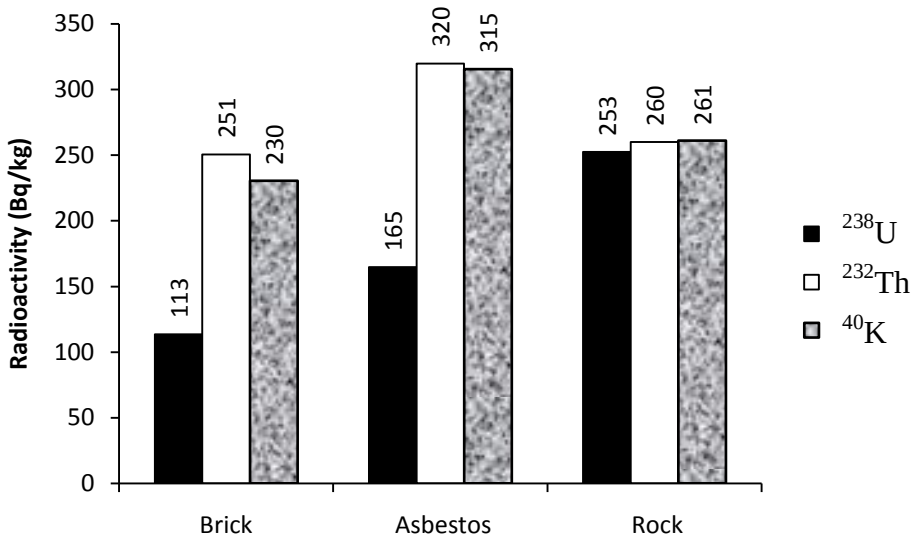

Figure 4.4 Radioactivity content of building materials.

In this study, since we relate the radioactivity content with the time-integrated indoor radon and thoron concentrations, hence we put our main concern to ^{238}U and ^{232}Th, neglecting the radioactivity content of ^{40}K.

The indoor concentrations of radon and thoron in dwellings of different building materials in the study area have already been shown in Fig. 3.8 of section 3.1.4(b). It has been shown that concrete building has the maximum annual average of indoor radon as well as thoron concentrations, while assam type building with wooden/bamboo walls has the lowest indoor radon and assam type building with asbestos walls has the lowest indoor thoron concentrations. Even though the maximum contribution was found in case of asbestos for its radioactivity content (^{238}U), indoor radon concentration in concrete buildings constructed using bricks and rocks were found to be highest. This is due to the fact that buildings having asbestos walls have higher average ventilation rate as compared to concrete buildings. There are many spaces between the walls and the roofs in buildings

having asbestos walls. The fact supporting higher indoor concentrations of radon in concrete buildings as compared to other buildings is that this type of buildings have lower pseudo-ventilation rate where there were no openings between the walls and the roof as well as on the floor.

Fig. 4.5 shows the relation of radon along with the radioactivity content of collected building materials. In order to have a comparable co-relation, obtained indoor radon levels were multiplied by a factor of 5. In buildings with asbestos walls, the measured indoor radon concentration does not become higher as expected from the radioactivity content. This is due to higher ventilation rate of this type of buildings.

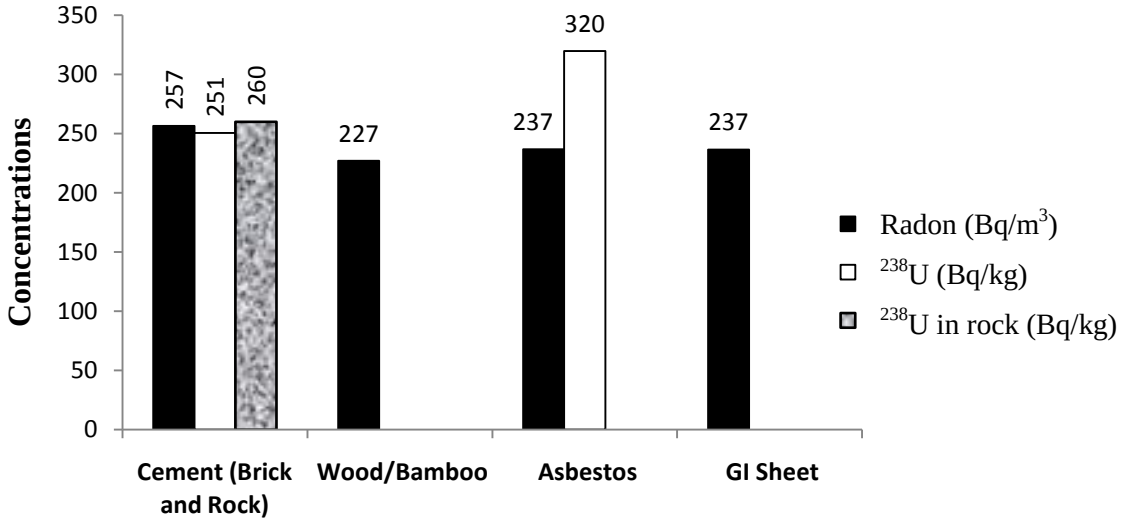

Figure 4.5 Relation of ^{238}U content of the building materials with indoor radon concentrations.

One important thing is that since most of the study area has a hilly terrain landscape, buildings are constructed on a steep slope. RCC buildings are constructed in such a way that not only the basement is in contact with the soil, but also the third or even

fourth floor may have a wall adjacent to the soil in its sides which may increase radon/thoron emanation from walls in addition to the contribution from the materials of the building. Consequently, in this study, indoor radon/thoron concentrations obtained are higher in RCC buildings as compared to assam type buildings. Due to limited sources and equipments, in this study we could not measure the radioactivity content from GI sheet and wood/bamboo.

In case of ^{232}Th also, the higher radioactivity content was found in asbestos samples, maximum indoor thoron concentration were found in concrete buildings constructed using bricks and rocks. Fig. 4.6 shows the relation of thoron along with the radioactivity content of collected building materials. In order to have a comparable co-relation, indoor thoron levels were multiplied by a factor of 15.

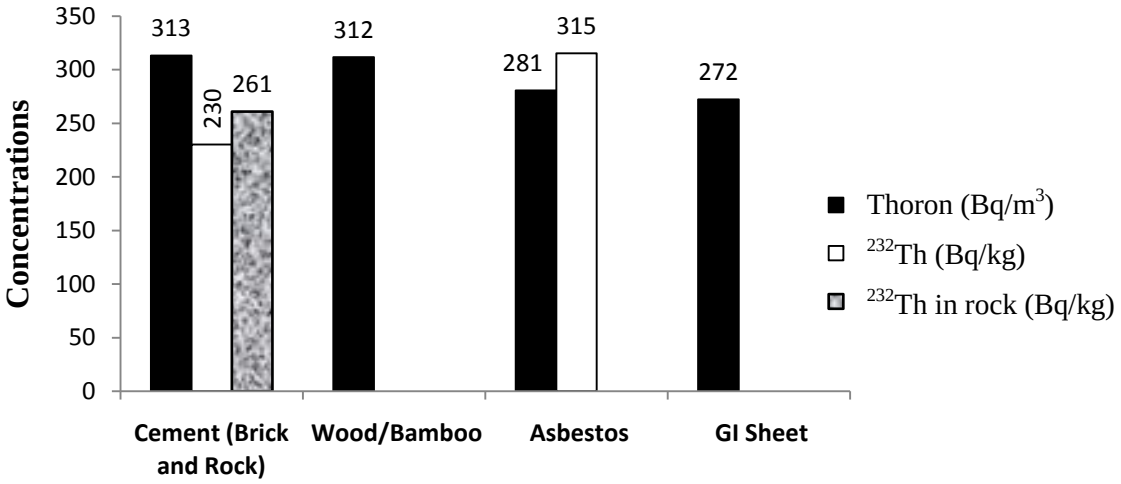

Figure 4.6 Relation of ^{232}Th content of the building materials with indoor thoron concentrations.

Observed indoor thoron levels are high in concrete buildings constructed using bricks and cement while the thorium content of this materials are low. This can be explained similarly as in the case of radon. The RCC building construction type is such a way that due to steep slope of the terrain, more areas of the walls are in contact with the soil which does not occur in assam type buildings. Hence, this may increase emanation of thoron from the walls apart from contribution of the building materials in RCC buildings and may increase indoor thoron levels. Since, ventilation rate does not affect indoor thoron concentrations due to its short half life; the main reason affecting indoor thoron concentrations in dwellings seems to be the emanation rate from the soil into the buildings.

4.3 Background gamma radiation

In general, gamma background radiation has a terrestrial source as well as cosmic source. The measured levels of background gamma level may also help us in predicting the content of source radioactive elements of radon as well as thoron in the vicinity of the study area. Simultaneous measurement of background gamma radiation level was done on ground level as well as at 1m height from the ground, both indoor and outdoor of the selected dwellings where dosimeters were deployed. The instrument used for this measurement is a portable device called Micro-R Survey Meter which automatically detects and measures the background gamma radiation for every 8 seconds (gate time).

