RADON, THORON AND THEIR PROGENY MEASUREMENTS IN DWELLINGS AND WORKPLACES OF SOUTHERN HARYANA, INDIA

A

THESIS

submitted in fulfillment of the requirement of the degree of

DOCTOR OF PHILOSOPHY

to

J. C. BOSE UNIVERSITY OF SCIENCE & TECHNOLOGY

by

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THIS THESIS

is

DEDICATED

to

My Father

Late Sh. Pawan Kumar Gupta

DECLARATION

I hereby declare that this thesis entitled **"RADON, THORON AND THEIR PROGENY MEASUREMENTS IN DWELLINGS AND WORKPLACES OF SOUTHERN HARYANA, INDIA" by NITIN GUPTA**, being submitted in fulfillment of the requirements for the Degree of Doctor of Philosophy in **Physics** under Faculty of **Humanities and Sciences**, is a bonafide record of my original work carried out under guidance and supervision of **Dr. Maneesha Garg, Assistant Professor (Physics), J. C. Bose University of Science and Technology, YMCA, Faridabad and Dr. Krishan Kant Gupta, Principal, Aggarwal PG College Ballabgarh, Faridabad** and has not been presented elsewhere.

I further declare that the thesis does not contain any part of any work which has been submitted for the award of any degree either in this university or in any other university.

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CERTIFICATE

This is to certify that the thesis entitled, **"RADON, THORON AND THEIR PROGENY MEASUREMENTS IN DWELLINGS AND WORKPLACES OF SOUTHERN HARYANA, INDIA"** by **NITIN GUPTA,** being submitted in fulfillment of the requirement for the Degree of Doctor of Philosophy in **Physics** under the Faculty of **Humanities and Sciences,** J. C. Bose University of Science and Technology, YMCA Faridabad, during the academic year 2019, is a bonafide record of work carried out under our guidance and supervision.

We further declare that to the best of our knowledge, the thesis does not contain any part of any work which has been submitted for the award of any degree either in this university or in any other university.

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ABSTRACT

The entire living organism is exposed to radiations from radionuclides that occur naturally in the environment. These radionuclides are present in the earth's crust since the formation of earth about 1.6×10^9 years ago. The exposure to these radionuclides depends upon the geology and location of the area. The natural radioactive gas radon (^{222}Rn) is a prime source of natural radiations to which the general population is exposed. Exposures to radon create some serious health issues. Radon originates naturally so, it is present everywhere in the environment and contributes about 50% of the total radiation dose received by the general public.

Most of the inhaled gas is exhaled during the process of breathing but the progenies of radon and thoron attach themselves to the lung tissues and cause lung cancer. Health hazards posed by radon and thoron gases are acknowledged worldwide by many agencies such as WHO (World Health Organization), UNSCEAR (United Nations Scientific Committee on the Effects of Atomic Radiation), USEPA (United States Environmental Protection Agency) and ICRP (International Commission on Radiological Protection). Efforts of these agencies were also a motivation towards the present research work. Keeping in view of the detrimental effects of radon, thoron and its progeny, measurements were carried out in the dwellings and workplaces of Southern Haryana, India.

In the present research work, LR-115 Type II plastic track detectors were used in the twin cup dosimeters. Spark counter automatically counts the number of tracks that are created on the LR-115 film due to the alpha particles present in the surrounding environment.

This thesis is arranged into six chapters namely Introduction, Literature review, Experimental Techniques, Results and Discussions in two chapters of dwellings and workplaces followed by Conclusions and list of research publications by the author.

Huge combustion of coal produces the large quantity of fly ash and the problems related to their safe management and disposal has become a major challenge to environmentalists and scientists. So that, the first case study is carried out for radon, thoron and their progeny measurements in dwellings nearby the fly ash dumping site situated in Faridabad, Haryana, India during all the four seasons of a calendar year. Results show that the dwellings nearest to the dumping site have the higher

concentration of radon and thoron as compared to other dwellings. As the distance of dwellings from the dumping site increases the radon and thoron concentration decrease. Variation in the concentration during the different seasons is because of different ventilation conditions, house structure and of their distances from the dumping sites.

Industrialization, urban expansion, sky touching prices of land and pressure on agricultural land for horizontal expansion in Faridabad, are main causes to promote the high rise buildings for housing and workplaces. In the second case study, measurements were done in the dwellings of high rise buildings of Faridabad, Haryana, India. Observations show that maximum concentration of radon, thoron and their progeny were found at the ground floors of the towers during the winter season and minimum concentrations were found at the ninth floor (top floor of the present study) of the towers during summers. An inverse relation was found in the height of the buildings and radon & thoron concentration mean that as the height of the building increases radon & thoron concentration decreases. The measurements indicate that results are below the action level (100 Bqm^{-3}) as recommended by WHO.

Radon and thoron, which are a topic of public health concern, have been found to be ubiquitous air pollutants in the environment of workplaces i.e. thermal power plants, refineries, LPG bottling plants, underground stores, schools, multi-storied malls and offices etc., to which all persons are exposed. In the first case study of workplaces, radon-thoron and their progeny dosimetry in the basements of multi-storied malls has been carried out during all the four seasons of a year. Results show that the maximum concentration of radon and thoron were found at the lowest basements (third basement) of the malls selected in the present study during winters because there is no any ventilation. As the height of the malls (buildings) increases, the radiological exposure to the workers and visitors to the malls decreases.

In the second case study of workplaces, measurements were carried out in the coal-based thermal power plants in Haryana, India during all the four seasons of a year. Findings show that maximum concentration of radon and thoron was observed at coal area for both the radon and thoron but the minimum value was found in the control room and near the entrance gate with slight variations to each other. During spring and summers, minimum values of radon concentration were observed in the control room whereas during winters and rainy season the minimum values were observed near the entrance gate.

Assessment of radioactivity (Radon-thoron) levels in the present research work implies that the inhabitants are at high risk of radon during winters as compared to the other seasons of a year. Ventilation condition and location selected also play an important role in the indoor radon-thoron levels.

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LIST OF ABBREVIATIONS

AERE	Atomic Energy Research Establishment
ATSDR	Agency for Toxic Substances and Disease Registry
BEIR	Biological effects of ionizing radiation
BARC	Bhabha Atomic Research Center
CRM	Continuous Radon Monitor
DNA	Deoxyribonucleic acid
DSBs	Double Strands Breaks
EURADOS	The European Radiation Dosimetry Group
ESP	Electrostatic Precipitator
GERDC	General Electric Research and Development Centre
HBRAs	High Background Radiation Areas
IAQ	Indoor Air Quality
IARC	The International Agency for Research on Cancer
ICRP	International Commission on Radiological Protection
ICRU	International Commission on Radiation Units and Measurements
IUPAC	International Union of Pure and Applied Chemistry
LET	Linear Energy Transfer
NCR	National Capital Region
NORM	Naturally Occurring Radioactive Materials
NRC	National Research Council
PAEC	Potential Alpha Energy Concentration
PAEE	Potential Alpha Energy Exposure
PGIMER	Postgraduate Institute of Medical Education and Research
RBE	Relative Biological Effectiveness
SSBs	Single Strand Breaks
SSNTD	Solid State Nuclear Track Detector
STP	Standard Temperature and Pressure
TEM	Transmission Electron Microscope
TENORMs	Technologically Enhanced Naturally Occurring Radioactive Materials
UNSCEAR	United Nations Scientific Committee on the Effects of Atomic Radiation

USEPA	United States Environmental Protection Agency
WHO	World Health Organization
WL	Working Level
WLM	Working Level Month

CHAPTER I

INTRODUCTION

CHAPTER I

INTRODUCTION

Radiations have always been there: not to be invented by the perception of man [1]. The entire living organism is exposed to radiations from radionuclides that occur naturally in the environment [2]. These radionuclides are present in the earth's crust since the formation of earth about 1.6×10^9 years ago [3]. Radionuclides can easily deploy to the environment and contaminate the surroundings to which human beings are exposed. This exposure may vary depending upon the geology and location of the area. Human activities and practices also play a significant role viz. technologically enhanced naturally occurring radioactive materials (TENORMs), particularly in building materials, phosphate fertilizers, coal etc.

The natural radioactive gas radon (^{222}Rn) is a prime source of natural radiations to which the general population is exposed [4]. Exposures to radon create some serious health issues. It is a decay product of radium, which originates from the naturally occurring ^{238}U (uranium) series. Radon originates naturally so, it is present everywhere in the environment and contributes about 50% of total radiation dose received by the general public [5]. Radiation dose delivered to the organism is not because of radon only, but of its particulate, short-lived alpha emitting particles (^{218}Po and ^{214}Po) called radon progeny or radon daughters.

Epidemiological studies have shown that radon is a second most common cause of lung cancer particularly for those who smoke [2, 6-7]. Chances of lung cancer increase by 16% per 100 Bqm^{-3} increases in radon concentration. Risk increases directly in the same proportion as the dose of radon, and shows the linearity in dose & response [8]. When radon gas is inhaled, ionizing alpha particles emitted by radon daughters, settled in the lungs and interact with biological tissues leading to DNA damage. DNA damage can start at any level of radon exposure because only a single alpha particle can initiate the genetic damage to a cell [9-10].

Radon gas seeps from the earth's crust, and because of its enough long half- life, approximately 3.84 days, it escapes easily to the atmosphere. Radon exist in the gaseous form and it can easily emanates even from a solid material, so it is present everywhere not only in soil and rocks, but also in air and water [11]. When radon migrates to the environment it easily dilutes in the outdoor spaces and not a significant health issue but indoor radon concentration level is always a matter of health concern especially in those buildings which are tightly packed or poorly ventilated [7]. Indoor radon poses health hazards not only in the residential buildings; it also plays a significant role in schools, workplace, supermarkets and hospitals etc. Dose received from the indoor radon also depends upon the time spent by the inhabitants, their life style, ventilation conditions, structure of the building and their vicinity to the ground etc. [12].

There are three main sources of indoor radon level as listed below [13]:

- Rocks and soil under the building.
- Building material used for the construction.
- Water supply.

a) Prime source of indoor radon is rocks and soil because they contain higher level of uranium and radium content. Radon from soil enters into the building through opening in walls, wires fitting, cracks in construction joints, loose fitting pipes and gaps in the flooring etc. Radon concentration is higher at those levels that are close to the soil i.e. basement or crawl spaces rather than the upper floors [14].

b) Emanation of radon (^{222}Rn) from the radium present in the materials like rocks, bricks, gypsum, sand and cement etc. used for the building construction contribute to the indoor radon concentration. Radon emanation depends upon the exhalation rate and porosity of the material. In addition of this, a slight variation in the radium concentration results in the significant variation in the radon concentration [15].

c) Ground water contains radon and escapes easily to the indoor air during the routine activities of inhabitants like washing dishes and clothes, showering, cooking and other house hold uses. Radon escaped from the water accumulated in the indoor environment and cause health hazards when inhaled [16].

Radon (^{222}Rn), is popularly known as an environmental pollutant and receiving a lot of attention. In contrast of this, ^{220}Rn, which is a member of radon isotope family commonly known as thoron is not so common. Thoron produced from the radium isotope ^{224}Ra, which is a decay product in the Thorium (^{232}Th) series. Traditionally, dose contribution to the public due to thoron and its progeny was underestimated and not a topic of health concern because of its short half-life (55.6 s) as compared to the radon (3.8 days) and only a limited literature is available related to the measurement of thoron in the environment [17]. However, recent studies show that dose delivered due to thoron and its progeny may be greater than the dose delivered due to radon in the indoor environment [18].

1.1. IONIZING RADIATIONS

Radiation is transmission of energy from a body either in the form of wave or particle. Mostly radiations are of two types i.e. ionizing and non-ionizing. Ionizing radiations have sufficient energy to strip off electron from an atom or molecule but non-ionizing radiation does not have enough energy to strip off electron from an atom.

Ionizing radiations further can be classified into two categories:

a) Natural radiations.

b) Artificial (man-made) radiations.

Natural background radiations comes from two sources i.e. cosmic radiations and terrestrial radiations. Cosmic radiations mean radiations from outer space [5]. Earth's magnetic field and ozone layer protect surface from cosmic rays. That is why it subsidizes a small percentage (about 8%) of the total dose from natural radiation a person is exposed to over the passage of a year. The major source of natural occurring radiation is terrestrial radiations.

Terrestrial radiations include radiations from the earth itself. Main isotopes of concern for terrestrial radiation are uranium and the decay products such as thorium, radium, radon and thoron. It contributes 8% to the total dose except radon (55%). Inhalation and ingestion are two main entry routes through which human being are exposed to radiations from the earth [4].

Besides the cosmic and terrestrial sources of radiations, internal radiations exist naturally in human beings and contribute 11% to the total dose. Radioactive substances such as potassium-40, lead-210, carbon-14 and some other isotopes exist inside the body of all the people from their birth and contribute towards the internal radiations. The deviation in dose from an individual to another is not as considerable as the deviation in dose from cosmic and terrestrial sources. Natural radiations contribute 82% (8% from cosmic, 8% from terrestrial, 55% from radon and 11% from internal radiations) to the total exposure from the ionizing radiations as shown in figure 1.1.

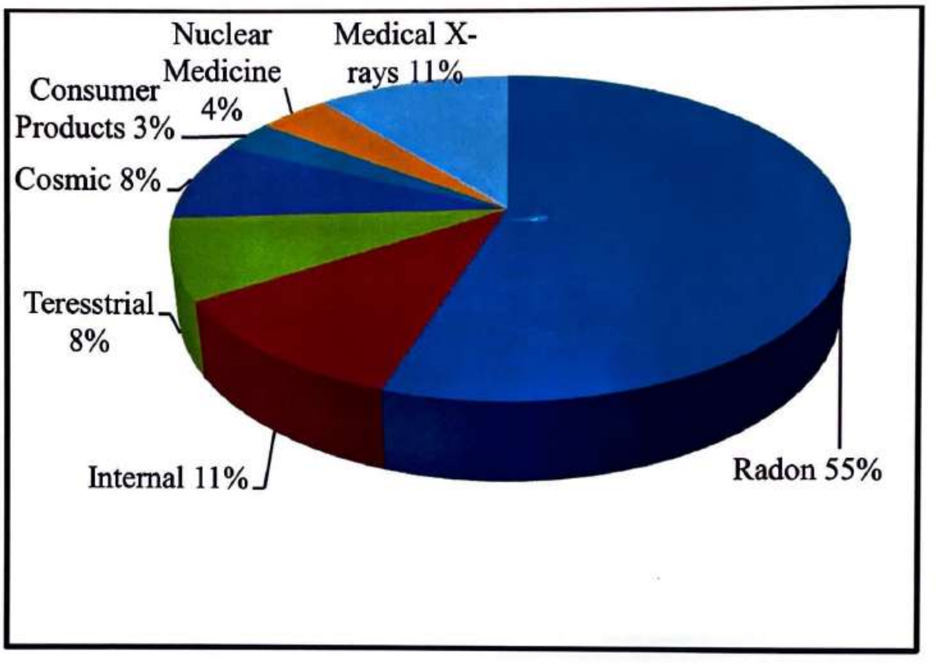

Figure 1.1: Ionizing radiation exposure to the public [19]

In spite of naturally occurring radiations, artificial (man- made) radiations also commence an extensive role on the environment and population exposed e.g. Tobacco, Nuclear medicine, Medical X-rays, Smoke detectors, Televisions, Lantern mantles, Building materials, Fuel cycle, Nuclear power plant etc. From the major part of the population, patients are regularly exposed to the ionizing radiations received from the medical sources such as radiation therapy, nuclear medicine and medical X-ray etc. In total ionizing radiation, man-made sources contribute 18% to the inhabitants exposed as shown in figure 1.1. For individual the limit of effective dose is 1 mSv per annum. To control the contribution of artificial radiations, inhabitants should be careful for the utilization of nuclear power sources.