4.3.1 Results and discussions

Spot measurement of background gamma radiation level ranges from 10 – 24 μR/hr, with slightly higher values at ground as compared to 1m height. Indoor gamma level was found to be highest in concrete building with an average of 20.71 μR/hr and lowest in building having asbestos walls with an average of 12.04 μR/hr. Obtained background gamma level using Micro-R Survey meter in this study seems to be little higher. This is due to small sample size of the survey meter, which is collected only within 8 sec. IERMON was installed recently in the study area, i.e., in Aizawl City which has larger sample size (5 min analysis). From this instrument, obtained background gamma level was found to be lower, which ranges from 8.05 – 11.5 μR/hr.

Taking ratio of background gamma level at ground and at 1m height, it is found that background gamma level is slightly higher at ground as indicated in Fig. 4.7.

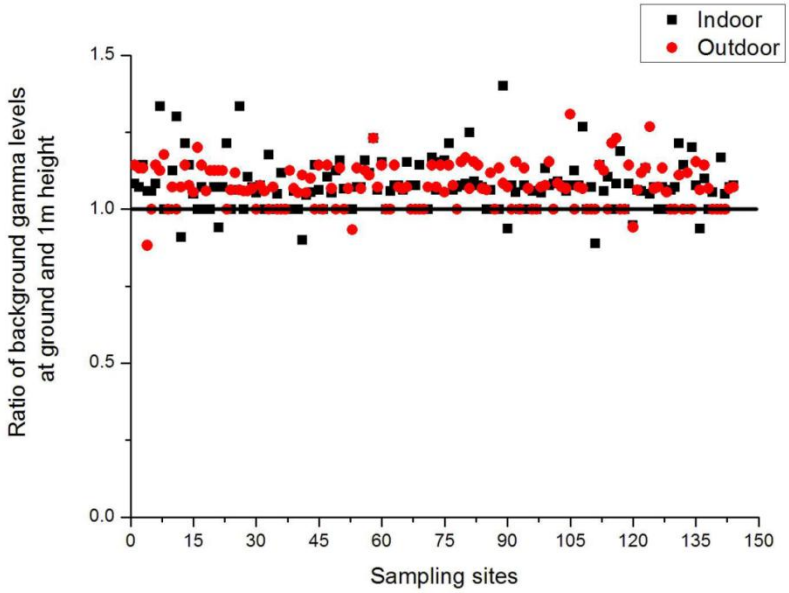

Figure 4.7 Ratio of background gamma radiation at ground and 1m height for indoor as well as outdoor.

The background gamma radiation levels do not provide us good and clear cut assumption or prediction for the levels of indoor radon as well as thoron. However, it is clear that terrestrial source is dominant as compared to cosmic source but only with slightly higher value.

4.4 Radon in caves and soil gas

There are two important caves within the study area playing a vital role in the history of Mizoram. These two caves are Khuangchera cave (23º41.49' N and 92º37.09' E; altitude – 1110 m), located near Ailawng Village in Aizawl District and Lamsial cave (23º08.42' N and 93º16.57' E; altitude – 1264 m), located near Farkawn Village in Champhai District. In these caves, measurements of radon in air have been done using RAD-7. In selected locations inside the study area, measurements of radon concentration content in the soil gas have also been performed using the same device, RAD-7 connected with a probe of 1.5 m in length.

4.4.1 Radon in caves

In Khuangchera cave, four measurements have been taken inside the cave and two measurements outside it. The concentrations of radon in air range from 11.3 ± 31 Bq/m^3 to 79.5 ± 55.3 Bq/m^3 with an average of 41.15 ± 42.77 Bq/m^3 inside the cave. It ranges from 17± 34 Bq/m^3 to 22.7 ± 36.7 Bq/m^3 with an average of 19.85 ± 35.35 Bq/m^3 outside the cave. The background gamma radiation levels have also been measured whose values range from 22 µR/h to 28 µR/h with an averge of 25.13 µR/h inside the cave and range from 15 µR/h to 18 µR/h with an average of 16.5 µR/h outside it.

At Lamsial cave, two measurements have been done inside the cave and one outside. Inside the cave, radon concentrations in air vary between 73.8 ± 33.7 Bq/m^3 and 412 ± 74.3 Bq/m^3 with an average of 242.9 ± 54 Bq/m^3. Outside the cave, measured radon concentration is 2.84 ± 15.5 Bq/m^3. The background gamma radiation levels range from 22 µR/h to 27 µR/h with an averge of 24 µR/h inside the cave and range from 10 µR/h to 13 µR/h with an average of 11.5 µR/h outside it.

In both the caves, background gamma radiation level inside it is slightly high as compared to other measured values at dwelling sites. Since the inner surface of the caves is made up of rock, this may results in higher background gamma levels. On the outside, gamma level becomes comparable to other sampling sites. In case of radon concentrations, the result is expected to be higher as compared to indoor measurements in other dwelling sites. This can be explained on the basis of air circulation rate as well as exhalation rate from the surface. Lesser ventilation rate with higher exhalation rate could possibly increase the radon levels inside the caves. The obtained value is much higher inside the Lamsial cave while it is comparable to dwelling sites in Khuangchera cave. When we look at the measured radon levels outside the caves, the value is low. This is because outdoor air has a very high air circulation rate which results in very low radon levels. One important thing regarding the result is that, the error obtained by the device seems very high, which could lead us into a position where making a clear cut conclusion regarding the radon levels inside the caves becomes difficult.

4.4.2 Radon content in soil gas

Soil gas probe of 1.5 m in length has been inserted into the soil upto 1.2 m depth in nine selected locations within the study area. This probe is connected to RAD-7 which passes through a moisture eliminator, silica gel containing cylindrical chamber known as Dryrite. The soil gas is pumped by RAD-7 into its detector chamber and automatically measures the radon concentration in the gas.

The average value of measured radon content ranges from 5.82 kBq/m^3 to 29 kBq/m^3 with a geometric mean of 12.9 kBq/m^3 and 1.74 GSD.

Chapter 5

Conclusion

The dose received from the inhalation of radon, thoron and progeny nuclides, which constitutes about 50% of the total dose is the main cause of the radiological health hazard from natural radiation to populations (BEIR, 1990; UNSCEAR, 2006). Therefore, estimation of this component is an important task. This calls for time integrated measurements of radon, thoron and progeny concentrations covering diurnal and seasonal variations. With the progress of studies and development of instruments, the measurement of these radionuclides has covered some of the states in India (Sadasivan *et al.*, 2003). In some part of India, apart from being determined, continuous monitoring is also in progress. In the north-eastern part of India, very little studies have only been done covering small part of the whole area (Srivastava *et al.*, 1996). In Mizoram, even though some previous studies had been done including only 17 houses, this is far less than the required data to show the exact status of the state (Ramachandran *et al*., 2003).

As discussed in Chapter 1, considerable work exists in the literature on the topic of radon and thoron measurements. However, measurement of population dosimetry particularly in the study area is the novel aspect dealt in the present work. The work regarding measurement of the concentration of these gases in the state of Mizoram is still in the initial stage and no data are available for the study of inhalation doses of these gases contained in the inhaled air in the dwellings as well as for the study of deposition in the soil. With this objective in mind, the study presented in this thesis details the measurement of indoor radon, thoron and their progeny concentrations and status of the exhalation of these gases from soil in the north-eastern part of India, covering three districts, viz.,

Aizawl, Champhai and Kolasib Districts in the state of Mizoram, which covers the northern part of the State. It also includes the study of the contribution of the building materials used for dwellings to the radon, thoron and their progeny concentrations besides the atmospheric air and also the determination of the activity content of radioactive elements in and around the dwellings. These constitute the bulk of the studies carried out in the thesis.

As already outlined in Chapter 3, training regarding calibration of most of the instruments used in the present work has been gone through at the beginning of the work using the facilities at Bhabha Atomic Research Center (BARC), Mumbai. Regarding some instruments like Spark counter, obtaining the operating voltage has to be done for each specific device. Hence, the operating voltage of the particular Spark counter used in this study has been determined experimentally at the laboratory in Aizawl, but, with the detection of slight change in the track densities, the required final calibration has been done with the scientists from BARC, Mumbai.

In measuring indoor radon and thoron concentrations, we have found that the results obtained in this study area are low, which lies in the range covered by nationwide survey result (Ramu *et al*, 1992) as well as the ICRP regulations (ICRP, 1993). The investigation shows no significant radiological risks for the inhabitants and is well within the limits prescribed by UNSCEAR (2006). We have found that radon has higher concentrations as compared to thoron. Among the three districts, maximum annual average indoor concentrations of radon has been observed in Champhai District which has the lowest average annual temperature. Maximum average indoor thoron concentration has been found in Kolasib District and minimum in Champhai District. There have been many factors affecting radon, thoron and their progeny concentrations in the environment. From

the present study, the pseudo-ventilation rate and air exchange rate as well as entry rate from the soil in to the dwellings plays a vital role in indoor radon concentrations while the emanation rate and entry rate from the soil into buildings are the main factors affecting indoor thoron concentrations in the study area.

As shown in chapter 3, section 3.1.4, monitoring the variation of these gases seasonally shows that indoor radon as well as thoron concentrations was found to be highest in winter season and lowest in summer. In winter, the temperature was lowest among the three seasons and hence ventilation rate was also lowest. Whereas in summer, because of high temperature which results in higher ventilation rate of the dwellings, minimum concentration of indoor radon was observed during this season. In rainy season, the temperature in the study area is in between summer and winter, with the result that measured indoor radon level was in between that of winter and summer. The climate of the State of Mizoram is moderate throughout the year. The temperature varies between 20ºC – 30ºC during summer and 11ºC – 21ºC during winter. It rains heavily from the month of May to September and lightly up to November. The average rainfall is 254 cm per annum (Tiwari, 2006). Hence, rainy season is long in the state and it is also difficult to draw a clear cut division of a complete one year into different seasons. The ventilation rate is always high and does not vary much during these seasons, especially during rainy season and summer season. But, it is still obvious that the air exchange rate due to ventilation plays the most important role in seasonal variation of radon levels in the state. This is due to the fact that the most contributor of radon gas is the rate of exhalation from soil and building materials, and the removal depends strongly on ventilation rate. Hence high ventilation rate will surely lowers the level and vice versa.

Maximum seasonal variation of indoor radon levels has been observed in Kolasib District due to hotter summer season as compared to other districts. Minimum seasonal variation of indoor radon levels has been observed in Aizawl district due to moderate temperature of the area as compared to other areas. It should be mentioned that ventilation rate does not affect indoor thoron levels due to its short diffusion length; as a result, the observed seasonal variation of indoor thoron concentrations become different with respect to that of radon. The exact cause of seasonal variation of indoor thoron is beyond this study. However, as already mentioned in chapter 3, section 3.1.4, it may be mentioned again that lower indoor thoron levels during rainy season as compared to summer and winter seasons may be due to the fact that, thoron cannot escape easily from the capillaries of soil, which are mostly occupied by water during rainy season. This can result in low emanation of thoron during rainy season.

Due to overall low concentration of radon in the environment, the ratio of radon level in winter and summer are low. During winter season, even with low ventilation rate or air exchange rate, the rate of accumulation of radon in indoors is not so high. As a result, with highest radon level observed during winter, this low rate of accumulation may results in low ratio of radon level comparing winter and summer. It can also be concluded that the rate of exhalation of radon from soil and building materials may also be low in the measured areas.

From the results obtained regarding types of materials used in construction of building and comparing with the radioactivity content as discussed in chapter 3, section 3.1.4 and chapter 4, section 4.2 respectively, we can conclude that higher air exchange rate or pseudo-ventilation rate due to more openings between the walls and roofs as well as

floors of assam type buildings results in lower indoor radon levels as compared to concrete buildings where there exists no openings between the walls and roofs or floors. More openings results in more escape rate for radon, and hence results in low indoor radon levels. Consequently, even with the observation of maximum radioactivity content and contribution for asbestos, indoor radon concentration in concrete buildings were found to be highest. In case of thoron, we can conclude that indoor thoron levels depend strongly on the entry rate from soil into buildings or dwellings apart from the contribution of building materials used. This has been discussed in section 4.2.1 and shown clearly in Fig. 4.6. In both cases of indoor radon and thoron, due to construction of buildings at steep slope, higher contribution of indoor radon and/thoron are expected in RCC buildings where more contact rate between the walls and soil has been observed. This rate of contact is not observed in other types (Assam type) of buildings. This condition supports the observation of higher indoor accumulation of radon/thoron gases with lower radioactivity content in RCC buildings.

Referring discussions from Fig. 3.10 and Fig. 3.11 in chapter 3, comparison of the annual average of indoor radon and thoron levels among each of the selected geological areas shows that among the three areas, viz., fossil, fault and unrepresented areas, annual average indoor radon concentration is maximum in fault region. This is due to the fact that fossil and/or fault region has higher exhalation rate of these gases due to more exposure, cracks, openings of earth's surface and often landslide in these regions. But for indoor thoron levels, the main reason for which minimum annual average is being observed in fault region as compared to unrepresented and fossil area is in contradictory to the expectation. However, as already discussed, indoor thoron levels depend strongly on the

building materials used for construction of dwellings, hence, this can be the reason for this contradictory results even though it is difficult to have a clear cut conclusion for the time being. It may be mentioned again that due to limited availability of recorded geological conditions to refer to in the study area, measurements of radon and thoron concentration based on geological conditions could be performed only in Aizawl district.

In case of progeny measurements also, due to limited source of DPS, progeny measurements as well as calculations of equilibrium factors and inhalation dose have been done from the study area covering only Aizawl district. The calculated annual average value of equilibrium factor for radon (F_R), 0.32 is slightly lower in comparison to average global level, 0.4. Whereas, the calculated annual average value of equilibrium factor for thoron (F_T), 0.05 is slightly higher with respect to average global level, 0.03 (UNSCEAR, 2000). Due to high indoor concentrations of radon as well as thoron and much high EETC values in comparison to average global level, the experimentally obtained value of F_R becomes slightly low with respect to average global level while F_T becomes slightly higher. Regarding annual effective doses, the obtained value for the total annual effective dose rate due to radon is lower than global average but in case of thoron the obtained value is higher than global average value. It has been found that the maximum inhalation dose rate for radon as well as thoron is obtained during winter season, while mimimum value is obtained during summer season. Since obtained F-factor for radon is lower and that for thoron is higher hence the inhalation dose value obtained using this factor along with the indoor concentrations gives us lower value for radon but higher value for thoron in comparison to global average value.

The present study finds that indoor radon levels of dwellings present in the study area depends not only on the ventilation rate, but also on the rate of exhalation of radon in the vicinity of the dwellings. This is discussed in section 4.1.1 where it has already been clearly shown that the indoor radon concentrations and radon flux are in good correlation. It can be concluded that surface radon flux persuade significant contribution to the indoor radon levels. Radon flux is also found to be higher in fault region as compared to unrepresented area which is due to loose binding and frequent movement of the soil in fault area, resulting in more exhalation rate from the inner soil to the atmosphere.

A few measurements carried out for radon content in soil gas and atmospheric radon content inside caves shows that the average value of measured radon content in soil gas is lower as compared to previous research findings in other areas (Singh *et al.*, 2010). This also helps in explaining the overall slightly lower determined radon levels in the whole study as compared to previous findings in other areas. In caves, background gamma radiation level inside it is slightly high as compared to other measured values at dwelling site because most of the inner surfaces of the caves are made up of rock. With respect to indoor measurements in other dwelling sites, the measured radon concentrations in air inside one of the cave is much high which may be due to lower ventilation rate and more exhalation rate from the surfaces. However, measured radon levels in the other cave are comparable with that obtained in dwelling sites.

The present study leads us into another conclusion that in the study area background gamma radiation level has slightly higher values at ground as compared to 1m height and indoor background gamma level is lower than outdoor. The higher value of gamma levels at ground shows that in comparison to the two types of background gamma sources, the

terrestrial source is dominant but only with slightly higher value as compared to cosmic source. The measured background gamma levels do not provide us good and clear cut assumption or prediction for the levels of radon as well as thoron. In Domiasiat area of Meghalaya, which is the proposed uranium mining site, gamma background radiation level range between 50 – 400 µR/h (Vanchhawng *et al,* 2009). In comparison to this value, the gamma background radiation level on an average obtained by spot survey in this report is very low.

It is hoped that the studies and observations discussed here will be of considerable help in generating large scale dosimetric data on the inhalation doses to the populations and contributes the status of Mizoram as well as north-eastern India in the mapping of radon and thoron in India.

Drawbacks involved in our measurement of atmospheric radon levels using RAD-7 where errors displayed automatically by the device become very high like in the case of measurement of radon in Khuangchera cave. High error indicates low accuracy for that particular measurement. However, this high error display may be due to low concentrations of radon in the atmosphere because when concentration reading is high, error levels become low as in the case of measurement inside Lamsial cave. And it is difficult for the time being to have a clear cut conclusion for the variation of observed thoron levels at geological sites. The measured background gamma level using Micro-R Survey seems to be little higher. This is due to small sample size of the survey meter, which is collected only within 8 sec. The measured background gamma level in Aizawl City using IERMON having larger sample size (5 min analysis) was found to be lower as compared to that obtained in the same area using Micro-R survey meter.

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LISTS OF RESEARCH PUBLICATIONS

(I) Journals:

(a) National:

(1) Measurements of the equilibrium factor of radon in Aizawl, Mizoram, IndiaRadon and the risk of lung cancer in Aizawl district, Mizoram, India, **Lalmuanpuia Vanchhawng**, P.C.Rohmingliana, R.K.Thapa,R.Mishra, B.K.Sahoo, B.Zoliana and Y.S.Mayya, *Sci. Vis.* **11** (2) 102-105 (2011).

(2) Radon and the risk of lung cancer in Aizawl district, Mizoram, India, B.Zoliana, **Lalmuanpuia Vanchhawng**, P.C.Rohmingliana and R.K.Thapa, *Sci. Vis.* **10** (2) 66-72 (2010).

(3) Measurement of indoor concentrations of radon and thoron in Mizoram, India, P.C.Rohmingliana, **Lalmuanpuia Vanchhawng**, R.K.Thapa, B.K.Sahoo, R.Mishra, B.Zoliana and Y.S.Maya, *Sci. Vis.* **10** (4) 148-152 (2010).

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(II) Conferences:

(a) International:

(1) Measurement of Equilibrium Factors and Inhalation dose for radon/thoron in dwellings using Direct Progeny Sensors in North-Eastern region of India, B.Zoliana, Lalmuanpuia Vanchhawng, P.C.Rohmingliana, R.K.Thapa, B.K.Sahoo, Rosaline Mishra, and Y.S.Mayya, *Proceedings of 7th International Conference on High Levels of Natural Radiation and Radon Areas (7HLNRRA)* during November 24 – 26,2010, The Park Hotel, Navi Mumbai.