1.2. RADONAND THORON: HISTORY, OVERVIEW AND PROPERTIES

1.2.1. History of Radon

Radon (^{222}Rn) is naturally originating radioactive gas and most common source of ionizing radiations. Risks associated to the health of general population from the radiation dose received from the natural sources of ionizing radiations, is well known.

In addition, exposure may be modified significantly by the human activities. Credit for the discovery of radon is always a remarkable question. A lot of literature is available in the favor of Ernst Dorn [20-21] but a limited version promotes the Rutherford as a discoverer of radon [22-23]. In fact in 1899, Ernest Rutherford was the first who identify the new radioactive substance generated from the thorium which is comparatively much more radioactive than its parent nuclei. During the same year Marie curie discoverer (1988) of radium, also observed a gas is emanated from the radium. In 1900, Friedrich Ernst Dorn a German physicist at Halle, Germany, observes a radioactive gas in the flask of radium during his study of radium decay chain [24]. He named it as "emanation". In 1900, Ernest Rutherford dedicated himself to explore the new radioactive gas and he shows that it can be condensed to a liquid state. Dorn, investigate the ^{222}Rn an isotope of radon with half-life of 3.824 days while Rutherford investigate the ^{220}Rn isotope emanated from thorium which was difficult to examine because of its short half-life of 55.6 s [25].

In 1908, Scottish chemist William Ramsay with the support of English chemist Robert Whytlaw-Gray at University College, London, define its various properties and discovered that it is the heaviest gas known [26]. Ramsay renamed it as 'niton' from the latin word 'nitens' means shining and later on after a number of names International Union of Pure and Applied Chemistry (IUPAC) named it as 'radon' in 1923 [20, 27]. Uranium, thorium, radium and polonium were already discovered as radioactive elements and radon was discovered as fifth one.

Unlike the other noble gases, radon does not react with other gases or chemically inactive in nature. It is nonmetallic element and chemically inert in nature. It does not have any color and can't be smelled or tasted [28]. Radon can't be detected by the human senses, only some special instruments have been used for measurements. Radon gas is present in the earth's crust. It is health hazard and leading cause of cancer, especially lung cancer [3]. It is a decay product of radium which originates from the radioactive decay chain of ^{238}U. Radon occurs in several isotopic forms. It has 35 known isotopes, all are radioactive but out of them three isotopes ^{219}Rn ($t_{1/2}$=3.96 s), ^{220}Rn ($t_{1/2}$=55.6 s), ^{222}Rn ($t_{1/2}$=3.824 days) are present in trace amount in nature. Two isotopes (^{222}Rn and ^{220}Rn) are present in significant concentration and of prime importance for environmental purpose. ^{222}Rn is most stable isotope with half-life of 3.824 days and named as radon [7]. Some isotopes of radon are unstable and disintegrate spontaneously into other nuclei.

Among the rare gas family, radon is the heaviest member, approximately 100 times heavier than hydrogen and 7.5 times heavier than air. The concentration of radon and its progeny play a counterpart role towards the environmental radioactivity. The dose due to inhalation of radon and its progeny contribute more than 50% of the total dose received to the general public by the natural sources of radiations [2]. Concentration of radon varies from location to location because of variation of geological and epidemiological conditions.

1.2.2. Physical and Chemical Properties of Radon

At standard temperature and pressure (STP) radon exist in gaseous form. Density of radon is 9.73 Kg/m^3 and it is densest gas among all the noble gases [29]. It is passive towards other chemical agent and can be identified only with some special instruments. In the rare gas family, radon has highest melting and boiling point. Other physical and chemical properties of radon are shown in table 1.1. Although it is colorless at STP but it emits a brilliant radio luminescence when it cooled below its freezing point and turns yellow to orange-red as temperature decreases.

Sr. No.	Properties	Values
1.	Symbol	Rn
2.	Atomic number	86
3.	Atomic weight	222
4.	Phase	Gas
5.	Density	9.96×10^{-3} gcm^{-3} at 20^0c 9.73 Kg/l at STP
6.	Classification	Noble Gas
7.	Atomic radius	1.34 Å
8.	Atomic volume	50.5 cm^3/mol
9.	Molar volume	50.5 cm^3/mol
10.	Mean excitation energy	794.0 eV
11.	Electron configuration	[Xe] $4f^{14}5d^{10}6s^26p^6$
12.	Oxidation state	0
13.	Melting point	-71.15^0C (202K, -95.8^0F)

14.	Boiling point	-61.85^{0}C (211.35 K, -79.1^{0}F)
15.	Critical point	377 K at 6.28MPa
16.	Critical pressure	62 atm
17.	Critical temperature	104^{o}C
18.	Molar heat capacity	20.786 Jmol^{-1}K^{-1} at 25^{0}C
19.	Specific heat capacity	94 JKg^{-1}K^{-1}
20.	Heat of fusion	3.247 KJ/mol
21.	Heat of vaporization	18.10 KJ/mol
22.	Enthalpy of fusion	2.7 KJ/mol
23.	Enthalpy of vaporization	18.1 KJ/mol
24.	Thermal entropy	176.1 J mol^{-1}K^{-1}
25.	Thermal conductivity	3.61x10^{-3} W/(m.K)
26.	Electrical conductivity	0.1 mOhm-cm
27.	Energy of first ionization	1037 KJmol^{-1} (10.74 eV)
28.	Polarizability	5.3x10^{-24} cm^3
29.	Solubility with water	230 cm^3/Kg at 20^{0}C

Table 1.1: Physical and chemical properties of radon [30-31]

Radon is less soluble in water in comparison to organic liquids. Its solubility decreases with increasing temperature [30]. It has lower electro negativity than Xenon. Its outer valance shell contains eight electrons and these electrons are tightly bound, so that to strip of one electron from its outer valance shell energy required is 1037 KJ/mol and known as its first ionization energy [32].

1.2.3. History and Properties of Thoron

In 1899, R. B. Owens in collaboration with Ernest Rutherford at Mc-Gill University observed a radioactive gas originating from thorium. Initially this gas is named as "thorium emanation" and later on this was named as thoron gas [33-34]. Uranium and thorium are present lavishly in the earth's crust. Probability of decay of thorium is much smaller as comparative to uranium. Thoron (^{220}Th) occurs naturally from the radium (^{224}Ra) isotope, a decay product in thorium (^{232}Th) series. It is an isotope of radon family with same atomic number (86) but mass number is different (220). Chemical properties of ^{220}Th are same as that of ^{222}Rn and it is present in the earth crust at the comparable rate of radon ^{222}Rn. Radon (^{222}Rn) being a radioactive element decays spontaneously into short-lived radionuclides and their properties are shown in table 1.2. Thoron has short half-life (55.6 s), even less than a minute. Radon and thoron both emit alpha radiations; radon emits an alpha particle with energy 5.49 MeV while thoron emits an alpha particle with energy 6.29 MeV [11].

Sr. No.	Property	Value
1.	Boiling Point	-61.8°C
2.	Melting Point	-71°C
3.	Diffusion coefficient in water	1.1 x 10^{-5} cm^2 s^{-1} at 18°C
4.	Diffusion coefficient in air	0.1 cm^2 s^{-1} at STP
5.	Solubility in water At 0°C 20°C 50°C	 0.51 0.25 0.14
6.	Solubility in acetone	8.0 at 0°C

Table 1.2: Properties of ^{220}Rn (thoron) [35]

For many years, radon (^{222}Rn) is receiving a lot of consideration as an indoor pollutant because of its adverse health effects to the general population [36]. On the other hand, thoron (^{220}Rn) an isotope of radon family is attributed a negligible attention and overlooked during the past years because of a perception that it cannot enter in the building because of its short half-life (55.6 s) [17, 37]. In the recent years, from the results of various studies in various countries thoron is recognized as a foremost contributor to the inhalation dose and it is essential to have statistics about the thoron levels in the surroundings for the radiological protection point of view [17, 33, 35, 38-40].

1.3. DECAY CHAINS

We all are exposed to the ionizing radiations which are present naturally in our surrounding environment since the existence of the planet [2]. The key source of these radiations on the earth is soil and rocks, because there are a number of elements are present in the earth crusts which are radioactive such as uranium (^{238}U), thorium (^{232}Th) and potassium (^{40}K). Uranium which is present naturally in the environment has three isotopes i.e. Uranium-238, Uranium-235 and Uranium-234 but out of these only Uranium-238 is present abundantly in nature [41]. Thorium exists in only single isotope i. e. ^{232}Th. These nuclides uranium and thorium both are not stable and decay continuously into other daughter nuclides which are also unstable and decay further with the emission of alpha (α) and beta (β) particles. Both of these series of decay nuclide will terminate at the stable isotope of lead and known as uranium and thorium series or decay chains. So, the presence of these Naturally Occurring Radionuclide Materials (NORMs) cannot be ignored and considered as permanent [42].

a) Uranium Series

This series is also named as uranium-radium series, it starts with uranium (^{238}U) isotope whose half-life is 4.5×10^{10} years but radium-226 isotope is also an important decay product of this series [43]. In this series uranium-238 emits an alpha (α) particle and decayed in a new unstable nuclide (Th-234). This nuclide further decayed in another unstable nuclide radium-226 whose half-life is 1600 years with the emission of two β-particles and two α- particles as shown in figure1.2. The process of decay chain can be expressed as [44]:

$$^{238}U \ldots\ldots\ldots\ldots ^{206}Pb + 8(\alpha) + 6(\beta) + (\gamma) \quad (1)$$

Now this radium-226 isotope decayed in gaseous nuclide which is radioactive in nature and commonly known as radon (Rn-222) gas with half-life of 3.82 days. This is a noble gas and inert in nature. It does not react with other chemicals and escapes easily in the atmosphere where it sticks to the aerosol and other dust particles present in the air. This radon-222 isotope decays further and emits harmful radiations that can damage the tissues of lungs and finally terminates the series at the stable isotope of lead (Pb-206) with the emission of alpha (α) and beta (β) particles together with gamma (γ) radiations [45].

This series involves 14 steps in total with the emission of 8 alpha (α) particles and 6 beta (β) particles together with the emission of gamma (γ) radiations and end at the stable isotope of lead (^{206}Pb) as shown in equation-1.

Various nuclides formed in the decay chain of Uranium are shown in table 1.3(a) with their energies in MeV and their intensities.

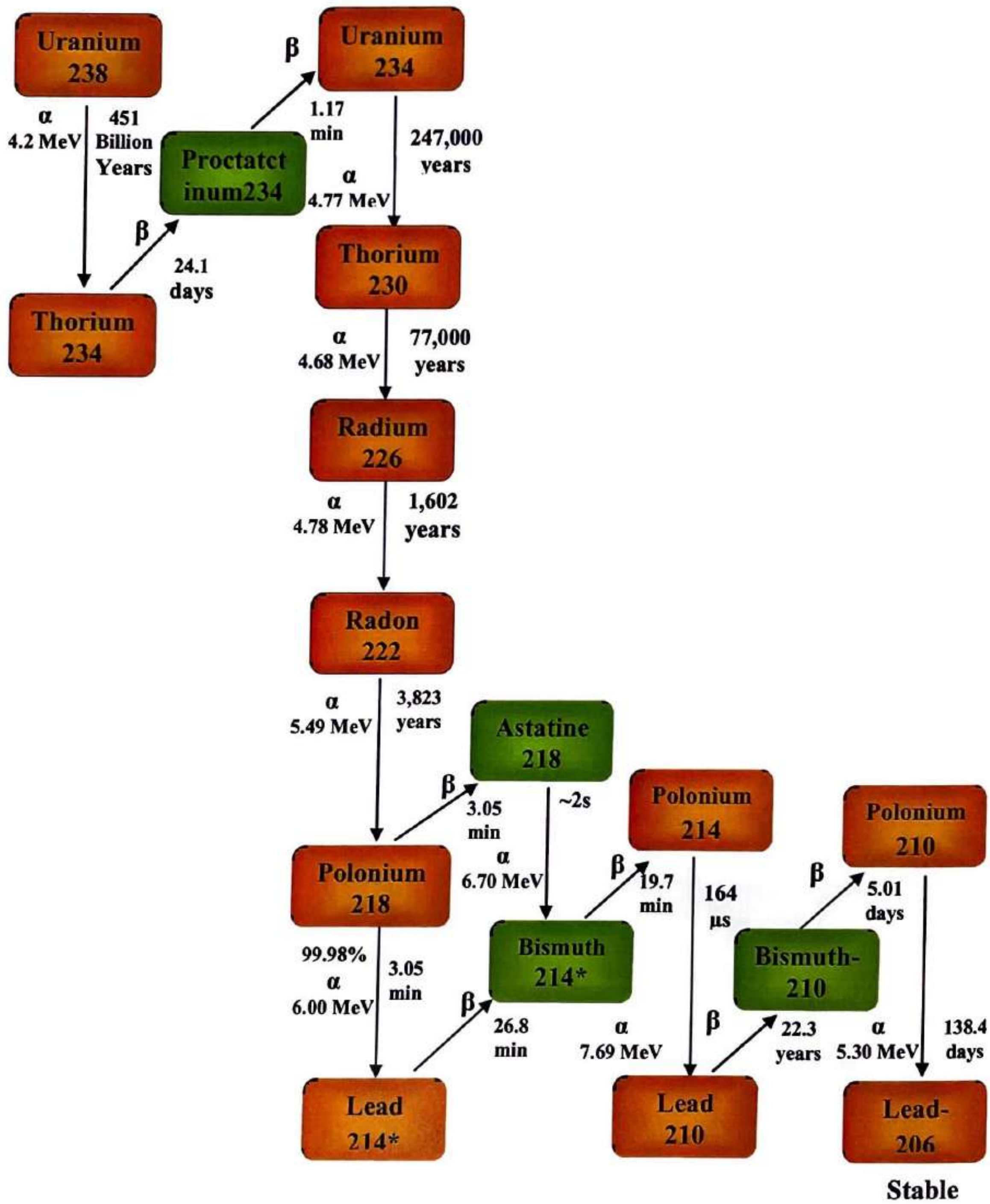

Fig.1.2: Mechanism of Uranium decay chain including ^{222}Rn (Reproduced from J. Magill and J. Galy2005) [46]