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(5) The study of Population Dosimetry in North East India. B.Zoliana, P.C.Rohmingliana, Lalmuanpuia Vanchhawng, R.K.Thapa, R.Mishra, B.K.Sahoo and Y.S.Mayya, *Proceedings of International Symposium on Natural Radiation Exposures and Low Dose Radiation Epidemiological Studies (NARE 2012)* at Hirosaki University, Japan during 29.2.2012-3.3.2012.

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(b) National:

(1) To Correlate Radon and Thoron concentrations with Gamma Background Radiation in Mizoram. (Special reference to Aizawl, Champhai and Kolasib districts), Lalmuanpuia Vanchhawng, P.C. Rohmingliana, R.K.Thapa, B.K.Sahoo, O.P. Singh, B.Zoliana and Y.S. Mayya, *Proceedings of the VI National Conference of PANE*, Tripura University, 2-4 April, 2009.

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(3) Study of radon concentrations in relation with radioactivity content of building materials in Aizawl District, Mizoram, India, Lalmuanpuia Vanchhawng, P.C.Rohmingliana, R.K.Thapa, B.K.Sahoo, Rosaline Mishra, B.Zoliana and Y.S.Mayya, *Proceedings of 17th National Symposium on Solid State Nuclear Track Detectors and Their Applications (SSNTD-17)* during October 17 -19, 2011, The M.S.University of Baroda, Vadodara.

(4) Study of radon flux from soil surface in middle part of Mizoram, Inida, P.C.Rohmingliana, Lalmuanpuia Vanchhawng, R.K.Thapa, B.Zoliana, B.K.Sahoo, R.Mishra, and Y.S.Mayya, *Proceedings of 17th National Symposium on Solid State Nuclear Track Detectors and Their Applications (SSNTD-17)* during October 17 -19, 2011, The M.S.University of Baroda, Vadodara.

(III) Workshops/ Training Programmes attended:

(1) DAE-BRNS Theme Meeting RADON-2008 on *'Advances in the methods of assessment of exposure due to radon, thoron and their decay products'*, Organized by Health, Safety and Environment Group, BARC, Mumbai, 11th – 13th March, 2008.

(2) 10th North East Workshop on Computational Information Processing, Organized by Electronics & Communication Sciences Unit, Indian Statistical Institute Kolkata and Govt. Zirtiri Residential Science College, Aizawl, Mizoram, 10th-12th November, 2010.

(3) DAE-BRNS sponsored Indo-Japan Workshop on Environmental Radon/Thoron-2010, Organized by Radiological Physics and Advisory Division, BARC, Mumbai, 22nd -23rd November, 2010.

APPENDIX - I

Experiment to find the calibration factor for radon and thoron using sources of known activity

APPARATUS :

Calibration chamber, dosimeters, LR-115 films, RAD-7, Etching bath, Spark counter, thorium nitrate (thoron source) and radium (radon source).

THEORY :

Dosimeter :-

In this experiment, Twin cup dosimeters are used. In this type of dosimeter, there are three compartments – Filter mode compartment, Membrane/Pinhole mode compartment and Bare mode.

In the filter mode, filter paper is used to cover the entry point of the compartment. This filter paper blocks the entry of the progeny while it allows both radon and thoron gas to pass through. So, tracks formed on the film inside this compartment are due to both radon and thoron gases and not the progeny. In the membrane mode, semi-permeable membrane is sandwiched between two filter papers which allows Radon gas only to pass through it hence in this compartment tracks on the film are produced due to radon gas only. In case of pinhole, we have a pinhole of 0.4mm diameter and 5mm thick in which radon gas only pass through. No membrane is used but filter paper is used to block the progeny. Similarly as in the case of membrane compartment tracks produced on the film in the pinhole side are due to radon gas only. In the 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 progeny.

We can calculate the concentration of radon gas from the Membrane or Pinhole compartment, the concentration of thoron gas can be calculated by simply subtracting the concentration of Radon gas from the concentration of both radon and thoron gases calculated from the Filter compartment. Subtracting the concentration calculated from the Filter compartment from the concentration calculated from the bare mode we can easily obtain the progeny concentration.

Similarly, for calculation of the calibration factor, the same method, i.e. simple subtraction method can be used.

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

$$T = kCt \tag{I-1}$$

where, we define k as the calibration factor.

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. The corresponding calibration factors may be defined as

$$k_{R(M/F)} = \frac{T_{R(M/F)}}{tC_{R(M/F)}} \tag{I-2}$$

$$k_{T(F)} = \frac{T_{T(F)}}{tC_{T(F)}} \tag{I-3}$$

where, $k_{R(M/F)}$ is the calibration factor of radon in membrane cup or filter cup and $k_{T(M)}$ 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. $T_{R(M)}$ is the tracks recorded for

radon on the detector in tr/cm^2 and $T_{T(M/F)}$ is the tracks recorded for thoron on the detector in tr/cm^2. The subscript *M* and *F* denote the compartments in the dosimeter. *M* represents membrane compartment and *F* represents the filter compartment.

In this experiment, radium is used as radon source and thorium nitrate is used as thoron source. The activity concentrations of the gases are continuously monitored using RAD-7.

PROCEDURE :

1. Cut the LR-115 film into 3 x 3 cm^2 and fix them on the dosimeter. For bare mode the film should be cut into 2.5 x 2.5 cm^2.
2. Note the number of each dosimeter and mount them inside the calibration chamber.
3. Note the exact mounting time.
4. Monitor the activity concentrations of the gases continuously using RAD-7 with 30 minutes cycle.
5. Remove the dosimeters from the calibration chamber and note the time of removal.
6. Etch the films in 2.5N NaOH solution for 60 min at 60^{o}C with continuous stirring.
7. Count the tracks on each film using Spark counter.
8. Calculate the Calibration factor using Eq. I-2 and Eq. I-3.

OBSERVATIONS :

Table I-1 Monitoring of radon and thoron concentration in the calibration chamber for calibration of twin cup dosimeter.

Starting Date/Time = Dt.18/03/08; 17:51.

Stopping Date/Time = Dt.19/03/08; 10:24.

Exposure period = 0.69 days.

Sr No	Time	Radon (Bq/m3)	Error	Thoron (Bq/m3)	Error	Temp(ºC)
1	17:01	22500	1070	5030	608	26.1
2	17:16	47200	1570	8980	819	26.1
3	17:31	47100	1580	9140	937	26.1
4	17:46	49800	1630	8980	848	27.1
5	18:01	47300	1590	9300	867	27.7
6	18:16	47700	1600	9040	864	28.3
7	18:31	46800	1590	9670	896	28.6
8	18:46	46300	1590	9160	882	28.9
9	19:02	46300	1600	9870	916	28.9
10	19:17	47000	1610	9590	906	29.2
11	19:32	46100	1600	9250	895	29.2
12	19:47	45100	1580	10300	938	29.2
13	20:02	46200	1600	10600	949	29.2
14	20:17	44900	1580	9910	922	29.2
15	20:32	45700	1590	8580	868	29.2
16	20:47	44700	1570	9460	903	29.2
17	21:02	45300	1590	9570	908	29.2
18	21:17	44200	1580	9980	927	29.2
19	21:32	44800	1580	10800	956	29.2
20	21:47	45400	1590	9710	914	29.2
21	22:02	43700	1570	9870	922	28.9
22	22:17	44300	1580	10700	949	28.9
23	22:32	45800	1610	10400	942	28.9
24	22:47	45600	1600	10100	932	28.9
25	23:02	45700	1600	9820	919	28.6
26	23:17	45500	1600	9790	919	28.6
27	23:32	46400	1620	11100	968	28.6
28	23:47	45700	1610	10900	962	28.6
29	00:02	46600	1630	11300	978	28.6
30	00:17	45600	1610	10600	953	28.6
31	00:32	46600	1630	10600	951	28.6
32	00:47	45600	1610	11000	966	28.6
33	01:02	45900	1620	11100	973	28.6
34	01:17	46100	1620	10400	946	28.6
35	01:32	46200	1620	10000	929	28.9
36	01:47	46000	1620	10000	929	28.6
37	02:02	46500	1630	10500	946	28.6
38	02:17	47700	1650	10600	954	28.6
39	02:32	45600	1620	10300	936	28.6

40	02:47	45100	1620	10500	951	28.6
41	03:02	45100	1610	11200	974	28.6
42	03:17	45800	1630	10700	954	28.6
43	03:32	47100	1650	9220	896	28.6
44	03:47	45300	1620	10700	956	28.6
45	04:02	48100	1670	1100	970	28.6
46	04:17	46300	1640	10700	955	28.6
47	04:32	46000	1630	10400	945	28.6
48	04:47	46000	1630	10200	934	28.6
49	05:02	46700	1650	10000	930	28.9
50	05:17	46100	1640	10100	932	28.9
51	05:32	48000	1670	10500	950	28.9
52	05:47	46800	1660	10200	941	28.6
53	06:02	47700	1670	9970	928	28.6
54	06:17	45800	1630	10300	939	28.9
55	06:32	45800	1640	9830	922	28.6
56	06:47	46800	1660	10700	954	28.6
57	07:02	47700	1670	10700	958	28.6
58	07:17	46300	1650	10200	934	28.6
59	07:32	48900	1690	10000	930	28.6
60	07:47	46700	1660	9810	919	28.6
61	08:02	45400	1640	10100	932	28.6
62	08:17	47300	1670	10700	958	28.3
63	08:32	44900	1620	10400	946	28.3
64	08:47	46700	1660	11200	975	28.3
65	09:02	46100	1660	9700	918	28.3
66	09:17	45300	1630	10300	940	28.3
67	09:32	47400	1670	10700	957	28.3
68	09:47	47300	1670	10400	948	28.3
69	10:02	46000	1690	10200	996	28.3
Average		**45884.05797**	**1615.072**	**9952.608696**	**928.1014**	**28.56087**

Table I-2

		Track density (track/cm^2)		
Dos. No.	**Dos. Type**	**Bare**	**Filter**	**Memb./Pinhole**
B129	Membrane	597	491	265
2178	Membrane	919	353	268
		787		261
2176	Membrane	1230	970	907
		2041	993	866
B238	Pinhole	700	473	312
		696	475	305
2146	Pinhole	1322	718	340
		1670	674	267
B331	Pinhole	1903	956	663
		2550	951	619

Table I-3 Monitoring of radon and thoron concentration in the calibration chamber for calibration of twin cup dosimeter.

Starting Date/Time = Dt.19/03/08; 14:35.

Stopping Date/Time = Dt.24/03/08; 09:35.

Exposure period = 4.79 days.

Sr No	Time	Radon (Bq/m3)	Error	Thoron (Bq/m3)	Error	Temp(ºC)
1	17:20	2840	411	11900	639	28.6
2	19:20	2800	411	12000	643	29.2
3	21:20	3130	429	11200	620	29.2
4	23:20	2880	433	10700	607	29.5
5	01:20	2740	439	10300	594	29.2
6	03:20	2550	438	10500	600	28.9
7	05:20	2470	431	11100	616	28.9
8	07:20	2500	441	10200	592	29.2
9	09:20	2490	452	10300	597	29.2
10	11:20	2700	450	9770	581	29.2
11	13:20	2450	453	10300	595	29.8
12	15:20	2440	459	9880	587	30.1
13	17:20	2390	456	10000	587	30.1
14	19:20	2400	449	10200	592	29.8
15	21:20	2970	466	9810	582	29.5
16	23:20	2510	463	10400	599	29.8
17	01:20	1740	449	9550	574	29.8
18	03:20	2120	455	9850	583	29.2
19	05:20	2610	463	10400	598	29.8
20	07:20	2200	463	10300	596	29.5
21	09:20	2500	461	10100	589	29.8
22	11:20	2630	466	10500	601	29.8
23	13:20	2330	458	10300	596	30.1
24	15:20	2670	466	10200	594	30.1
25	17:20	2310	462	10100	589	30.4
26	19:20	2320	465	11000	616	29.8
27	21:20	2460	464	10200	593	29.8
28	23:20	2230	465	10500	600	30.1
29	01:20	2190	458	10700	606	30.1
30	03:20	1850	456	10000	587	29.5
31	05:20	2410	464	10300	594	29.8
32	07:20	2210	465	10700	607	30.1
33	09:20	1930	457	10600	604	30.1
34	11:20	2030	460	9730	579	30.4
35	13:20	2390	455	10300	595	30.7
36	15:20	2180	463	9610	576	30.7
37	17:20	2090	457	9470	571	30.7
38	19:20	1940	462	9730	579	30.4
39	21:20	2160	461	10400	598	30.4

40	23:20	2200	456	9960	585	30.4
41	01:20	2020	459	10000	588	30.7
42	03:20	2210	458	9620	576	30.4
43	05:20	2000	444	9580	574	30.4
44	07:20	2060	458	9400	569	30.4
45	09:20	2160	451	9280	566	30.4
46	11:20	2200	455	10200	592	30.7
47	13:20	2160	450	9580	574	30.7
48	15:20	2240	452	9890	584	30.7
49	17:20	2170	459	9880	583	31
50	19:20	2000	452	9680	577	30.7
51	21:20	2270	453	9650	576	30.7
52	23:20	2050	447	10100	588	30.7
53	01:20	1920	449	9680	577	30.7
54	03:20	1900	450	8930	555	30.7
55	05:20	2200	448	9620	575	30.4
56	07:20	1910	441	10100	588	30.4
57	09:20	2030	452	10100	590	26.8
Average		**2306.315789**	**452.8070175**	**10146.49123**	**590.7544**	**29.96842**

Table I-4

		Track density (track/cm^2)		
Dos. no	**Dos Type**	**Bare**	**Filter**	**Memb./Pinhole**
2186	Membrane	2430	365	160
		2921	327	159
2178	Membrane	1985	563	148
				146
2146	Pinhole	2520	693	74
			691	77
B328	Pinhole	1778	1045	62
			1028	66

Table I-5 Monitoring of radon concentration in the calibration chamber for calibration of twin cup dosimeter with radon source only.

Starting Date/Time = Dt.24/03/08; 12:15.

Stopping Date/Time = Dt.26/03/08; 11:05.

Exposure period = 2 days.

Sr No	**Time**	**Radon (Bq/m3)**	**Error**	**Temp(ºC)**
1	15:17	1040	381	24.6
2	15:47	1160	382	24.9
3	16:17	1260	376	24.9

4	16:47	1600	382	25.2
5	17:17	1500	373	25.5
6	17:47	1060	349	25.8
7	18:17	1380	359	26.1
8	18:47	1560	360	27.4
9	19:17	1260	356	28
10	19:47	1290	345	28.6
11	20:17	1460	349	28.6
12	20:47	1020	329	28.9
13	21:17	1050	338	29.2
14	21:47	892	327	29.2
15	22:17	934	323	29.2
16	22:47	1090	320	29.2
17	23:17	876	304	29.2
18	23:47	1120	306	29.2
19	00:17	1270	308	29.2
20	00:47	1120	305	29.2
21	01:17	1000	296	29.2
22	01:47	937	294	29.5
23	02:17	784	288	29.5
24	02:47	943	283	29.2
25	03:17	872	273	29.2
26	03:47	754	278	29.2
27	04:17	1230	279	29.2
28	04:47	789	271	29.2
29	05:17	895	269	29.2
30	05:47	854	267	29.2
31	06:17	977	264	29.2
32	06:47	977	260	29.2
33	07:17	930	251	29.2
34	07:47	936	248	29.2
35	08:17	965	249	28.9
36	08:47	770	237	28.9
37	09:17	958	245	28.9
38	09:47	894	242	28.6
39	10:17	708	241	28.3
40	10:47	704	230	28.3
41	11:17	1150	245	28.3
42	11:47	785	233	28.3
43	12:17	867	226	28.3
44	12:47	820	228	28.3
45	13:17	583	213	28.3
46	13:47	965	224	28.3
47	14:17	686	215	28.6
48	14:47	802	216	28.6
49	15:17	692	207	28.6
50	15:47	610	208	28.3
51	16:17	814	213	28.6
52	16:47	853	207	28.6
53	17:17	749	201	28.6

54	17:47	656	200	28.6
55	18:17	976	210	28.9
56	18:47	804	200	28.9
57	19:17	698	187	28.9
58	19:48	780	201	28.9
59	20:18	892	200	28.9
60	20:48	692	193	28.9
61	21:18	569	183	28.9
62	21:48	634	183	28.9
63	22:18	657	187	28.9
64	22:48	628	185	28.9
65	23:18	692	180	28.9
66	23:48	587	183	28.6
67	00:18	634	184	28.6
68	00:48	698	179	28.6
69	01:18	657	176	28.6
70	01:48	557	168	28.6
71	02:18	616	170	28.6
72	02:48	786	183	28.3
73	03:18	698	174	28.6
74	03:48	674	173	28.6
75	04:18	639	176	28.6
76	04:48	709	176	28.6
77	05:18	768	176	28.6
78	05:48	651	167	28.6
79	06:18	528	161	28.3
80	06:48	651	165	28.6
81	07:18	516	156	28.6
82	07:48	563	158	28.6
83	08:18	815	179	28.6
84	08:48	709	164	28.3
85	09:18	539	150	28.3
86	09:48	592	158	28.3
87	10:18	633	155	28
88	10:48	685	169	28
Average		**861.1136364**	**240.7045**	**28.4625**

Table I-6

	Track density (track/cm^2)		
Dos. no	**Bare**	**Filter**	**Pinhole**
	68	38	34
2146	71	42	34
	72	34	33
	68	45	31
B328	69	47	29
	67	42	29
	53	47	33
B331	56	56	34
	55	53	35

Table I-7 Monitoring of radon and thoron concentration in the calibration chamber for calibration of twin cup dosimeter with thoron source and slight radon source.

Starting Date/Time = Dt.26/03/08; 17:30.

Stopping Date/Time = Dt.27/03/08; 10:05.