Nuclide	Major Radiation Energies (MeV) and Intensities		
	α	β	γ
Uranium-238	4.15 (25%) 4.20 (75%)	-	-
Thorium-234	-	0.103 (21%) 0.193 (79%)	0.063 (35%) 0.093 (4%)
Protactinium-234	-	2.29 (98%)	0.765 (0.30%) 1.001 (0.60%)
Uranium-234	4.72 (28%) 4.77 (72%)	-	0.053 (0.2%)
Thorium-230	4.62 (24%) 4.68 (76%)	-	0.068 (0.6%) 0.142 (0.07%)
Radium-226	4.785 (94%) 4.602 (6%)	-	0.186 (4%)
Radon-222	5.490 (100%)	-	0.510 (0.07%)
Polonium-218	6.003 (99.98%)	0.33 (~0.019%)	-
Lead-214	-	0.650 (50%) 0.71 (40%) 0.98 (6%)	0.292 (19%) 0.352 (36%)
Bismuth-214	-	Up to 3.26 MeV	-
Polonium-214	7.687 (100%)	-	-
Lead-210	-	0.015 (81%)	-
Bismuth-210	-	1.161 (100%)	-
Polonium-210	5.303 (100%)	-	-

Table 1.3(a): Nuclides of Uranium decay Chain with their energies in MeV and intensities

b) Thorium Series

Naturally occurring thorium has only single isotope i.e. ^{232}Th which is an unstable radioactive element. It decays into its subsequent nuclides after the emission of alpha and beta particles and finally ends at the stable isotope of lead-208. This series of decayed radioactive nuclides is known as thorium series. This series starts with ^{232}Th with longer half-life of 1.4×10^{10} years and it emits an alpha (α) particle and transformed to a new nuclide Ra-228 with half-life of 5.75 years. The nuclide Ra-228 decays further to a gaseous nuclide (Rn-220) which is radioactive in nature with half-life of 55.6 s and popularly known as thoron as shown in figure1.3. Thoron is a radioactive gas and it can easily escapes to the atmosphere from the top few layers of the soil and may cause serious health hazards [47]. Now, thoron (^{220}Rn) decays further in other nuclides and finally terminate the series at the stable isotope of lead (^{208}Pb) after the emission of 4 alpha (α) and 3 beta (β) particles as shown in equation-2. The process of decay chain can be expressed as [47].

$$^{232}Th \ldots\ldots\ldots\ldots\ldots ^{208}Pb + 6(\alpha) + 4(\beta) + (\gamma) \quad (2)$$

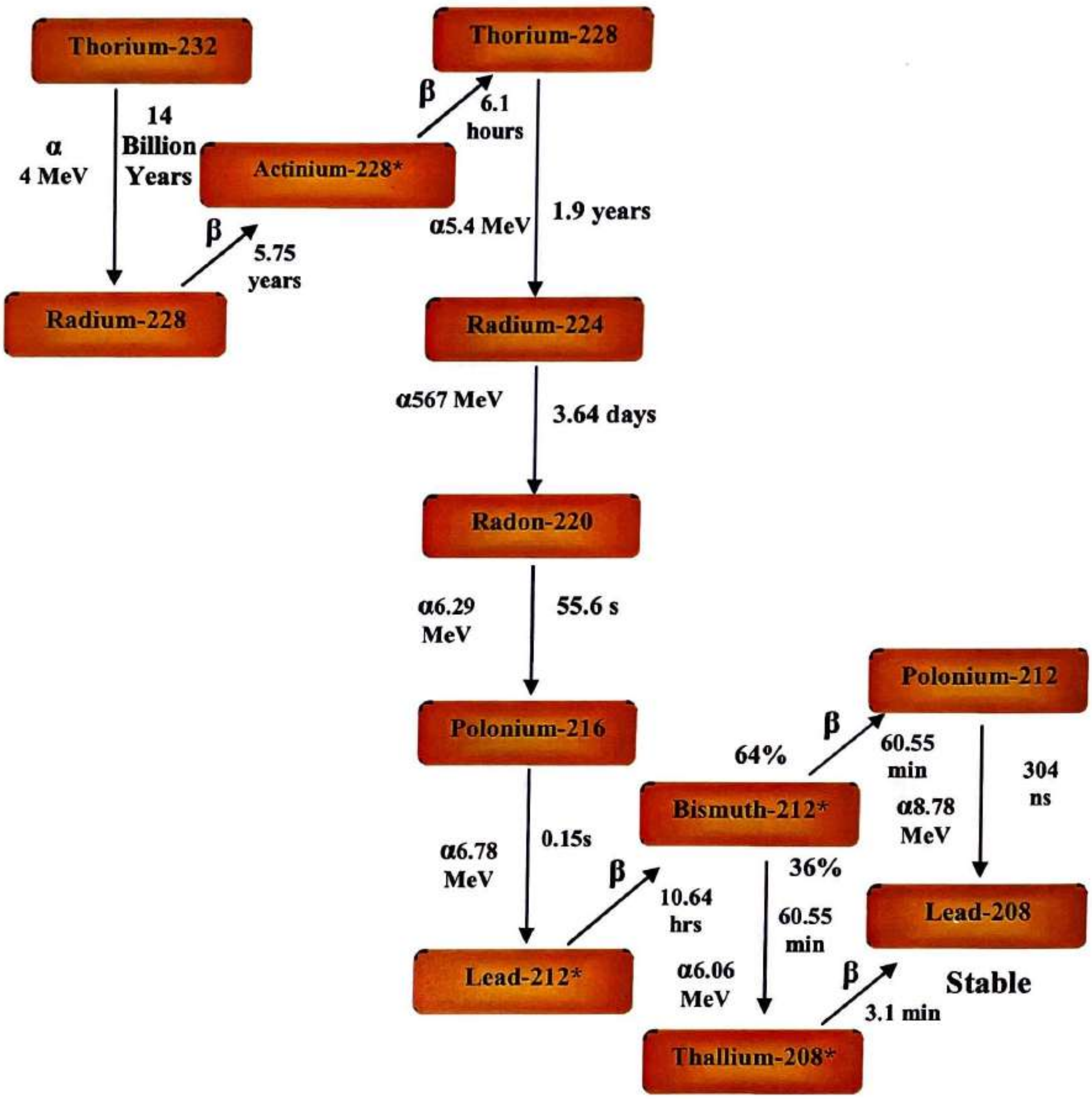

Fig.1.3: Mechanism of Thorium decay chain including ^{220}Rn (Reproduced from J. Magill and J. Galy 2005) [46]

Nuclide	Major Radiation Energies (MeV) and Intansities		
	α	β	γ
Thorium-232	**3.94 (24%)** **4.01 (76%)**	-	-
Radium-228	-	**0.055 (100%)**	-
Actinium-228	-	**1.18 (35%)** **1.75 (12%)** **2.09 (12%)**	**0.34 (15%)** **0.908 (25%)** **0.96 (20%)**
Thorium-228	**5.34 (28%)** **5.43 (71%)**	-	**0.084 (1.6%)** **0.214 (0.3%)**
Radium-224	**5.45 (6%)** **5.68 (94%)**	-	**0.241(3.7%)**
Radon-220	**6.29 (100%)**	-	**0.55 (0.07%)**
Polonium-216	**6.78 (100%)**	-	-
Lead-212	-	**0.346 (81%)** **0.586 (14%)**	**0.239 (47%)** **0.300 (3.2%)**
Bismuth-212	**6.05 (25%)** **6.09 (10%)**	**1.55 (5%)** **2.26 (55%)**	**0.040 (2%)** **0.727 (7%)** **1.620 (1.8%)**
Polonium-212	**8.78 (100%)**	-	-
Thallium-208	-	**1.28 (25%)** **1.52 (21%)** **1.80 (50%)**	**0.511 (23%)** **0.583 (86%)** **0.860 (12%)** **2.614 (100%)**
Polonium-208	-	-	-

Table 1.3(b): Nuclides of Thorium decay Chain with their energies in MeV and intensities

Various nuclides formed in the decay chain of Thorium are shown in table 1.3(b) with their energies in MeV and their intensities are also shown.

1.3.1 Importance of Decay Chain

From the two decay chains as shown in figure 1.2 and 1.3 it is clear that Uranium and Thorium are present still today and decaying into their daughter nuclides continuously. In Uranium and Thorium series an intermediate gaseous nuclide ^{222}Rn and ^{220}Rn is shown respectively. These nuclides are isotopes of radon. Actually there are three isotopes of radon ^{219}Rn, ^{220}Rn and ^{222}Rn and commonly known as actinon with half-life of 3.96 s (shortest half-life isotope), thoron with half-life of 55.6 s and radon gas with half-life of 3.82 days respectively [48]. These radioactive isotopes are intermediate after products of one of other isotope of radium in the ^{235}U, ^{232}Th and

^{238}U decay chains respectively [49]. So, it can be concluded that radon is still present in the earth as decay product of radium and to be found continuously in future also. Uranium and thorium series are well defined but the actinium series (progenitor of ^{219}Rn isotope) is not mentioned because of its relatively lower amount of production in the soil [50].

1.3.2 Significance of Radon, Thoron and Their Progeny

In 1879, high lung cancer was diagnosed by [51] among the miners and known as "Schneeberger Berkrankheit" and after 45 years it was recognized that this high lung cancer may be because of high radon activity [51-52]. On the basis of these studies many researchers renewed their interest in field of radon and WHO concluded that exposure due to the radon is second leading cause of cancer after smoking [53]. Now radon (^{222}Rn) is considered as the leading contributor towards the radiation hazards because it is long lived isotope as compared to thoron so it can migrate to longer distance as compared to thoron (^{220}Rn) [6, 54]. In air ^{222}Rn (radon) can be diffused up to 2.2 m for the diffusion constant of 0.1 cm^2s^{-1} whereas mean diffusive motion for thoron is 0.029 m. But in any of the circumstances, the presence of thoron cannot be ignored especially in High Background Radiation Areas (HBRAs) for example Kerala, India and some places in china also. G. de with et al. reports that thoron emanates from the building materials without any diffusive barrier and a well-known contributor towards the indoor radiological health hazards [55]. Actually radon and thoron itself are not primary source of health hazards but their short lived progenies play a dominant role when they inhaled [7]. Most of the inhaled gas is exhaled during the process of breathing but their progenies attach themselves to the lung tissues and causes lung cancer [56-57]. Health hazards posed by radon and thoron gases are acknowledged worldwide by many agencies such as WHO (World Health Organization), UNSCEAR (United Nations Scientific Committee on the Effects of Atomic Radiation), USEPA (United States Environmental Protection Agency) and ICRP (International Commission on Radiological Protection). On behalf of above stated facts, it is clear that the study of naturally occurring uranium, thorium and their subsequent daughter products is necessary.

1.4. RELEASE MECHANISM OF RADON AND THORON: EMANATION, TRANSPORTATION AND EXHALATION

Radon/thoron atoms to be found in solid grain release to the interstitial space between the solid grains as a recoil effect of alpha particle produced from the decay of radium isotopes. Now, these atoms in the interstitial space can easily diffuse to the atmosphere [58]. Release mechanism of radon/thoron from the radium isotopes to the open surface as shown in figure 1.4 can be described in three steps [59].

a) Emanation: it is a process in which radon atoms emanates from the soil grain to the interstitial space between the soil grains due to the recoil effect of alpha particle produced during the decay of radium isotope.

b) Transport: a process in which radon atoms placed in the soil pores migrate (move) to the ground surface by the process of diffusion or advective flow.

c) Exhalation: in this process the radon atoms transported to the surface of ground are free to release in the open atmosphere.

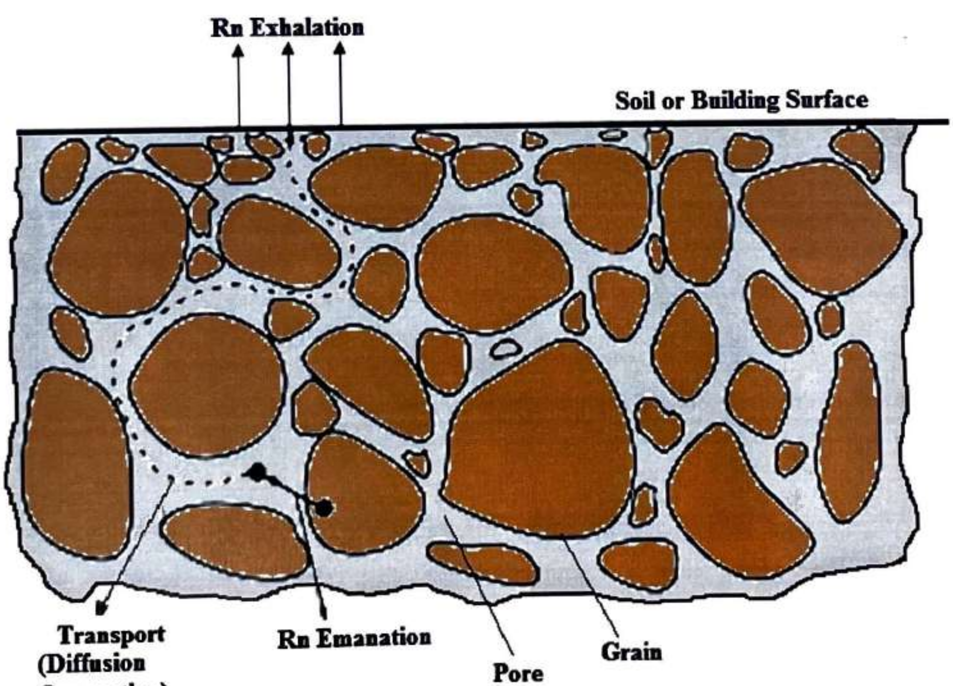

Figure 1.4: Release mechanism of radon (^{222}Rn)/thoron (^{220}Rn)

Radon/thoron both are well known source of lung cancer so that from the safety point of view, it is essential to know the complete process from the production to the exhalation of radon and the various factors that impact these processes [60]. Half-life and alpha recoil energy of radon (^{222}Rn) and thoron (^{220}Rn) are shown in table1.4.

Sr. No.	Parameters	^{222}Rn	^{220}Rn
1.	Half-life	3.82 days	55.6 s
2.	Average recoil energy on formation	86 kev	103 kev
3.	Alpha recoil energy in air	77	87
4.	Alpha recoil energy in water	34	38

Table 1.4: Half-life and alpha recoil energy of radon and thoron [61]

1.4.1 Emanation process of radon (^{222}Rn) and thoron (^{220}Rn)

Radon/thoron atoms released in the interstitial space are generated from the decay of radium isotopes present in the mineral grains. Only a small fraction of atoms can be released from the soil grain, because of its small recoil range (< 5×10-2 μm) in solids. In 1971 Kigoshi proposed the direct ejection of radon/thoron atoms recoiled from the alpha particle emitted during the decay from the radium isotope [62]. Conservation of momentum tells that when radium isotopes (^{226}Ra and ^{224}Ra) decays they produces alpha particles with energy 4.78 MeV and 5.7 MeV and residual atoms of radon and thoron with recoil energy of 86 KeV and 103 KeV respectively. Emanation of radon/thoron from the mineral grain can be expressed in three possible ways as shown in figure 1.5 and expressed as [62-63]:

(i) The recoiled atoms (radon/thoron) get trapped within the same mineral grain where they originate and get immobilized (A).

(ii) They crossed the interstitial space filled with soil gas and moved to the adjacent grain (B).

(iii)They emit in the interstitial space filled or partly filled with water and free to migrate towards the atmosphere (C).

The fraction of radon/thoron atoms generated in the soil grain to the atoms released in the pore space is known as "emanation coefficient" or "emanation power". It depends upon the radium distribution, size of soil grain, porosity and moisture level [64].