Exposure period = 0.69 days

Sr No	Time	Radon (Bq/m3)	Error	Thoron (Bq/m3)	Error	Temp(ºC)
1	17:48	757	167	27200	955	28.9
2	18:18	631	165	28500	978	29.5
3	18:48	421	169	27500	959	29.8
4	19:18	951	220	27800	966	29.5
5	19:48	673	218	26500	943	29.5
6	20:18	974	250	25600	928	29.2
7	20:48	806	269	26000	935	29.2
8	21:18	831	288	25100	918	28.9
9	21:48	837	298	25000	917	29.2
10	22:18	856	316	24400	907	28.9
11	22:48	1140	332	24200	903	28.9
12	23:18	791	340	24400	907	28.9
13	23:48	930	359	23600	892	28.9
14	00:18	713	360	24000	901	28.9
15	00:48	659	375	23500	892	28.9
16	01:18	1010	393	23300	888	28.9
17	01:48	1010	401	24300	907	28.9
18	02:18	1110	418	22900	880	28.9
19	02:48	1240	423	23100	886	28.9
20	03:18	1270	431	23600	894	28.9
21	03:48	1320	439	22700	879	28.9
22	04:18	1240	442	23400	892	28.9
23	04:48	1300	458	22600	878	28.9
24	05:18	1080	451	22800	880	28.9
25	05:49	1140	468	23400	894	28.9
26	06:19	1230	476	22900	884	28.9
27	06:49	1480	483	22800	882	28.9
28	07:19	1100	482	23200	891	28.6
29	07:49	1330	489	23200	889	28.6
30	08:19	1480	504	23100	888	28.6
31	08:49	1210	503	23200	890	28.6
32	09:19	1190	505	23200	891	28.3
Average		**1022.1875**	**371.625**	**24281.25**	**906.0625**	**28.95625**

Table I-8

	Track density(track/cm2)		
Dos. No	**Bare**	**Filter**	**Pinhole**
	296	98	6
2146	303	105	8
B328	631	117	11
	643	134	10
B331	319	85	6
	316	88	4

RESULTS :

Table I-9 Calibration factor calculated from the first observation.

Calibration factor (Track/cm^2/d/Bq/m^3)			
		Radon	**Thoron**
	Pinhole	0.015	0.047
	Membrane	0.017	0.022
	Combn.	0.016	0.035
Left	2 P + 1 M	0.022	0.043
Right	1 P + 2 M	0.01	0.026
Left	1 Pinhole	0.011	0.027
	2 Memb.	0.01	0.026
Right	2 Pinholes	0.017	0.057
	1 Memb.	0.032	0.015

Table I-10 Calibration factor calculated from the second observation.

Calibration factor (Track/cm^2/d/Bq/m^3)			
S.N.		**Radon**	**Thoron**
1	Pinhole	0.007	0.013
2	Pinhole	0.006	0.02
3	Membrane	0.015	0.004
4	Membrane	0.013	0.009

Table I-11 Calibration factor calculated from the third observation.

	Calibration factor for Radon (Tr/cm^2/d/Bq/m^3)		
Dos. no		**In Pinhole**	**In filter**
2146		0.0196	0.022
B328		0.017	0.026
B331		0.0197	0.03
	Average	**0.018767**	**0.026**

Table I-12 Calibration factor calculated from the fourth observation.

	Calibration factor (Track/cm^2/d/Bq/m^3)	
S.N.	**Radon in pinhole**	**Radon+Thoron in filter**
1	0.01	0.006
2	0.015	0.008
3	0.007	0.005
Average	**0.0106**	**0.0063**

DISCUSSIONS :

In the first calibration experiment, the calculated calibration factor for radon is quiet good but for thoron the difference in the results obtained for different dosimeters is high. This is due to the fact that thoron source was kept in the left side in the chamber, hence the calibration factor obtained for dosimeters mounted on the left side were higher than that obtained for dosimeters mounted on the right side.

In the second calibration experiment, the calibration factor obtained for both radon and thoron were very low. This may be due to low activity concentration of the sources comparing to the exposure time.

In the third calibration experiment, the thoron source was removed and only radon source was kept inside the chamber. The purpose of this experiment is to study the pinhole type dosimeter and compare it with the membrane type dosimeter. From the

result, pinhole type dosimeter works very well for detection of thoron and comparing with the membrane type, the calibration factor of radon obtained using pinhole type was slightly less.

In the fourth calibration experiment, there was an unexpected radon source which results into unsatisfactory result. The main aim of the experiment was to obtain the calibration factor for thoron using the pinhole type dosimeter with thoron source only and to compare it with membrane type. But, unfortunately there was a radon source building up inside the chamber after the source has removed and radon gas was also pumped out from the chamber for about 3 hours. The obtained value of the calibration factor for thoron in this experiment was ***unacceptably*** small.

PRECAUTIONS :

1. The LR-115 films should be handled carefully and there should be no scratch on it. And the film should not be peeled even on the edge. This will be etched away and may lead to incorrect result.
2. The etching time should be carefully maintained and the etching solution should also be prepared carefully and accurately.
3. The films should be dried completely before counting.
4. Pre-sparking should be done for new films.
5. Each tracks should be counted atleast three times for better result.
6. The films should not be mixed up and should be kept properly and carefully.

APPENDIX – II (a)

Standardization of Bulk Etching Rate without stirring

APPARTUS :

LR-115 Film, NaOH palettes, Balance, Distilled water, Etching Bath, etc.

THEORY :

A special detector film, particularly suitable for the spark counter, has been manufactured by Kodak under the trade name LR-115. This detector consists of thin films of cellulose nitrate coated on a 100 μm thick polyester backing. The thickness of the sensitive layer of films (Type II) is 12 μm. These films are not sensitive to electrons and electromagnetic radiations and care should be taken to avoid any abrasion on the films. 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. The purpose of this experiment is to standardize the bulk etching rate. Bulk etching rate is the rate of etching of the film (LR-115) per unit time.

Let $\Delta \boldsymbol{W}$ be the change in weight of the film in grams, $\boldsymbol{A}$ be the area in cm^2 and ρ be the density in $gram/cm^3$, then Bulk Etching Rate is given by

$$V_B = \frac{\Delta W}{\Delta t \times \rho \times A} \qquad \text{(II-1)}$$

where Δt is the time of etching in seconds and ΔW is the change in weight.

PROCEDURE :

1. 2.5N NaOH solution is prepared.
2. Cut the film (LR-115) which is 6 x 12 cm^2 into a smaller pieces (3 x 3 cm^2) so that 12 films which are exactly equal in size are cut out. Separate the films into two groups – 4 films each group.
3. Take the weight of each film by using a microbalance and note them carefully.
4. Put the NaOH solution in the beaker of the etching bath and fix the temperature of the thermostat at 60ºC.
5. When this temperature is reached dip the weighted films into the 2.5N NaOH solution.
6. Note the starting time of the etching.
7. After 60 minutes, take the first group having 4 films out of the solution (NaOH) while etching is still continued for the second group.
8. Wash the films with running water in order to remove the solution and dry them between filter papers.
9. Take the weight of each film after etching by using microbalance and note them carefully.
10. Take out the second group after 90 minutes, wash and weight them individually.
11. By using Eq. II-1 the bulk etching rate can be calculated.

OBSERVATIONS :

S.N.	Bulk Etching Rate (VB)	
	60 min without stirring (micrometer/hr.)	**90 min without stirring (micrometer/hr.)**
1	4.37	5.51
2	3.63	3.47
3	3.63	3.75
4	1.11	4.25
Average	*3.185*	***4.245***

RESULTS :

The bulk etching rate calculated for the first group (60 min without stirring) is 3.185 µm/h and for the second group (90 min without stirring) is **4.245 µm/h**.

APPENDIX – II (b)

Standardization of Bulk Etching Rate without stirring

APPARTUS :

LR-115 Film, NaOH palettes, Balance, Distilled water, Etching Bath, etc.

THEORY :-

Same as in Appendix – I (a)

PROCEDURE :-

Same as in Appendix – I (a)

OBSERVATIONS :-

S.N.	**Bulk Etching Rate (VB)**	
	60 min without stirring (micrometer/hr.)	**90 min without stirring (micrometer/hr.)**
1	2	3.21
2	2.82	3.51
3	3.48	3.46
4	4	4
Average	*3.08*	***3.55***

RESULTS :

The bulk etching rate calculated for the first group (60 min without stirring) is 3.08 µm/h and for the second group (90 min without stirring) is **3.55 µm/h.**

CONCLUSION :

From the two sets of experiments shown in appendix II (a) & (b), the average value of experimentally determined bulk etching rate is ***3.9* µm/h.**

APPENDIX – III

Experiment to find the operating voltage of a given Spark Counter

APPARATUS REQUIRED : Spark Counter, exposed film.

THEORY :

Spark counter is an instrument used to count the number of tracks on the films. In the spark counter the thin etched detector (which is an insulating material) is placed between two electrodes forming a capacitor. The thin detector is placed on top of a thick conductive electrode, commonly made of brass, and covered with an aluminized plastic foil namely 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. When the high voltage is applied across the capacitor, an electrical discharge or spark takes place through a track-hole. The voltage pulse produced across the resistor, can easily be counted electronically by a scalar.

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.

PROCEDURE :

1. Place the exposed film on the electrode in such a way that the electrode is in contact with the middle portion of the film.
2. Set the voltage at 900 volts for pre-sparking.
3. Set the voltage at 150 volts and count the tracks.
4. Repeat procedure no.4 by increasing the applied voltage by 50V each up to 800V and count the tracks for each applied voltage.
5. Plot a graph between the Applied voltage and Counts, i.e. Applied voltage versus Counts.
6. The plateau of the curve gives the operating voltage of the given Spark Counter.