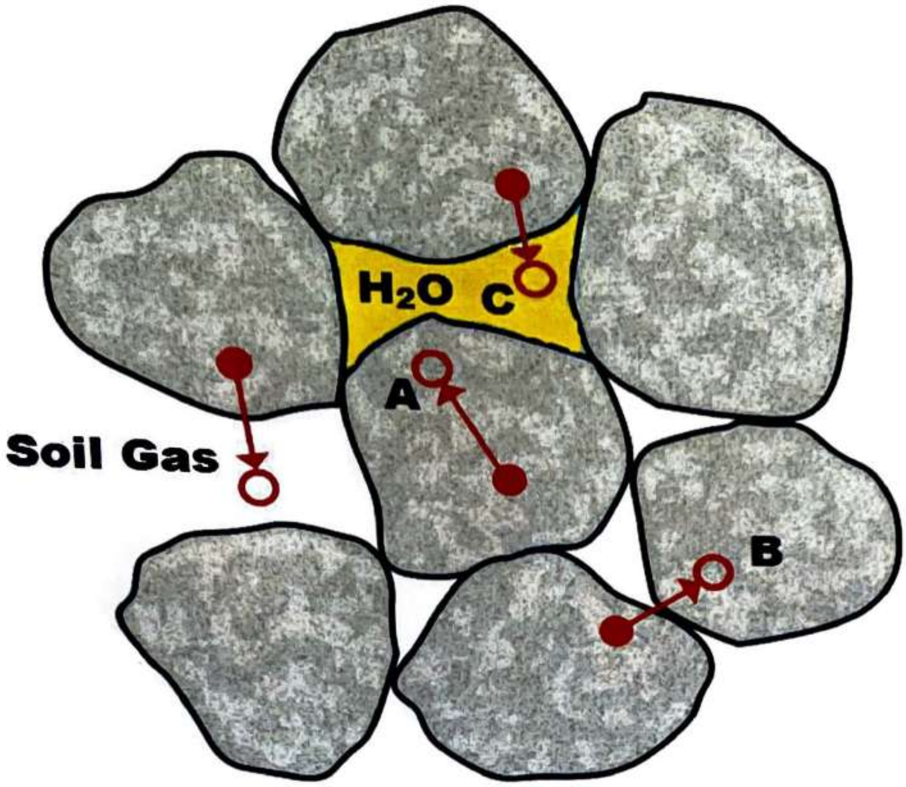

Figure 1.5: Emanation of radon in water or air filled pore space

1.4.2 Factors affecting the emanation coefficient

Distribution of radium in the soil grain, moisture content in the pore space, shape and size of the grain and porosity etc. all these factors influence the emanation coefficient and described as:

a) Emanation coefficient and radium distribution: Radium distribution among the soil grain is a prime factor to affect the radon emanation coefficient. In the earlier studies during 1993 on radon emanation, uniform distribution of radium was assumed from the single grain but later on Tanner [63] described the non-uniform distribution of radium among the soil and rocks. In 1993, Morawska and Phillips represents a model for the radon emanation and according to that radium distribution was uniform throughout the soil grain and the grains were spherical in nature [63, 65]. In 2004, Holdsworth and Akber calculate the emanation coefficient for Monazite with uniform distribution and Zircon with crumbs of ^{232}Th (thorium) for small size grain and the reported results are $(9.0\pm2.6)\times10^{-4}$ and $(4.1\pm1.9)\times10^{-2}$ respectively [66]. But it was estimated that radon emanation coefficient would be in a smaller amount for those materials in which radium distribution is homogeneous, as compared to the surface distribution. Though, the radium distribution is a key point for radon/thoron emanation but some other factors like porosity, grain size. Moisture content etc. should also have the combined effect on emanation coefficient.

b) Moisture Content: After the distribution of radium, moisture content is second most important factor for the radon/thoron emanation coefficient [67-70]. If the interstitial space in between the soil grains is fully or partly filled with water then the recoil radon will be trapped in the interstitial space before it enters in the neighboring grain. It is because the recoil range of radon nuclei is shorter in water as compared to air as shown in table 1.4. The radon/thoron emanation coefficient increase with the moisture content. Initially increases with gradual increase in moisture but emanation comes in the steady state and start decreasing with higher moisture.

c) Size of particle and porosity: Size and shape of particle also estimates that exactly how much radium is near to the surface of the grain to permit the radon to release to the interstitial space. If radium is distributed homogeneously throughout the grain then the emanation coefficient follows the inverse relation to the size (diameter) of particle that means if the size of the particle increases radon emanation decreases [71]. In contrast to this, if radium is distributed on the surface of grain then the emanation coefficient is constant irrespective to the size (diameter) of particle [72]. In addition to this, temperature also contributes towards the emanation coefficient. Iskandar reported that if temperature increases, emanation coefficient also increases [71, 73]. Porosity also affects the emanation coefficient and defined as the ratio of pore (interstitial) space volume to the total volume. An increase in the interstitial space means increase in the porosity. In that case radon has greater probability to trap in the interstitial space after release from the grain [74].

1.4.3 Transport and exhalation of radon-thoron (^{222}Rn-^{220}Th)

Transportation/migration of emanated radon/thoron to the soil surface can be expressed in two basic mechanisms: diffusive transport and forced flow [63, 71].

a) Diffusion takes place from the higher concentration to the lower concentration so that radon/thoron will be diffused towards the open atmosphere when the pore space will have higher concentration of emanated radon/thoron atoms than the open atmosphere. Flicks Law describes the diffusion process and it states that "Flux density of radon is linearly related to the concentration gradient". In soil diffusion coefficient of radon depends upon the type of soil, distribution of pore size, moisture content and the mode of its compaction [61]. Diffusion coefficient and diffusion length of radon/thoron for some materials are shown in table 1.5. Diffusion is a main process for the exhalation of radon/thoron atoms from the porous substances such as building materials and soil etc. Only a fraction of emanated atoms exhaled at the soil surface because of their radioactive decay before the migration to the surface. Basically, radium atoms present at a depth of 1-m of soil contributes toward the migration of radon or thoron atoms respectively.

Sr. No.	Medium	Mean Distance (cm)		Diffusion Coefficient (cm^2s^{-1})
		^{222}Rn (Radon)	^{220}Rn (Thoron)	
1.	Air	220	2.85	10^{-1}
2.	Porous Soil	155	2.00	5×10^{-2}
3.	Water	22	0.0285	10^{-5}
4.	Saturated Porous Soil	1.55	0.020	5×10^{-6}

Table 1.5: Diffusion length and mean diffusion distance of radon and thoron in different media [4, 71]

b) Darcy's law described the forced flow transport and states that, the transport of radon/thoron atoms is governed by the flow of soil gases (CO_2 and CH_4) due to the pressure gradients. Transport of radon/thoron to the long spaces by the means of air flow is acknowledged as advective Transportation. Transportation of radon/thoron gas atoms to the surface of the atmosphere is known as exhalation.

Radon/thoron exhaled to the atmosphere mainly by the path of soil-air interface and by building materials-air interface. Some physical parameters such as atmospheric pressure and temperature, wind speed, soil moisture content and soil temperature etc. influence the exhalation rate [75]. The exhalation rate is defined as the released activity per unit area per unit time ($Bqm^{-2}s^{-1}$). Exhalation rates of radon and thoron for soil are 0.02 $Bqm^{-2}s^{-1}$ and 1 $Bqm^{-2}s^{-1}$and for building materials are 5.0 x10^{-4} $Bqm^{-2}s^{-1}$ and 5.0 x 10^{-2} $Bqm^{-2}s^{-1}$ respectively [76].

1.5. SOURCES OF RADON AND THORON

Presence of radon/thoron radionuclides in the surrounding environment may be because of naturally occurring (NORM) and man-made (TENORM) sources of radiations. Ingestion and inhalation are main routes of exposure to these radiations via contaminations enter through mouth and breathing air, smoke and dust particles respectively. Basically there are three types of sources for radon and thoron contribute to the indoor and outdoor environment such as soil and rocks, building material (natural and technically enhanced) used for construction and ground water [13, 77].

a) Soil and rocks under beneath: Soil and rocks rich of uranium (^{238}U) and thorium (^{232}Th) are the main source of indoor and outdoor radon/thoron levels [14]. When radium isotope (intermediate product of uranium and thorium series) decays, it releases the radon/thoron atoms to the soil pore. After the emanation they migrate to the surface of the soil and enter in the outdoor as well as indoor environment via micro-fissures and foundations. In the outdoor environment it mixes with other gases and dispersed but in the indoor environment its concentration is high especially at those levels which are close to the soil such as basements and crawl spaces.

b) Building Materials: After the soil, building materials used for the construction and decorative purpose are considered as second main cause of indoor radon/thoron exposure by inhalation [78]. Radon because of its long half-life (3.82 d) was constantly a matter of concern whereas thoron because of its short half-life (55.6 s) was not to be counted for the indoor radiological assessment. But now days it is well known that building materials are a significant source of indoor thoron levels [15]. Some building materials like sand stone, bricks, granite, marble and concrete etc. emanates radon/thoron just after the radium during the decay of uranium and thorium from Building materials and contribute a significant role to the indoor exposure to radiations.

c) Ground Water: ground water is also a potential source of indoor radon/thoron levels by ingestion and inhalation at whatever time of their use [16]. Frequent activities of the inhabitants like Showering, cooking, washing dishes and clothes etc. released radon/thoron from the water supply where it mix in the indoor air and can be inhaled [79].

Apart of all these burning of coal in the power station, production and usage of agricultural fertilizer and other industrial wastes also release the radon/thoron. The distribution of radon/thoron in ground depends upon the number of factors like soil temperature, humidity. Porosity, soil moisture content and surface winds etc.

1.6. ENTRY ROUTES OF INDOOR RADON AND THORON

There are a number of entry routes of indoor radon and thoron from top few cm of soil as shown in figure 1.6.

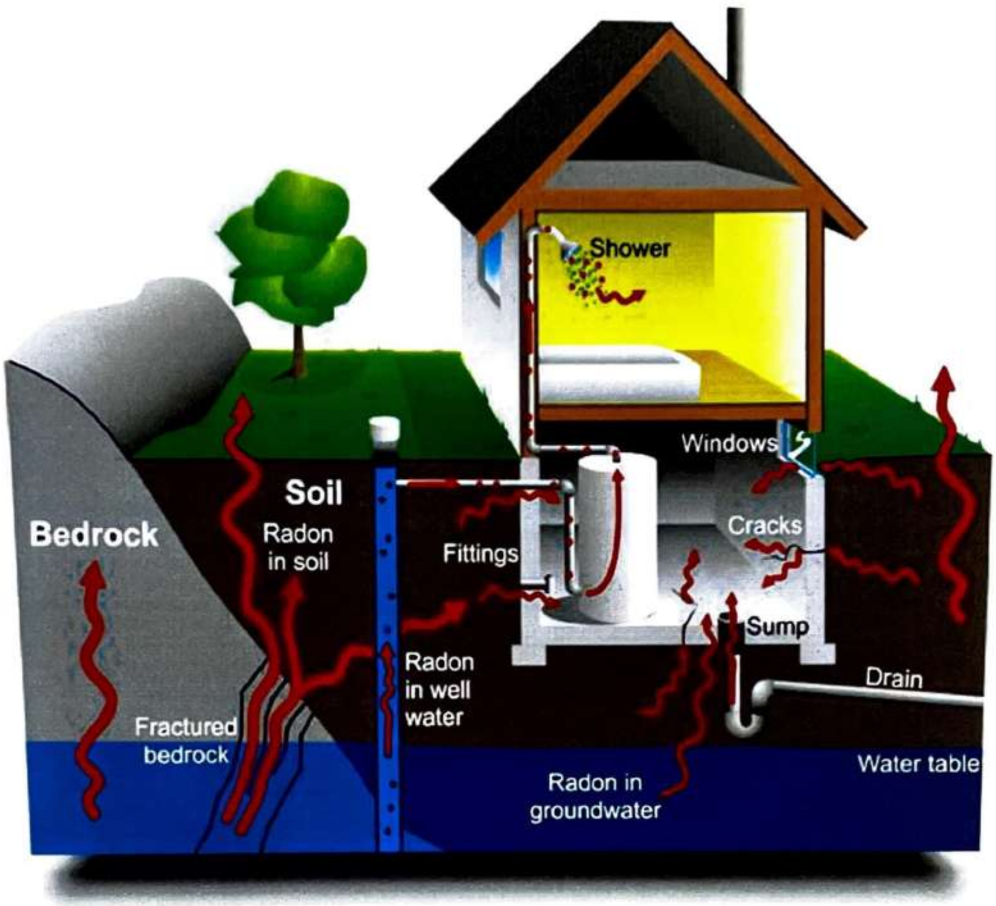

Figure 1.6: Entry routes of radon and thoron in dwellings [79(a)]

1. Cracks in the floor
2. Joints between floor and wall
3. Construction joints
4. Pores in concrete blocks
5. Cracks in walls below the ground level
6. Loose fitting pipe
7. Fractured bedrock
8. Building materials and
9. Water from wells

1.7. FACTORS INFLUENCING THE INDOOR RADON/THORON LEVELS

Several factors are there who influence the indoor radon/thoron levels and some are as follows:

1. The ventilation condition
2. Life-style of inhabitants (smoker or non-smoker)
3. Building material used for the construction
4. Water supply
5. Soil Permeability
6. Local geology of the environment
7. Type of building structure (high rise or low rise)

1.8. RADON AND ASSOCIATED BIOLOGICAL AFFECTS

1.8.1 Ionizing Radiations and Living Matter

All living matters are exposed to the ionizing radiations present in the environment all-around of us and we cannot ignore their presence because of industrial and medical science of our daily life. When the ionizing radiations permit through the biological environment it produced the functional or structural alterations at molecular or macromolecular levels [80]. When the ionizing radiations interact with the cells from which our body is made up, the following possibilities may be occurred [81]:

a) The ionizing radiations may pass through the cell without initiating any damage.
b) The ionizing radiations may damage the cells but the damage is repairable that means damaged cells are able to reproduce themselves correctly.
c) The ionizing radiations may affect the ability of cells to reproduce correctly i.e. functioning of cells may be altered and cause mutations and other transformations.
d) The ionizing radiations may kill the cell. Death of one cell is not so matter but if numerous cells are dead in one organ then the organism will die.

In the nucleus of each cell, some macroscopic bodies exist and known as chromosomes. Different species have different number of chromosomes and these chromosomes are arranged in pair's e. g. human beings have 46 chromosomes in 23 pairs [82]. Functioning of each cell in each organism depends upon the chromosomes and these chromosomes are made of two large strands of deoxyribonucleic acids (DNA). DNA is made of four type of nucleic acids; adenine (A), cytosine (C), guanine (G) and thymine (T). Arrangement of these nucleic acids inside the DNA gives the genetic code which provides the information about everything; from hair color to how tall one can grow and even weakness to certain diseases. These nucleic acids form the base pairs of DNA and bound together with weak hydrogen bonds. Adenine pair with thymine and guanine is paired with cytosine [83]. Bonding of these pairs can be affected by direct or indirect action of ionizing radiations.

1.8.2 Direct and Indirect action of Ionizing Radiations

When the ionizing radiations interact with the cells then some radiochemical changes occur by the direct and indirect action of radiations [84]. Alpha, beta and gamma are three types of ionizing radiations; the exposure due to beta and gamma radiations can be flouted because of their lower effectiveness but alpha radiations cannot be ignored because they are massive and heavily charged as compared to other ionizing radiations.