OBSERVATIONS :

S.N.	Applied Voltage (Volts)	Track density (Tracks/cm^2)
1	250	-----
2	300	24
3	350	88
4	400	225
5	425	324
6	450	437
7	475	427
8	500	534
9	525	654
10	550	676
11	600	851
12	650	1550

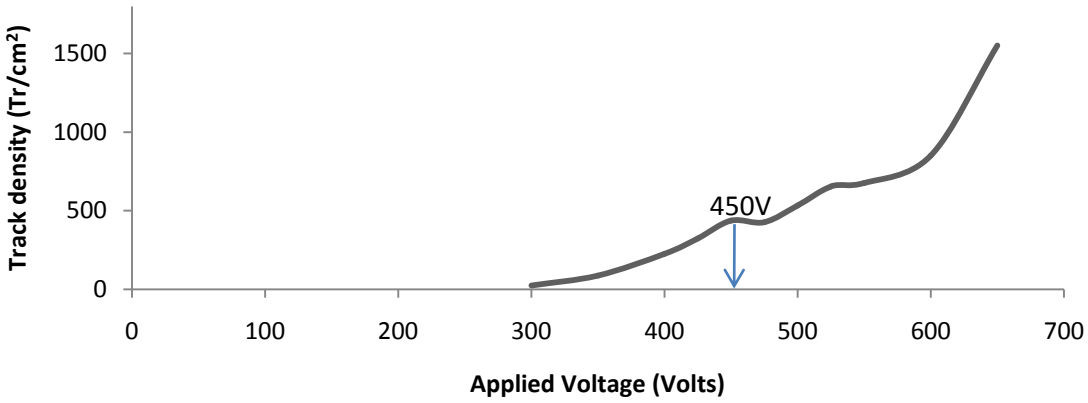

Figure III-1 Graph plotted between applied voltage and tracks density.

RESULTS :

The operating voltage for the given Spark Counter was found out to be **450 volts.**

PRECAUTIONS :

1. Pre-sparking is always required for newly etched film.
2. Film with less number of tracks should be use because with high number of tracks holes can be formed which will cause error and underestimation.
3. It should be ensured that there are no scratches on the film.

APPENDIX – IV

Experiment to measure the Radon flux from soil

(Surface flux measurement)

APPARATUS REQUIRED : RAD -7, Accumulator.

THEORY :

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. The soil area of interest is placed with an accumulator 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.

$$C(t) = \frac{J_s A}{V\lambda_e}\left(1 - e^{-\lambda_e t}\right) + C_o e^{-\lambda_e t} \qquad \text{(IV-1)}$$

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); λ_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. IV-1 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

$$Y(x) = Y_o + A_1 e^{-x/t} \qquad \text{(IV-.2)}$$

where, Y_o, A_1 and t_1 are the fitting parameters.

Comparing Eq. (4.1) and Eq. (4.2),

$$Y(x) = C(t), \quad Y_o = \frac{J_s A}{V\lambda_e}, \quad A_1 = \frac{-J_s A}{V\lambda_e} + C_o, \quad x = t \quad \text{and} \quad t_1 = \frac{1}{\lambda_e}$$

In order to avoid interference of initial radon concentration (C_o) present in the accumulator 'J_s' should be obtained from the fitting parameter 'Y_o' i.e.

$$J_s = \frac{Y_o V}{t_1 A} = \frac{Y_o}{t_1} H \qquad \text{(IV-3)}$$

where H is the height of the cylinder accumulator.

PROCEDURE :

1. Connect the accumulator with the RAD – 7.
2. Set the RAD – 7 in Sniff mode.
3. Clean the surface where the accumulator is to be fixed.
4. Fix the accumulator in the soil.
5. Start monitoring the radon concentration as soon as the accumulator is fixed.
6. Take 15 minutes cycle reading of radon concentration using RAD – 7.
7. Print out the reading and calculate the flux.
8. The building up of radon concentration is plotted using Origin Pro 7.5.
9. Calculate J_s by inserting the values of Y_o and t_1 in Eq. IV-3.

OBSERVATIONS :

Table IV-1 Measurement of radon concentrations inside the accumulator using RAD-7.

Sr No	Time	Radon(Bq/m3)	Rn error	Temp(°C)
1	15	50	45	34.1
2	30	142	174	38.6
3	45	190	185	40.8
4	60	533	204	42.3
5	75	594	227	42.6
6	90	499	224	41.7
7	105	570	220	42
8	120	689	238	42.3
9	135	558	214	42.3
10	150	487	217	42.6
11	165	308	179	43.2

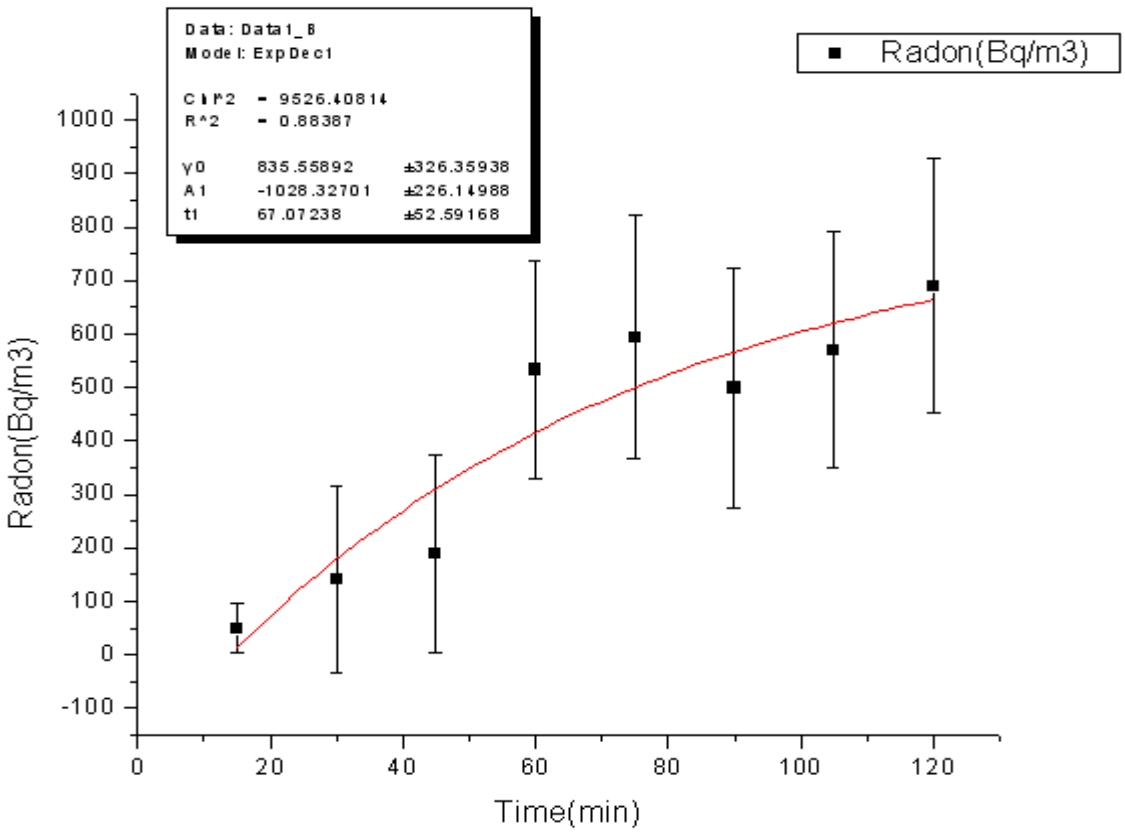

Figure IV-1 Graph plotted between concentration of radon and time.

RESULTS :

Radon flux from soil was calculated to be **35 mBq $m^{-2}s^{-1}$**.

PRECAUTIONS :

1. All the connections should be done before fixing the accumulator.
2. Once the accumulator is fixed in the soil counting should be started without delay.
3. Leakage should be avoided as far as possible.

BRIEF BIODATA OF LALMUANPUIA VANCHHAWNG

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Educational Qualifications :

• H. S. L. C	1996 (Dec)	Second Division.
• H. S. S .L. C. (Sc)	1999	Second Division.
• B. Sc (Chemistry Honours)	2002	First Division.
• M. Sc. (Physics)	2007	First Class First.
• Pre-Ph. D. Course	2010	Grade 'O'

Research Experience:

- Completed M. Sc. Project work (on Advance Electronics) entitled "Multipurpose regulated power supply" at Department of Physics, Mizoram University, Aizawl 2007.
- Started research works in Project on Measurement of radon and thoron Research group under the guidance of Dr. R. K. Thapa, Department of Physics, Mizoram University, Aizawl, Mizoram and co-guidance of Dr. B. Zoliana, Project Principal Investigator, Department of Physics, Govt. Zirtiri Residential Science College, Aizawl since March 2008.
- Completed 2 weeks training course for the Project on Measurement of radon and thoron in Environment Assessment Division (EAD), BARC, Mumbai in March 2008.
- Calculations of radon, thoron and their progeny concentration, Equilibrium factors and Inhalation dose rate.
- Measurement of radioactivity content using γ-spectrometer.
- Measurement of surface flux and radon content in soil gas using RAD-7.
- Measurement of Background gamma radiation level using Micro-R Survey Meter.
- Preparation of DRPS and DTPS using LR-115 films.