In direct action of ionizing radiations, alpha particles transfer their energy in DNA and directly break one or more strands or sugar phosphate backbone of DNA. It can also break the base pairs of DNA by displacing the electron or by break the weak hydrogen bond between the base pairs [85]. This type of damages dominates at high Linear Energy Transfer (LET) radiations. Basically two types of damages can be produced by ionizing radiations: Single Strand Breaks (SSBs) and Double Strand Breaks (DSBs) [86]. In single strand break only one strand or backbone will break and this damage is repairable using another strand as a template. In double strand breaks, both the strands will break and are opposite to each other [87]. In DSBs most injurious lesions will be produced in the chromosomes by the ionizing radiations. Injuries during the DSBs are difficult to repair and cause mutations or cell death. Double strand breaks that are not able to rejoined are cytotoxic and they kill the cells [88].

In the indirect action of ionizing radiations, damage produced in the cells by creating free radicals or by the radiolysis of water. These free radicals are capable to diffuse over enough distances to interact with DNA and cause damage. Because of unpaired electrons, free radicals are highly reactive and form the compounds such as hydrogen peroxide. These compounds start the detrimental chemical reactions in the cells and leads to the transformed function or cell death [89].

1.8.3 Biological effects

Biological effects mainly depend upon the amount of energy deposited per unit mass of the tissue. Biological effects of ionizing radiations can be categorized in two types [90]:

a) Stochastic Effects (non-threshold function of the dose)

b) Non-Stochastic Effects (also known as deterministic effects)

a) Stochastic Effects

Stochastic effects occur by chance and there in no any limit below which one can say the effect will not occur. This is no-threshold function of dose which means that exposure to minimum dose can also initiate the pathological changes to the exposed organism [91]. Several diseases like sickness, internal bleeding and hair loss appear after the exposure but cancer appears after a number of years.

b) Non-Stochastic Effects

Non-Stochastic effects are also known as deterministic effects by ICRP and in this effect a threshold limit is set on the dose below which this cannot be occur. Non-stochastic effect appears when an organism is exposed to high radiation dose for a short period of time and shows a clear connection between exposure (dose) and effect [10]. Non-stochastic effects appeared as skin reddishness, loss of visual acuity (cataract), burning of skin and tissues and radiation sickness. These after effects of radiation exposure can be characterized within few days to few weeks of exposure [92]. These effects occur at high radiation dose even much higher than we receive from the modern radiology. Among the human species, the acute exposure needed is 200 mSv for any deterministic effect.

1.8.4 Radon/ Thoron Daughters and Induction of Lung Cancer

Health effects of radon, thoron and their daughters to the exposed inhabitants are well known. When radon and thoron decays to their daughter products they attach themselves to the small dust particles (aerosols), indoor air, water vapors, trace gases and other solid particles surroundings. These radioactive aerosols can be inhaled very easily through the passage in the nose known as nostrils. Then the tiny hairs in the nostrils known as cilia filter the dust particles from the inhaled air [93]. Now the inhaled air will pass through the Pharynx, and the bottom path of the Pharynx is divided in the two parts; one for the food and another for the air (air-only passage). From the air-only passage air enters to the trachea or windpipe which lies between the neck and chest cavity. The bottom end of the trachea is divided into left and right air tubes named as bronchi which are connected to the lungs where it is further divided into even smaller tubes known as bronchioles. Bronchioles ends at the tiny air sacs called alveoli. Finally, the air we breathe in reaches to these air sacs and thus irradiate the tissues especially at the epithelial cells [94]. The diagram of human respiratory track is shown in figure 1.7.

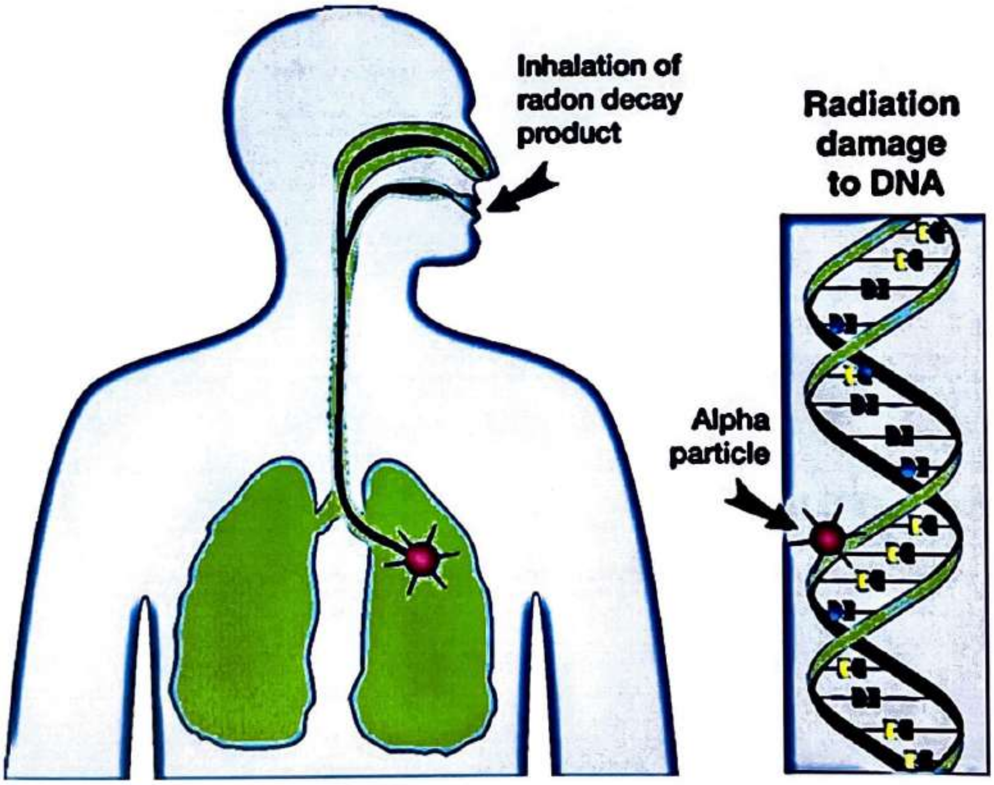

Figure 1.7: Human respiratory track [94(a)]

Alpha particles emitted from the decay of radon and thoron daughter products may be a significant agent of biological damages in the tissues because of their higher relative biological effectiveness (RBE) as compared to the beta and gamma radiations [9]. The Biological effectiveness to a tissue by the given type of radiation is expressed in terms of "Relative Biological Effectiveness" (RBE). There are a number of factors which affect the amount of damage to the sensitive lung tissues; first is half-life of radioactive element, second is extent of energy at which the alpha particle is emitted, third is the thickness of the surface epithelial cells through which the radiation penetrate to hit the basal epithelial cells (sensitive tissues) and fourth is probability of alpha particle to miss the nuclei of the sensitive cells [95]. As a result the energy transferred by alpha particles deposited on the sensitive lung lining has greater biological impact and initiate an event which leads to the lung cancer [81].

1.9. UNITS AND DEFINITIONS RELATED TO THE PRESENT WORK

Units and definitions as reported in literature are discussed in [31, 97]:

Radioactivity (Activity): It is defined as the process of spontaneous transformation of the nucleus, generally with the emission of alpha particles, beta particles or gamma rays. This process is referred to as decay or disintegration of an atom.

Traditionally, radioactivity was measured in Curie abbreviated as Ci and this unit of radioactivity was based on the number of disintegration per second in one gram of radium-226 (37 billion). In the International system of units (SI) Curie replaced to Becquerel (Bq) and 1 Bq is defined as one disintegration per second.

1 Curie = 3.7×10^{10} disintegration per second = 3.7×10^{10} Bq

Activity Concentration: It is defined as the amount of radioactivity present per unit volume of the radioactive material. Its SI unit is Bqm^{-3}.

1 Bqm^{-3} = 0.027 p $Ci.l^{-1}$

In case of water it is defined as the activity present per liter of water.

1 $pCil^{-1}$ = 37 Bqm^{-3}

Specific radioactivity: is defined as the amount of radioactivity present per unit mass of the radioactive material and calculated in units of $Bqkg^{-1}$.

1 $Bqkg^{-1}$ = 0.02 $p.Ci.kg^{-1}$

Potential Alpha Energy: The potential alpha energy of an atom in the decay series of radon (^{222}Rn) / thoron (^{220}Rn) is the total alpha energy emitted during the decay of this atom through the decay chain (excluded lead the stable isotope).

Potential Alpha Energy Concentration (PAEC): The potential alpha energy concentration of any combination of short lived radon or thoron daughter products is the sum of the total potential alpha energy of all daughter atoms per unit volume of the air. Historical unit of PAEC is Working Level (WL) but the SI unit is Jm^{-3}.

Working Level (WL): one working level is any combination of short-lived decay products in one liter of air which will ultimately emit 1.3×10^5 MeV of alpha energy.

$$1 \text{ WL} = 1.3 \times 10^5 \text{ MeV}$$

In SI units $1\text{WL} = 2.08 \times 10^{-5} \text{ J m}^{-3}$

Exposure due to radon/thoron progeny concentration is expressed in terms of WLM (Working Level Month). 1 WLM is an exposure of 1 WL during a reference-working period of one month (170 hrs).

Exposure: It is a measure of total dose in the environment caused by x-rays or gamma rays to which we exposed (amount of radioactivity passing through the environment. Unit of exposure is Roentgen.

Roentgen (R): One roentgen is the amount of gamma rays or x-rays required to create ions carrying one electrostatic unit of electrical charge (e.s.u) in 1 cubic centimeter of dry air under standard conditions. It is abbreviated as "R".

$$1 \text{ R} = 2.58 \times 10^{-4} \text{ C/kg}$$

Absorbed Dose: It is amount of radiations absorbed by an object or person. This is the amount of exposure that actually "sticks" to the material. Its units are rad and gray. "rad" radiation absorbed dose is CGS unit of absorbed dose whereas, gray is SI unit and abbreviated as Gy.

rad: 1 rad is equals to an absorbed dose of 100 ergs per gram (0.01 J/kg).

gray (Gy): 1 Gy is equals to an absorbed dose of 1 J/kg (100 rad).

$$1 \text{ rad} = 0.01 \text{ J/kg} = 0.01 \text{ Gy}$$

$$1 \text{ Gy} = 100 \text{ rad} = 1 \text{ J/kg}$$

Dose Equivalent: It is the measurements of absorbed dose that affects medical conditions in living tissues. Unit of dose equivalent is rem and Sievert.

rem (Rontgen equivalent man): This is c.g.s. units of dose equivalent and considers the relative biological effectiveness of different kind of ionizing radiation

Sievert: it measures the effective dose relative to sensitive tissues and organs exposed to ionizing radiations. It is abbreviated as "Sv".

1 Sv = 100 rem

1.10. OBJECTIVES OF PRESENT STUDY

It is well known that exposure of general public, to high concentrations of radon, thoron and its daughter products for a long period lead to pathological changes like the respiratory functional changes and the occurrence of lung cancer [7]. A number of researchers reported that, lung cancer risk to the workers and the public areas of indoor setting is associated with the exposure to high concentration of radon, thoron and their progeny [97-98]. Radon in itself is not a problem because it exhaled from the body just after the inhalation, but the exposure from their daughters are associated with an increased risk of cancer. For this reason, unprotected excessive exposure to radiation should be reduced and kept below the known standards for the public. Lubin and Boice, 1997 demonstrated a strong relationship between lung cancer and the inhalation of radon, thoron and its decay products [99]. The US Environmental Protection Agency (EPA) recommended that all the levels below the third floor should be tested for radon [28] whereas Thomas Pugh and Clark Eldredge 2009 reported a study from 3rd floor to the 20^{th} floor of the building [100]. So, health and hygiene point of view, it is important to make a systematic study of indoor exposure due to radon, thoron and their decay products. Radon has a direct significance to the public in general and the workers of Industries in particular.

In the present thesis work, radon, thoron and their progeny levels were estimated in dwellings and work places of Haryana, India. This study is significant as it is directly related to the health risk of domestic and industrial population of Faridabad, southern Haryana, India. The radon and thoron measurements in the dwellings may help in preparing the radon map of the country and the data obtained can be pooled with the existing data and one can enable to access overall statistics on radon distribution in the country. The concentration of radon and thoron in the environment varies with seasons, so, that the seasonal variation of radon thoron concentration levels in indoor environment of dwellings and work places is estimated where radon level is expected to be very high. Modern houses or high rise buildings are very common in the densely populated city Faridabad to fulfill the demand of land for the purpose of residence and workplaces. These buildings are liable to build up of radon and thoron, because the building structure is almost airtight and the foundations are leaky to soil gas. In addition to this, there are a large number of radon sources in domestic buildings: ground underneath a dwelling, water supply, building materials and ambient air etc. The alpha particles emitted from radon and thoron decay can damage the cells, lining the airways, which may eventually result in lung cancer.

The assessment of radiological exposure to the individual over a long period is essential as it poses serious health hazards not only to uranium miners but also to the population living in normal houses and at the work place in industry. . Based on the study, the annual effective dose received by the persons and health risk assessment is made as per ICRP (International Council for Radiation Protection) Recommendations.

1.11. ORGANIZATION OF THESIS

Thesis is divided into six chapters. The contents related to these chapters are as follows:

Chapter-1- Introduction — It introduces the radioactivity, and how the natural and artificial radiations contribute towards the total radiation dose. It gives an overview of radon and thoron and explains their sources and properties. Release mechanism of radon and thoron is discussed in detail. The biological effects due to radon, thoron and their daughters are elaborated. Various units and quantities used for the measurements of various doses are focused. This chapter is enclosed with the objectives of the study and the organization of the thesis.

Chapter-2- Literature review — This chapter introduces the review on literature related to the radon, thoron and its progeny concentration levels published by different scientists at national and international levels using different techniques. This chapter also discusses the publications reported the suitable methods for the indoor assessment of radon and thoron. Various publications are reported who support that the indoor assessment of dwellings and workplaces is necessary to estimate the exact picture of radiation dose to the inhabitants,

Chapter-3- Experimental Techniques — It discusses the various techniques either active or passive/time integrated used for radiological assessment of radon/thoron and progeny concentration as per available literature. In the present work the passive/time integrated 'Twin Cup Dosimeter' technique has been used for the measurements of radon, thoron and their progeny levels in the environment of dwellings and workplaces of Southern Haryana, India. Twin cup dosimeters loaded with LR-115 type-II SSNTD'S exposed at the targeted locations during all the four seasons (three months each) of a calendar year. After exposure the detectors were retrieved and etched in 2.5N NaOH solution. Etched tracks were counted using spark counter.

Chapter-4- This chapter deals with the study of radon, thoron and their progeny concentration in the indoor environment of dwellings. This chapter reveals the experimental measurements of proposed aims and objectives. Here two case studies are discussed: first in the dwellings nearby fly ash dumping site of Faridabad, Haryana (India) and second for dwellings of high rise buildings situated in Greater Faridabad, Haryana (India) during all the four seasons in a year (Spring, summer, rainy and winter). Results of radon, thoron and their progeny concentration, Potential Alpha Energy Concentration (PAEC) due to radon and thoron progeny and the annual effective dose are discussed with graphical representation.

Chapter-5- This chapter emphasizes studies in the environment of different workplaces and carried out over a year. In the modern era, offices, banks, parking, business stores etc. are so common in basements. So, the people who are working at these places spent most of their time in poorly ventilated areas. So, radiological assessment of these workplaces is necessary for health and hygiene point of view. In one of the case study, Malls of Delhi-NCR and Faridabad regions with multiple basements used for parking and stores have been investigated. People, who are working there, spent 8-12 hours per day in poorly ventilated basements or low ventilated area. In another case study, environment of thermal power plants of Delhi-NCR and Haryana have been investigated and reported for radon, thoron and their progeny concentrations and annual effective dose during all the seasons of a year.

Chapter-6- Conclusions: This chapter concludes the entire work carried out in the indoor environment of dwellings and workplaces of Haryana, India. It summarize and compare the whole work with the recommended safety levels given by various regulatory bodies and shows the significance of present work. Scope for future work is also discussed in the chapter.

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CHAPTER II

LITERATURE REVIEW

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This chapter describes the wide studies and surveys conducted for the measurements of $^{222}Rn/^{220}Rn$ and their daughter product concentration in the different environment of the world. This extensive survey comprises the origin, history, existence and various measurements up to the date. Although, Radon was discovered in 1900, but the adverse effects due to their prolonged exposure were perceived about 300 years prior to their discovery.

G. Agricola, 1556 [1] A German Physician, perceived the high frequency of lung cancer in the local miners. A Swiss Physician named Paracelsus from his survey over 10 years among the underground miners in Erz Mountains of Eastern Europe, found that a number of miner were died because of lung cancer and he also found that the main reason of these deaths was dust and gases present in the mines.

F. H. Harting 1879 [2] found that about 75% uranium miners was died surprisingly who worked in Germany and Czechoslovakia and the miners who worked for more than 10 years probably suffered from the Erz Mountain lung disease. Later on, "Erz Mountain disease" was known as lung cancer. In work strength of around 650 men, Harting and Hesse found 150 deaths from "miner's disease" from 1869 and 1877; in survey, most of these deaths were possibly found from the lung cancer.

M. Uhlig 1921 [3] proposed that the occurrence of lung cancer may be because of radium emanation. After the three year of Margaret, Ludewig and Lorenser, 1924 [4] reported that radioactivity can be measured in the water and air samples in the mines of Schneeberg and that might be a cause of lung cancer among the miners.

Pirchan and Sikl, 1932 [5] report a relation between radon and lung cancer. On the basis of findings among the miners in the region of Joachimstal and in miners of Schneeberg during the period of 1924-1932 authors recommended that exposure to radon was a main source of lung tumor in the miners at Joachimstal. He also found that more than 50% deaths were caused by the lung cancer among the miners before they cross the age of 50. Later on research related to radium emanation and exposure to radon was shifted to another factory workers, radium dial painters and medical patients etc.

J. H. Harley, 1953 [6] confirm the presence of radon daughter products in the environment, at high concentration. Harley and was the first who emphasize that radon is not a problem in itself, but the exposure to alpha particle emitted during the decay of radon daughters placed in the respiratory track is main source of lung cancer.

Bale and Shapiro, 1956 [7] conclude that, analysis of dose delivered to the lung tissues from the inhalation of radon, thoron and their particulates is necessary and a number of experiments were carried out at the University of Rochester to find the quantitative analysis of dose transported to the lung tissues.

F. E. Lundin Jr et al., 1971 [8] reported that, the correlation between lung cancer and exposure to high concentration of radon decay products was established during a quantitative investigation of cohort among U. S. miners during a study carried from a period of 1950-1960.

Hultquist, 1956 [9] was the first that reported the indoor radon measurements in 225 houses in Sweden. Results show that the radon concentration ranges from 20 Bqm^{-3} to 69 Bqm^{-3}. But a little courtesy was waved to the Hultqvist because it was supposed that it is a local Swedish problem.

R. C. Bruno, 1983 [10] examine the major sources (soil gas, building construction materials and tap water) of indoor radon concentration in a model of a single story typical house whose walls were made of masonry. In addition to this, its primary paths to enter in the indoor environment were also investigated. Results of this study after the comparison with other studies of indoor radon show that permeation of soil gas and water drained from the aquifers in granite may be a significant contributor to indoor radon levels. But later he said that Masonry (unit structure) used as a building material will merely be a substantial source of radon in homes.

Behera and Kashyap, 1988 [11] explored the pattern of malignancy in the patients from 1973 to 1982 admitted to PGIMER, Chandigarh and authors found 863 patients developed lung cancer out of the 223,930 hospital admissions,. So it becomes an extensive concern in terms of radiological protection.

IARC, 1988 [12] The International Agency for research on Cancer (IARC) acknowledged the radon as A-level cause of cancer from the epidemiological studies among the uranium miners. While a little attention was given to the indoor assessment but the scenario was changed after an incidence at the Watras house at USA as reported by Lowder.

W. M. Lowder, 1989 [13] reported that, the systematic study was started in several countries after the incidence of Watra's house located in eastern Pennsylvania, USA where the high radon levels ~ 105 Bqm^{-3} were estimated in 1984. After the incidence a number of efforts were made at national and international levels for the indoor radiological estimations.

S. D. Schery, 1989, 1990 [14-15] shows that radon and thoron both are present in the environment but thoron (^{220}Rn) and its daughter products which are most important radioactive elements in indoor and outdoor environment were neglected in the earlier studies because of their short half-life (55.6 s). Transport of radon and thoron is affected by the common factors such as diffusivity, physical structure of soil particles and content of moisture. So, that thoron cannot be neglected under any circumstances especially in High Background Radiation Areas (HBRAs) for example Kerala in India and some regions of Yangjiang in China.

Kotrappa and Dempsey, 1990 [16] reported that thoron (^{220}Rn) and its daughter products does not contribute a significant health effects as compared to radon and its progeny but in case of sampling from the soil gas, the thoron may be a substantial source of interference in the assessment of radon concentration if lack of proper instruments.

Subba-Ramu et al., 1990 [17] was one of the first who coordinate the systematic studies in India and started a programme to measure the indoor radon levels in the 15 Indian houses located in High Background Area (HBA). Measurements show that the Potential Alpha Energy exposure due to radon decay products was found to be 9.4 mWL. As a part of ongoing programme, Subba Ramu made parallel measurements in 150 houses of different types, using solid state nuclear track detector and equilibrium factor was estimated for each house. Srivastava extended the study by conducting the additional analyses in the north eastern region of India.

Srivastava et al., 1996 [18] reported the observed data for Potential Alpha Energy Exposure (PAEE) due to indoor radon and its daughter products in the north eastern region of India. During the work Indian dwellings in 24 towns were examined using

LR-115 Type-II SSNTDs. Results obtained from the study show that geometric mean of PAEE due to indoor radon was estimated to be 8.8±3.6 mWL and annual effective dose equivalent was found to be 2.7±1.1 mSv/y. The results were compared with the corresponding data at national and international data recommended by the ICRP.

Nikolaev and Ilic, 1999 [19] review some passive devices and classify them into the 8 categories used for the measurement of radon, thoron and their daughter's concentration. Some of them are open detector and some are the chamber with an inlet filter. Authors conclude that in addition to CR-39, cellulose nitrate (LR 115) and polycarbonate (Makrofol E) are frequently used detectors for the radon measurements in the outdoor as well as indoor environment.

J. Lembrechts et al., 2001[20] studied the air flow and transportation of radon in approximately 1500 Dutch dwellings constructed newly between 1985 and 1993. Author concluded that, the average radon concentration in the living rooms of the dwellings was found to be 28 Bqm^{-3} which was 50% higher than the concentration found in the dwellings constructed before 1970. From the air flow estimations it was observed that building materials contribute approximately 70% to the total indoor radon concentration in the living room and rest of the 30% involved the outside air.

P. Korhonen et al., 2001[21] reported the comparison of measured indoor radon concentration and calculated radon concentration from the building materials at 23 workplaces of Finland. Author conclude that, concentrations of radon levels measured continuously or by the integrated method were found to be higher than the calculated values of radon concentration exhaled from the building materials. The soil was found as the leading source of indoor radon concentration whereas the building materials contribute only 7-19% to the indoor radon levels. The maximum mean value of radon concentration, measured continuously (933 Bqm^{-3}) and integrated (1679 Bqm^{-3}), and calculated (70 Bqm^{-3}-169 Bqm^{-3}) from building materials were found at the hillside stations. In contrast of this, calculated value of median (27 Bqm^{-3} and 43 Bqm^{-3}) and variations in calculated indoor radon concentrations (626 Bqm^{-3} and 1002 Bqm^{-3}) exhaled from the building materials were found to be maximum at the ground floors.

F. Abu-Jarad et al., 2003 [22] reported an indoor survey of 724 houses and 98 schools in the nine cities of Saudi Arabia. Results show that minimum and maximum value of radon concentration was found to be 1 Bqm^{-3} and 137 Bqm^{-3} respectively with an average value of 19 Bqm^{-3}. Results for all the dwellings are within the safe limits as recommended by ICRP except one dwelling in Qatif city, where the radon concentration calculated with the passive system was found to be 535±23 Bqm^{-3} and the result was reconfirmed with the active system and the result was again 523 ± 22 Bqm^{-3}. The maximum value of average radon concentration was found to be 40 Bqm^{-3} in Khafji whereas the minimum value was found to be 8 Bqm^{-3} in Al-Ahsa. On the other hand, from the survey of 98 schools, the average radon concentration was found to be varied from 15 Bqm^{-3} to 32 Bqm^{-3}.

M. A. Lopez et al., 2004 [23] reported the individual monitoring, due to internal and external exposure to radon and other sources of radiations occur naturally, at the workplaces of Europe. During the work a questionnaire associated with radon and other natural sources of radiation at workplace "EURADOS questionnaire Q3" was circulated among the appropriate institutes across the whole Europe. To determine the individual doses at the workplaces, data was also collected from the individual and area monitoring. In both the cases, underground workplaces, exposure to miners, schools, offices, water workers, industry workers and day-care homes was considered. The results indicate that, organization is needed among the countries to regulate and use the reference level for the workplaces.

S. Oikawa et al. 2006 [24] reported a survey of indoor radon concentration at 705 workplaces (offices, schools, factories and hospitals) in Japan with the installation of passive type Rn monitors at the selected workplaces during all the four seasons of a year. Results show that annual value of mean ^{222}Rn (radon) concentration at all the workplaces ranges from 1.4 Bqm^{-3} to 182 Bqm^{-3} and the arithmetic mean and the standard deviation was found to be 20.8 and 19.5 Bqm^{-3} respectively. Annual effective dose for the workers was found to be varied from 0.42 mSv/y to 0.52 mSv/y. Mean radon concentration at all the selected categories decreases in the order of; school (28.4 Bqm^{-3}) > offices (22.6 Bqm^{-3}) > hospitals (19.8 Bqm^{-3}) > factory (10.1 Bqm^{-3}). The seasonal observations of radon concentration at offices, hospitals and schools were found to be same as in the indoor environment but in case of factory, results were same as the outdoor environment.

K. Kant et al., 2006 [25] reported the monitoring of radon concentration in Indian dwellings made up of a variety of building materials including concrete blocks, fly ash bricks, stones, fired mud bricks and mud with the installation of LR-115 Type-II SSNTDs. Results indicate that radon concentration and effective dose varied from

86.48 Bqm^{-3} to 196.66 Bqm^{-3} with an average value of 22.42±6.16 Bqm^{-3} and 1.49 mSv to 3.38 mSv with an average value of 2.09±0.10 mSv respectively. The Potential Alpha Energy Concentration (PAEC) varied from 9.34 mWL to 21.24 mWL with an average value of 13.11±0.63 mWL. Author also found that the dwellings made of fly as bricks with cement plaster and paint have lower radon concentration than the dwellings of fly ash bricks with cement plaster and white wash or with cement plaster only.

A. Clouvas et al., 2007 [26] performed the indoor radon measurements in 561 workplaces in 19 regions of Greece. The maximum value of radon concentration was found to be 695 Bqm^{-3}. Approximate 10% workplaces exceed the radon concentration from the 200 Bqm^{-3} and a very small segment of workplaces approximately 1% go beyond the value of 400 Bqm^{-3}. From the observations it was clear that more extensive research is required for certain regions.

B. Danalakshmi et al., 2008 [27] performed radon measurements in the newly constructed residential colony of Nuclear Power Station at Kalpakkam, India. The colony with large no of houses (550) was divided into four types; B, C and D (Two–story buildings) and E (independent Bungalow). The study was performed with the installation of LR-115 SSNTD films for a duration of I year comprises all the four seasons of a year. Results show that in the two-story buildings, radon concentration ranges from 13.2±1.7 Bqm^{-3} (type-D) to 35.6±1.6 Bqm^{-3} (type-A) whereas, in the bungalow radon concentration ranges from 16.3±1.6 Bqm^{-3} to 24.3±1.4 Bqm^{-3}. Maximum value of radon concentrations in two story building was found to be higher than the bungalow but below the action level of ICRP (200-600 Bqm^{-3}).

K. Kant et al., 2008 [28] observed the concentration of radon, thoron and their decay products in the environment of LPG bottling plant in Haryana, India during all the four seasons of a calendar year. The measurement was carried out with LR-115 Type-II SSNTDs employed in twin-chamber dosimeter cups (a passive technique). Seasonal variations show that maximum value of exposure and annual effective dose due to radon, thoron and their progeny were found during winter and minimum value was found in summers. Lower level concentrations in rainy season were reported because of soil saturated with water. The dose levels found in the environment of the LPG bottling plant were considerably below the action level of ICRP for workers (20 mSv).

C. Nemeth et al., 2010 [29] execute the integrated measurements of radon and thoron in the Hungarian villages situated in the vicinity of impulsive uranium mine. Inhabited areas of 35 single story houses made of brick were investigated with the passive instrument RADUET based on CR-39 track detector. The results show that, considerable part of the dwellings investigated, have significantly higher radon concentration than the Hungarian average (152 Bqm^{-3}) for ground floor houses. In some case thoron concentration also cannot be ignored and may be a contributor to extra dose.

R. I. Obed et al., 2010 [30] reported a survey of 24 offices at Nigeria oldest university campus for the estimation of radon concentration with the passive detector (CR-39) for a period of 3 months. From the observed data it is clear that, arithmetic means and the standard deviation of radon concentrations were found to be 293.3 Bqm^{-3} and 79.6 Bqm^{-3} respectively and geometric mean was found to be 283.6 Bqm^{-3}. The mean value of annual effective dose to the public exposed to radon was found to be 1.85 mSv/ y. The workers in the offices of ceramic tile flooring receive higher dose (by a small amount 0.04 mSv) as compared to others working in the office of carpet or linen flooring. The values calculated in the present survey are within the safe limits of ICRP.

Rao and Sengupta, 2010 [31] studied the seasonal variations of radon and thoron concentration among the dwellings of southern coastal Orissa, Eastern India. For the measurements LR-115 plastic track detectors were used. The results show that, maximum values of radon and thoron concentration were found during winters whereas the minimum values were found during summers and rainy season. The thoron concentrations levels were found to be high than the radon in all the dwellings and during all the seasons of a year with the exception of some cases. The inhalation dose found in the range of 0–0.06 $mSvh^{-1}$ and is not high from those who found elsewhere in India.