Teaching experience:

- Part-time Lecturer in Electronics at Govt. Zirtiri Residential Science College, Aizawl, under the Directorate of Higher and Technical Education, Govt. of Mizoram from June, 2007 to July, 2008 and from March, 2012 till date.

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Measurements of the equilibrium factor of radon in Aizawl, Mizoram, India

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ABSTRACT

Radon (^{222}Rn), being a radioactive gas has its parent nucleus originated from ^{238}U. From ^{238}U there is a series of 14 decays to form a stable nucleus of ^{206}Pb. The equilibrium factor in its simple term may be defined as ratio of the amount of progeny nucleus to that of a parent nucleus. Measurement of Equilibrium Factor (F-factor) for radon has been carried out in 24 dwellings in Aizawl City, which were specifically selected according to the site location and materials used for construction of the dwellings. In measuring F-factor for radon we have made use of absorber-mounted nuclear track detectors (LR-115) which selectively register the tracks due to alpha emissions from ^{214}Po which is the ^{222}Rn progeny species. This detector is termed as DRPS (direct radon progeny sensor). DRPS is used for estimating the Equilibrium Equivalent Radon Concentration (EERC). The concentration of ^{222}Rn is measured by using Solid State Nuclear Track Detector (LR-115) mounted in a BARC type twin cup dosimeter. The F-factor for radon is then calculated using the measured EERC and measured concentrations of radon. Our measurement shows the F-factor for radon in Aizawl city is 0.3, which is close to the worldwide value (0.4) for indoor conditions.

Key words: DRPS; EERC; equilibrium factor; radon; progeny, SSNTD.

INTRODUCTION

Radon is constantly decaying and giving rise to radon progenies. These are short-lived and decay until reaching a long-lived isotope of lead. The F-factor is used to describe the ratio between radon and its progeny. An F-factor of 1 means equal amounts of radon and its progeny. It is well-known that in radon problem, the progeny species and not the radon are primarily responsible for lung doses. Among the progenies, short lived nuclei viz. ^{214}Po is focused due to its high contribution in deposition and emission of alpha particles inside the lung.

In the past years, the equilibrium factors (F

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-factor) for radon was a globally assumed value and even the calculation of radon progenies were inferred using this value. Based on the available data, UNSCEAR specified a value of F = 0.4 for indoor environment.[1] These are understood as representative mean values in a global sense and might vary across countries and geographical locations. In the absence of better locally available estimates, these values have been employed for estimating progeny concentrations and lung doses in several programmes across the world.

With the advent of passive detection techniques using solid state nuclear track detectors (SSNTDs), direct progeny sensor (DPS) has been developed. Direct radon progeny sensor (DRPS) is a passive, deposition-based technique for estimating the time-integrated equilibrium equivalent radon concentration (EERC) in indoor environment. The values of equilibrium factor (F) of radon are bounded between 0 and 1. Its value in the indoor air depends mainly on the pseudo-ventilation rates, which is the sum of the air exchange rate and the wall removal rate in the dwelling. These quantities are expected to vary from house to house as well as from time to time in a given house. In a statistical sense, these may be treated as distributed quantities. In turn, this would result in the distribution in the equilibrium factors.

FORMULAE, MATERIALS AND METHODS

In measuring the equilibrium factor, one has to know the concentrations of the parent nuclei and progenies. The concentrations of progeny was determined through EERC by using DRPS. DRPS detector system is based on selectively registering alpha tracks originating from the deposited progeny activity on LR-115 type solid-state nuclear track detectors. The selection of alpha particle energies was achieved by mounting absorbers of suitable thicknesses on the LR-115 detectors. The radon progeny sensor has an absorber thickness of 37 μm to detect mainly the alpha particles emitted from ^{214}Po (7.69 MeV) formed from the eventual decay of ^{218}Po, ^{214}Pb and ^{214}Bi atoms deposited on it. This thickness mainly ensures that lower energy alpha emissions (from the gases and other airborne alpha emitters) do not pass through the absorber.[2] Since the system is intended for use in the deposition mode, it is necessary to avoid uncontrolled static charges from affecting the deposition rates and hence aluminized side of the mylar was chosen to act as the deposition surface.[3]

The indoor measurement of parent radon concentrations was carried out also using LR-115 detector film. These films were exposed for a minimum of 90 days using Twin cup dosimeter, which was hanged overhead on the ceiling at the height of minimum 1.5 m from the floor and at least 10 cm away from any surface. Twin cup dosimeter was of BARC Type and was a cylindrical plastic chamber divided into two equal compartments.[4] Films were inserted at these compartments by which tracks were recorded. In one compartment, pin hole cap was used to block the entry of nuclei other than radon. Filter paper was used to cover the entry point of the compartment blocking the entry of the progeny.[5] Dosimeters and DRPS were together exposed adjacent to each other for the same duration.

The exposed films were then etched using 2.5N NaOH solution at 60°C for 90 mins for clear visibility of tracks for counting. The tracks recorded in this SSNTD films were then counted using a spark counter. The track densities were used to calculate the radon and progenies concentrations and hence these were related to find the equilibrium factor of radon.

Important Formulae used in calculation of F-factor for radon were:

(1) *For calculating radon concentration from the track density of pinhole compartment of the dosimeter.*

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

where C_R is the radon concentration and T_P is the tract density of films in pin hole compartment. Calibration factor used = 0.023 for radon in pinhole.

(2) *Equivalent Equilibrium Radon Concentration is calculated as*

$$EERC\ (Bq/m^3) = \frac{T_{DRPS}}{Calibration\ factor \times Exposure\ period\ (days)}$$

where T_{DRPS} is the track density obtained by counting tracks in the etched film of the DRPS. Calibration factor used[6] = 0.09

(3) *Equilibrium Factor for Radon is calculated as*

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

where C_R is the concentration of radon calculated using track density from Pin hole compartment and *EERC* is the Equivalent Equilibrium Radon Concentration.

RESULTS

Figure 1 shows the average concentrations of radon for two seasons in each dwelling within Aizawl City in which dosimeters and DRPS were deployed together side by side. 24 dwellings were selected at different localities. The radon concentrations vary from 4.03-40.44 Bq/m^3 with geometric mean of 11.35 Bq/m^3.

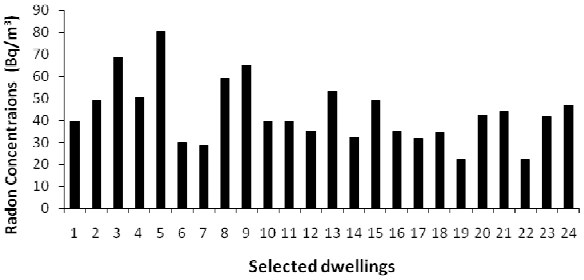

Figure 1. Average concentrations of radon in Aizawl City for rainy season 2008 and summer season 2009.

Figure 2 is the average EERC values which were obtained from the DRPS collected in two seasons. The EERC values vary from 22.37-80.77 Bq/m^3 with a geometric mean of 41.39 Bq/m^3.

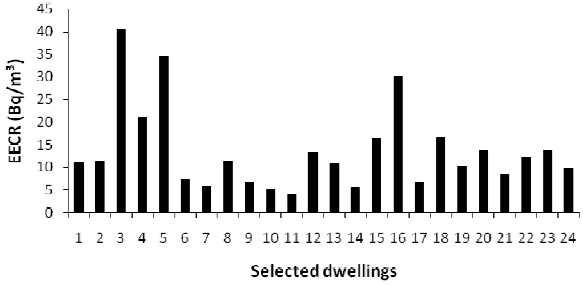

Figure 2. Average EERC in Aizawl City for rainy season 2008 and summer season 2009.

Figure 3 shows the equilibrium factors which were obtained by calculating the values obtained from radon concentration and EERC values in each dwelling. The equilibrium factors for each of the dwellings were found to be ranging from 0.10-0.86 and the average value of equilibrium factor is 0.32.

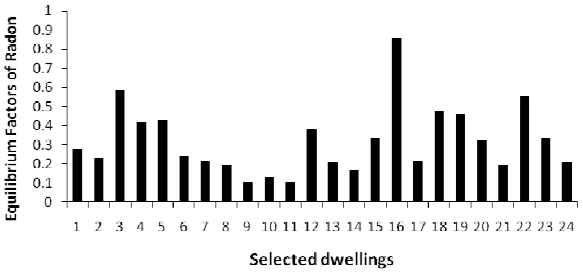

Figure 3. Equilibrium factors of radon (FR) in Aizawl City.

DISCUSSION AND CONCLUSION

From Figures1 & 2, it was observed that

the EERC value is always lower than that of the parent nuclei concentration. Hence the F-factor for radon will never be 1 or more than 1.

As any other part of the state of Mizoram, the climate of Aizawl is moderate throughout the year. The temperature varies between 20° C-30°C during summer and 11°C-21°C during winter. As a result, the ventilation rate is always high and does not vary much during winter and summer. This can be attributed to the range of F-factor found within Aizawl City.

The variation of radon concentration in building type materials is reported elsewhere.[7] It is worth noting that a complete re-inforced concrete building has the highest concentration of radon in a year. However, due to mild climatic condition throughout a year, seasonal variation of radon concentration do not vary much and the concentration of radon inside the dwellings is found to be much below the action level of WHO prescription throughout a year. As a result the progeny concentration is also found to be very low.

It is interesting to conclude that the globally assumed value of F-factor and our experimentally obtained value are also in good agreement.

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