J. Chen et al., 2011 [32] gives an update to thoron exposure in Canada and measure the radon and thoron concentration in 45 residences selected in Fredericton and 65 residences in Halifax for duration of 3 months. Results show that radon concentration in Fredericton and Halifax varied from 16 to 1374 Bqm^{-3} and 4 to 2341 Bq m^{-3} respectively. Estimations also show that the radon levels in 18% Fredericton homes and 32% homes of Halifax have high concentration than the Canadian indoor radon guidelines of 200 Bqm^{-3} whereas, the thoron concentration was lower than the exposure limit in 62% houses in both cities. Thoron concentration ranges from 12 to 1977 Bqm^{-3} in Fredericton and from 6 to 206 Bqm^{-3} in Halifax. In the combined effect of present measurements and the earlier studies in Ottawa, Winnipeg and Mont-Laurier area of Quebec, it was expected that approximately 8 % of the total radiation dose was owed by the thoron concentration to indoor radon exposure in Canada.

Ramachandran and Sathish, 2011 [33] reported a review study on the measurement of thoron (^{220}Rn) in the indoor environment of India. On the basis of literature and data available in India, authors projected that thoron concentration in Indian dwellings ranges from 5.7 Bqm^{-3} to 42.2 Bqm^{-3} with a geometric mean of 12.2 Bqm^{-3} and the dwellings that are situated around the thorium (^{232}Th) rich soil have high thoron levels. Inhalation dose due to thoron (^{220}Rn) and its particulates varied from 0.047 mSv/y to 0.39 mSv/y with a geometric mean of 0.14 mSv/y. Inhalation dose due to thoron and its particulates in the dwellings of high background regions (HBR) were found to be approximately 3.2 times higher than those dwellings located around the normal background regions in India. Authors conclude that a number of research bodies reported the thoron (^{220}Rn) as a significant contributor to the total dose due to both ^{222}Rn+^{220}Rn so further studies are essential to deliberate the impact of both ^{222}Rn and ^{220}Rn.

J. Wang et al., 2011 [34] reported the alleviation of ^{222}Rn and ^{220}Rn decay products through infiltration. Newly constructed buildings with decreased ventilation to maintain the energy comfort promotes the additional mitigation technique to reduce the indoor exposure. Filtration technique with HEPA filters were used in radon and thoron mixed environment. Filtration effectively removes the attached decay products of radon and thoron and increase the concentration of unattached decay products. Removal rate of attached radon decay product was found to be weak as compared to attached thoron decay products and with effect of this, filtration considerably decrease the total effective dose contributed from thoron whereas the effect on the radon dose was found to be small and permanent filtration was recommended because thoron decay products decrease slowly.

El-Ghossain and Abu Shammala, 2012 [35] measure the radioactivity in the tap water in Gaza Strip. For the purpose of measurements CR-39, Geiger counter and NaI detector were used. The average gross alpha concentration calculated from CR-39 was found to be 35.50 Bqm^{-3} whereas, maximum and minimum concentration was found to be 64.67 Bqm^{-3} and 24.20 Bqm^{-3} respectively. At Nasser, radioactivity concentration found in the tap water was close to the levels found in other countries and lower to the world average of UNSCEAR 1986 (10 kBq / m^3).

Matiullah et al., 2012 [36] reported an extensive survey of indoor radon measurement at 25 workplaces in the surrounding region of the uranium mining site in Dera Ghazi (DG) Khan District, Pakistan. For the measurements CR-39 SSNTDs were exposed for duration of 60 days. Results indicate that, radon concentration varied from 386±161 Bqm^{-3} to 3028±57 Bqm^{-3} with an average of 1508±81 Bqm^{-3} and annual effective dose varied from 2.22±0.93 mSv/y to 17.44±0.33 mSv/y with an average of 8.68±0.47 mSv/y. In the present study only 4% workplaces are within the safety limits of workers (400 Bqm^{-3}) as given by USEPA and doses due to radon at about 36% workplaces exceeds the safety limits as recommended by ICRP 1990 (3-10 mSv/y).

K Kozak et al., 2013 [37] studied the impact of air conditioning (AC) on the subtleties of radon and its decay products concentration. The experimental measurements were conducted in the auditorium or lecture hall in both the situations; when the auditorium was unoccupied (AC was switched off) and when the auditorium was in normal use (AC was switched on). Results show that mean value of radon and its attached daughters and mean value of radon equilibrium factor F were found to be lower (0.49) when AC was working than the situation when AC was switched off (0.61). Main motive of this study is to measure the equilibrium factor which is an essential term used in the measurement of effective dose due to radon and its particulates inhalation.

R. C. Ramola et al., 2013 [38] studied the radon and thoron levels in the indoor environment of a high background area (HBA) in coastal Orissa. For the measurements calibrated twin cup dosimeters were installed. Author found that concentration and annual effective dose due to thoron were found to be comparatively higher in the area. Radon concentration in the dwellings of selected area ranges from 24 Bqm^{-3} to 98 Bqm^{-3}whereas, thoron concentration ranges from 46 Bqm^{-3} to 689 Bqm^{-3}. The annual effective dose due to radon and thoron progeny was found to vary from 0.70 mSv to 2.84 mSv and 1.16 mSv to 17.36 mSv respectively.

A. Keramatollah et al., 2013 [39] investigated the effects of intake fans, doors and exhaust fans on radon concentration. In the case study single family separated house situated in Stockholm, in direct contact with the ground and built on bedrock in 1975. The house consists of one door & one window, three intake fans and three exhaust fans. A mechanical ventilation system and a CRM (continuous radon monitor) were used in the present study. From the indoor air quality and energy savings points of view, ventilation has two contradictory roles; from the positive point of view it improves indoor air quality (IAQ) and creates the thermal comfort, and from the negative point of view it increases the consumption of energy. This paper outlines the search for a solution to deal with this contradiction. Numerical study shown that the indoor pressure generated by the ventilation systems and infiltration via doors or windows have substantial effects on indoor radon content. The position of vents was found to disturb the indoor radon level and distribution.

B. D. Dung et al., 2013 [40] survey the indoor radon levels in the Ninh Thuan territory where the Vietnam government plans to construct the two nuclear power plants. In the operation, 59 populated locations were investigated using LR-115 SSNTDs for the duration of 1 year and the results show that the maximum value of radon concentration (27 Bqm^{-3}) was found to be lower as compared to other international surveys. This data will act as a background data in the survey after the completion of power plants and provide trustworthy information to the community, living in the surrounding area of the nuclear power plants.

M. S. Khan et al., 2014 [41] reported the measurements of radon, thoron, and their progeny levels in the four villages situated in rural area of district Kanshiram Nagar (Kasganj) in the state of Uttar Pradesh, India. From the observed data authors analyzed that the inhabitants living in this area do not have any problem due to radon exposure. The maximum value of radon and thoron concentration was found to be 72.24 Bqm^{-3} and 84.49 Bqm^{-3} with a GM of 29.49 Bqm^{-3} and 31.20 Bqm^{-3} respectively. The concentration of radon and thoron daughter products ranges from 1.11 mWL to 7.80 mWL and 0.31 to 2.28 mWL respectively. The annual exposure to the inhabitants due to radon and thoron vary from 0.05 to 0.30 WLM. During the same time another study was reported in the north Indian dwellings by Amit Kumar et al.

Kumar and Chauhan, 2014 [42] reported the measurements of indoor radon and thoron concentration in the environment of north Indian dwellings in consort with the radon soil gas underneath the ground using twin cup dosimeters. Measurements show that radon concentration ranges from 17 Bqm^{-3} to 51 Bqm^{-3} and thoron concentrations varied from 9 Bqm^{-3} to 73 Bqm^{-3}. However radon soil gas ranges from 2.80 k Bqm^{-3} to 6.46 k Bqm^{-3}. It was also observed that the indoor radon–thoron concentration and radon soil gas potentially influenced by the geological formations. A good correlation was observed among the indoor radon and thoron levels for mud houses. Authors also report the effect of ventilation rate on the indoor radon–thoron concentration in north dwellings and their correlation with soil exhalation rates in another publication during the same year.

R. P. Chauhan et al., 2014 [43] reported the observations of indoor radon and thoron concentration in selected dwellings of northern India with different ventilation rate using pin-hole based dosimeter. The data was correlated with the exhalation rate observed from the soil samples collected from the respective dwellings. Results from the various dwellings show that the minimum concentration of radon was observed in the storage room while the minimum radon levels were found in the bedrooms and it may be credited to the different ventilation rate but no any inclination was noticed in case of thoron. A weak correlation was observed between indoor radon/thoron concentration and radon/thoron exhalation rates of soils samples. The maximum indoor radon concentrations (97 Bqm^{-3}) were found to be lower than the100 Bqm^{-3} (worldwide average of UNSCEAR).

N. Barros et al., 2014 [44] investigated the radon concentrations at first floor workplaces in Missouri, USA and compared the results with concentrations in above-ground neighboring homes and outdoor locations. However statistically radon concentrations at workplace were not different from, concentration at home and the outdoor places was a poor predictor of the radon concentration at a neighboring workplace. Overall, 9.6%homes and 9.9 % workplaces, exhibited the radon concentrations of $\geq$148 Bqm^{-3}. Because a percentage of workplaces show the prominent radon concentrations, So that to estimate the individual's overall radon exposure an additional survey of workplaces is needed, especially in high radon potential area.

N. Gupta et al., 2014 [45] reported the monitoring of radon, thoron and their daughter product concentration in the 100 dwellings near fly ash dumping sites situated in Faridabad, Haryana, India with the help of LR-115 Type-II SSNTDs. Results show that the radon and thoron concentration at the nearest location to the fly ash dumping site was found to be 76.98 Bqm^{-3} and 39.39 Bqm^{-3} respectively which are below the action levels as recommended by various regulatory bodies. The maximum value of 129.91 Bqm^{-3} was found in a cave inside a temple, situated near to the site where there was no any ventilation. The variations in the observations are because of different ventilation conditions and different house structures. The radon concentration levels were found to decrease with the increase in distance of the dwelling from the fly ash dumping site.

J. Chen et al., 2015 [46] reported a survey of radon and thoron concentrations in approximately 4000 dwellings in the 33 urban cities of Canada. The survey assures that indoor radon and thoron concentrations are not associated with each other and, thoron concentrations cannot be estimated from commonly available radon data. On average, thoron contributes approximately 3% of the radiation dose, from the exposure due to radon and thoron. Estimated average indoor radon concentration (population weighted) is more than twice, the global average radon concentration. It is clear that sustained efforts are essential to further diminish the exposure and effectively reduce the probability of lung cancer caused by radon.

N. Gupta et al., 2015 [47] observed the radon, thoron and their progeny levels in the 100 dwellings around the fly ash dumping sites situated in the Faridabad, Haryana using twin cup dosimeters for duration of 3 months. Observations show that the maximum value of radon and thoron concentration was found to be 133.10±3.05 Bqm^{-3} and 72.23±3.96 Bqm^{-3} respectively. Inhalation dose varied from 0.46mSv/y to 5.21 mSv/y. However annual effective dose ranges from 0.23 mSv to 2.52 mSv. Observations are below the safety levels as recommended by various regulatory bodies. Maximum value of 133.10±3.05 Bqm^{-3} find inside the cave of a temple as there is no ventilation. Variation in the observed data is because of different types of walls, floors and ventilation conditions of dwellings. The concentration of radon decreases as the distance between dwellings and dumping sites increases.

P. Singh et al., 2015 [48] reported a study of radon, thoron and their daughter product concentration in the indoor environment of ninety dwellings of 13 villages of

Tosham region Haryana, India. The dwellings were selected on the basis of different building materials and different ventilation conditions. The measurements were done using LR-115 based single entry twin cup dosimeter and DRPS/DTPS technique. Results show that the maximum concentration of radon and thoron and, the inhalation dose were found during winters and within the safety limits as recommended by ICRP 1993 and UNSCEAR 2000.

A. M. A. Mostafa et al., 2015 [49] reported the behavior of radon daughter products in the indoor environment of Nagoya University, Japan during the five seasons of a year. Radon, thoron and their progeny concentration along with the inhalation dose were estimated in the university and findings show that the maximum dose (0.22 mSv/y) was observed during winters whereas the lowest dose (0.02 mSv/y) was observed during spring season.

M. Yarahmadi et al., 2016 [50] reported the measurement of radon concentration in residential units and at the public spots of city Shiraz, Iran. Observed data was correlated with the type and age of the selected buildings. In the study, CR-39 polycarbonate films (SSNTDs) were used for the period of three months during winters. This study shows that the average indoor radon concentration and average effective dose was found to be 57.6 ± 33.06 Bqm^{-3} and 1.45 mSv/y respectively. The 5.4% of indoor radon concentration in the dwellings was found to be higher than 100 Bqm^{-3}, which is above the level permitted by the WHO. So, it is necessary to take the remedial action at those places, where the radon levels are above the WHO's guideline.

T. Kandari et al., 2016 [51] reported the measurements of indoor radon concentration and their correlation with soil gas and drinking water radon concentration. Measurements were conducted in Rajpur (Dehradun) area located in the vicinity of the geological fault line named as Main Boundary Thrust (MBT). For the measurements RAD-7, a solid state detector was used. Because of tectonically vigorous nature of MBT radon concentration is moderately high in both of the soil-gas and drinking water of the investigated area. The results show that indoor radon concentration has positive correlation with soil-gas radon concentration and drinking water radon concentration. This concludes that soil underneath the houses, building material and drinking water plays a significant role to the indoor radon concentration.

It is also concluded that most of the inhalation dose was received from the ingestion of drinking water and found within the safe limit.

Novikov et al., 2016 [52] reported the estimations of radon concentration by means of Xenon gamma-ray spectrometer for seismic observations of the Earth. This equipment was set up in a seismic research laboratory of the North-Osetian branch of the Russian Academy of Sciences Geophysical Survey (Vladikavkaz). An experiment conducted with this method shows the possibility of its utilization. For the more consistent division of the possible precursors, detailed measurements and placement of more equipment's is needed at the locations of high radon concentration and high seismic activity area. A huge numbers of gamma-spectrometric devices are required to place at the various locations to know the more exact information about the expected time and location of earthquake.

Y. Li., 2016 [53] estimates the radiological hazards due to the building materials used for the construction in Dingxi, China. Estimations were done using gamma ray spectrometry. Results show that the maximum value of activity concentrations due to ^{226}Ra, ^{232}Th and ^{40}K was found to be 64.7Bqkg^{-1}, 46.7 Bqkg^{-1}and 1283.5 Bqkg^{-1} respectively, which are in the limit of soil values of China. Estimations of radiological hazards to the dwellers living in the houses made of materials under study was done with the evaluation of various parameters and authors found that all the parameters are within the safety limit as purposed by various regulatory bodies except the mean absorbed dose rate of sand.

C. Ningappa et al., 2016 [54] measured the radon, thoron and their progeny concentrations at different workplaces of Mysuru, Bengaluru and Kolar districts of Karnataka. For the measurements 60 workplaces were investigated at 10 selected locations using SSNTD technique. Founding's show that the radon Concentration at different work places depends on local geology, types of building materials and ventilation conditions. The maximum concentrations of radon, thoron and their daughter products were found in granite and stone crush industries planted at Jigani, Bengaluru. Workplaces with granite floors show somewhat higher concentration when compared to the workplaces with other floorings. Minimum concentrations were observed in good ventilated workplaces with mosaic floorings. Radon, thoron and their progeny levels decrease as the number of floors increases.

M. Prasad et al., 2016 [55] reported the assessment of indoor radon, thoron and their decay product concentrations in the residences of Uttarkashi and Tehri districts of Garhwal Himalaya, India. In the present study, pinhole dosimeters (LR-115 detector based) and DRPS/DTPS techniques were used for the measurements. The data obtained from these techniques were used for the measurement of equilibrium factors for radon, thoron and their decay products. The equilibrium factor between radon and its progeny during all the seasons was found to be 0.44 (rainy), 0.39 (autumn), 0.39 (winter) and 0.28 (summer), which is dependent on the seasonal changes. In case of thoron and its progeny, the average values of equilibrium factor found to be independent of the seasonal changes i. e. same (0.04) for rainy, autumn and winter season and slightly change (0.03) for summer seasons.

K. Saini et al., 2017 [56] conducted a survey to evaluate the unattached fractions and equilibrium factor of radon and thoron in the different areas of Punjab state, India. For the measurements, direct progeny sensor and Pin-hole based twin cup dosimeters have been used. Results reveal that, the equilibrium factor from radon and thoron was found to vary from 0.15 to 0.80 with an average value of 0.44 and 0.008 to 0.101 with an average value of 0.036 respectively. Highest value of equilibrium factor for radon was found in winters and minimum was found in summer season whereas, maximum value of thoron was detected in winters and rainy season and lowest was detected in summers. Unattached fractions of radon and thoron were found to vary from 0.022 to 0.205 with an average value of 0.099 and 0.013 to 0.212 with an average value of 0.071 respectively. Highest value of unattached fractions was found in winter season and lowest was found in rainy and summer season. Study predicts that, the equilibrium factor and unattached fractions of radon and thoron was found to be dependent on the seasons.

M. R. Usikalu et al., 2017 [57] investigate the radon concentration in fifty dwellings selected in three local government regions of Ibadan, Nigeria. Mud and brick, both type of houses were investigated. For the measurements, a calibrated continuous monitor (RAD7) manufactured by Durridge company was used. Dwellings were selected at a consecutive distance of 100 to 200 m at all the locations. The living room remained closed for the period of measurements. The mean radon concentration measured in Egbeda was found to be 10.54 ±1.30 Bqm^{-3}, in Lagelu was 16.90 ± 6.31 Bqm^{-3} and in Ona- Ara was 17.95 ± 1.72 Bqm^{-3}. The radon concentration at Ono-Ara local government surpassed the recommended limit. Even though, the average value of overall indoor radon concentration was found to be less than the world average value of 40 Bqm^{-3}. Hence, it is necessary to be aware about the danger of radon buildup in dwellings.

O. Meisenberg et al., 2017 [58] investigated the southern Germany dwellings with earthen architecture using different independent measurement techniques to conclude the suitable methods for consistent dose assessment of the dwellers. Thoron as compared to radon comes into the focus recently because of its short half-life. Active but also passive/time integrating measurements of the total concentration of thoron daughter products, established precise and effective methods for the assessment of inhalation dose and exposure from the thoron gas and its daughter products. If the exhalation rate is uniform throughout the house then the exhalation rate measurements are a suitable method for a rough estimation of dose. Pre measurements of exhalation rate of building materials used for the construction purpose can yield the information about the expected exposure to the dwellers. Assessment of unattached fraction of radon and even more of thoron, decay products indicate a somewhat better precision and admire that the unattached thoron is relatively unimportant.

M. Kumar et al., 2017 [59] performed the measurements of radon, thoron and their progeny in 140 houses selected in 25 villages around the Harduaganj Thermal Power Plant (HTPP), India using single entry pin-hole based dosimeter and DRPS/DTPS technique. The data obtained in the process used to measure the inhalation dose and equilibrium factors for radon and thoron. Estimations show that the indoor radon levels were below the limit recommended by the WHO and ICRP. The equilibrium factor for radon was found to be higher and for thoron was found to be lower than the world average level as prescribed by UNSCEAR. The annual effective dose received by the inhabitants living around the HTPP was found to be low as per the recommended limit of 1.25 mSv. It was also noticed that thoron and its daughter products contribute only 26% to the total annual effective dose.

N. Gupta et al., 2017 [60] reported the seasonal measurements of radon, thoron and their progeny concentration in the fifteen multi-storied malls in Delhi National Capital Region (NCR) including district Faridabad, Haryana (India) using LR-115 (type-II) SSNTDs. The average value of inhalation dose was found to be higher at some floors of the malls as compared to the worldwide average value (UNSCEAR, 2000). Annual effective dose was found to be lower at above-ground floors as compared to the lower basements of the malls. It may be because of poor ventilation condition and vicinity of the basements with the ground. The maximum value of annual effective dose (1.13 mSv) was found to be slightly more than the safety limit of 1 mSv/y for general public and hence calls for the remedial measures to be taken to reduce/remediate the levels by proper ventilation, proper sealing of the floors and selection of proper building material.

J. H. Park et al., 2018 [61] develop a model to evaluate the indoor radon concentrations in 196 ground floor residences in Korea using passive alpha-track detectors. The arithmetic mean of indoor radon concentrations was found to be 117.86±72.03 Bqm^{-3} and geometric mean was found to be 95.13±2.02 Bqm^{-3}. Questionnaires were issued to consider the characteristics of each residence, lifestyles of the residents and the environment surrounding the measuring equipment. In addition to this, national data on indoor radon concentrations was reviewed at 7643 separate houses for 2011-2014 to conclude radon concentrations in the soil. To estimate the ventilation rates, wind speed and meteorological data on temperature were utilized. The ventilation rates and radon exhalation rates estimated from the soil was fond to be 0.18 to 0.9/hr and 326.33 to 1392.77 $Bq/m^2/hr$ respectively. To measure the indoor radon concentration the developed model with the estimated results was applied to the randomly selected 156 houses out of 196 houses and the results found in better consistency for Gyeonggi and Seoul provinces of Korea except to some residences of low concentration. This model and method is not specific to a particular site, rather it can be applied to other residences and have wider applications.

L. Vimercati et al., 2018 [62] evaluate the radon exposure to health care workers of the university hospital in Bari (Apulia), Southern Italy, constructed on the base of calcarenite of gravina (clastic rock) formed almost of calcium carbonate. For the measurements 401 samples were selected at 28 different buildings using passive technique with the CR-39 detector. Authors found that the radon concentration was ranges from 6.5 Bqm^{-3} to 388 Bqm^{-3} with an average of 48 Bqm^{-3}.The average value of radon concentration in total of 76.1% investigated environment, was below than the WHO reference level (100 Bqm^{-3}) however 0.9% were higher than 300 Bqm^{-3}. Most of the workplaces were reported within the reference level recommended by WHO and risk to the workers can be considered as low.

D. Shikha et al., 2018 [63] reported investigation of indoor environment of Union Territory Chandigarh to estimate the integrated radon, thoron and their progeny concentration using pin-hole based dosimeter loaded with LR-115 SSNTDs. Results shows that indoor radon concentration ranges from 24.2±1.1 Bqm^{-3} to 62.1±3.1 Bqm^{-3} and thoron concentration was found to be ranges from 3.0±0.1 Bqm^{-3} to 99.2±4.9 Bqm^{-3}. The annual inhalation dose 1.9 mSv received by the populations of these residences is within safe limits. The soil and the construction material also play a vital role in the indoor air quality. Thus, the radon exhalation rates were measured in some soil samples collected from the study area using the active technique and a positive correlation was observed between the radon exhalation rate and the indoor radon levels.

M. Zhukovsky et al., 2018 [64] reported the survey that includes the review of 63 national and provincial indoor radon levels in kindergartens and schools. Primary estimation of the worldwide population weighted characteristics of radon levels in children's institutions reported that the arithmetic mean was 59 $Bqm^{-3}$and geometric mean was 36 Bqm^{-3}. Elevated concentrations of indoor radon gas in children's institutions in comparison with the residences can be described by the characteristics of reduced ventilation rate during night hours, attendance system and construction features. Special procedure is required for the measurements in the kindergartens and schools.

From the above stated data, now it is well-known that exposure to high concentration of radon, thoron and their decay products causes lung disorder and second leading cause of lung cancer after smoking. Therefore, it is necessary to estimate the radon, thoron and their progeny levels in the environment of dwellings and workplaces i.e. uranium mines, thermal power plants, refineries, LPG bottling plants, underground stores, schools, banks, multi-storied malls, building and offices etc. A number of active or passive methods and techniques are reported in the literature. Nikolaev and Ilic, 1999 concluded that cellulose nitrate (LR-115) is frequently used detector for the radon measurements in the outdoor as well as indoor environment and still used commonly as stated in literature. In a study during 2017, O. Meisenberg reported that, passive/time integrating measurements established accurate and effective methods for the assessment of inhalation dose and exposure from the radon, thoron and its daughter products. In the present study, LR-115

SSNTDs were used in the twin cup dosimeters: a passive/time integrated technique for the indoor assessment of dwellings and workplaces of Southern Haryana, India.

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CHAPTER-III

EXPERIMENTAL TECHNIQUES

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3.1. INTRODUCTION

Radon a leading cause of lung cancer is known as the largest contributor to the radiation exposure that takes place at home and at workplaces. From literature, it is evident that most of the observations are based on the measurements of radon exposure at homes. Traditionally, radon was a problem only for underground workers such as mines, but nowadays a lot of literature is available which justify above ground workers also have high radon level risk. So, it is necessary to estimate the radon health risk (lung cancer) to the general population at their homes and at their workplaces. A number of techniques and instruments are available for the assessment of radon, thoron and their progeny concentrations in the environment of homes and workplaces. Every instrument has their own advantages and disadvantages at the different situations. Maximum of these techniques are based on the detection of alpha particles emitted from the radioactive decay of radon, thoron, and their progenies, whereas some are aimed at the detection of beta and gamma emission. In the case of decay products, Potential Alpha Energy Concentration (PAEC) is measured in terms of working level (WL). Techniques for the radon, thoron and their decay products measurements can be categorized as i.e. active techniques and passive techniques. Active techniques are the short term measurements, require minimal labor and power supply for the operation. Whereas passive techniques are time integrated (long-term) techniques and do not require the power supply for the operation [1].

3.2. ACTIVE TECHNIQUES

Active sampling involves the use of an air sampling pump to actively pull air through a collection device such as filter. This technique requires an electrical power supply for the necessary operation. Active measurements can be done with Grab sampling process and continuous monitoring process for radon, thoron and their progeny concentration.

3.2.1. Grab sampling techniques

In this process radon (^{222}Rn) concentration is estimated in discrete samples of air and water collected at a particular location over a short period of time. The grab sampling technique (active), provides prompt measurements of radon and its progeny [2]. Some grab sampling techniques are

(i) Double Filter Method

Double filter method, is a cylindrical tube has been made up of metal and fitted with high-efficiency filters at both the ends of the cylinder. The volume of the cylinder varies from 0.5 liter to 1000 liters. In this method, air is drawn in the cylinder through the inlet filter paper that removes the radon daughters from the sampled air [3-4]. The sampling time depends upon the flow rate of air and typically it is about 5 minutes to half an hour. Air sampled in the cylinder again produced radon/thoron daughter products during its passage from one end to the other end of the tube and collected at the second filter paper fitted at the exit point. The alpha activity at the exit filter paper measures the radon/thoron concentration. Double filter cylinder, with large volume and detection limit of 0.7 Bqm^{-3} are used for the environmental purposes.

(ii) Scintillation cell

Scintillation cell was first introduced by Henry F. Lucas in 1957 and commonly it is known as Lucas cell or scintillation flask [5]. It is the oldest method used for grab sampling of radon and its particulates. The scintillation flask is a glass or plastic container and its size ranges from 0.09 liter to 3.0 liter. The inner side of the flask is coated with the scintillation material ZnS (Ag) (silver activated zinc sulfide powder) [6]. The bottom side of the flask is usually transparent and coupled with PMT (photomultiplier tube) [7]. For measurements, radon gas sampled in the flask and once the flask is filled radon decays further inside the flask and produced alpha particles and these alpha particles interact with the scintillating material and produced photons or light pulses in the range of the visible spectrum. These pulses will be amplified and counted with the help of photomultiplier tube [8]. These flasks can be reused for years with proper handling and after the cleaning with nitrogen gas [6].

Grab sampling techniques are very simple, low cost and require minimal labor. These techniques are suitable for large-scale measurements. The disadvantage of these techniques is that they do not provide the precise information on the time-averaged value of radon concentration in dwellings, and measurements vary widely depending upon the various aspects, therefore, grab sampling techniques mainly used in the monitoring of the industrial area.

3.2.2. Continuous Monitors

Various types of instruments are available in the market for continuous radon concentration measurements. Most of them are designed to detect only alpha radiations because; it is a tedious job to construct a portable detector (low background and high sensitivity) for beta and gamma radiations detection. Presently, three types of detectors are in use to detect alpha radiations: Ionization chambers, Solid state alpha detectors, and Scintillation cell

(i) Ionization chamber

The ionization chamber is a portable continuous monitor and designed to identify the existence of an ionizing particle [9-11]. In the chamber, an electric field is applied between the electrodes. Then air is allowed to pump inside the chamber through a filtered area. When radon gas diffuses into the chamber, then alpha particles will be emitted during the decay of radon atoms, and these alpha particles ionize the air inside the chamber and produce a burst of positive and negative ions in the chamber. Ionization caused by the disintegration of radon and its particulates will be recorded as the electrical pulses for each alpha particle separately [12]. The response time of the ionization chamber depends upon the rate of renewal of the sampling air in the chamber. In the ionization chamber, the pulses registered due to radon and its daughter products can be distinguished separately but this technique can be used only for the measurement of low-level radon concentration.

(ii) RAD7

The RAD7 is a continuous monitor and it uses the solid-state alpha detector to detect the alpha particles. RAD7 a solid state semiconductor device (usually silicon), is advantageous because of its ruggedness and its ability to determine the energy of each alpha particle electronically [13]. RAD7 change the energy of each alpha particle directly into an electrical signal which helps to convey precisely which isotope (polonium-218/polonium-214) produced radiations. This makes it possible to distinguish the old radon from the new one, radon from thoron and signal because of noise immediately [14]. RAD7 is a high-quality alpha detector.

RAD7 pulls the air sample through the fine inlet filter, which eliminates the decay products to diffuse into the chamber. Radon decays further in the chamber and produced polonium isotopes after the emission of an alpha particle. The RAD7 internal sample cell is glazed on the inside surface through an electrical conductor. A solid-state, ion implanted, silicon alpha detector is at the center of a 0.7-liter hemisphere [15]. The high voltage power charges the conductor up to a potential of 2000 V to 2500 V and create an electric field throughout the volume of the cell [16]. The electric field drives the positively charged particles onto the detector.

When radon-222 decays it emits an alpha particle and leaves its transformed polonium-218 nucleus, as a positively charged ion. This positively charged ion is drifted to the detector with the electric field generated within the cell [17]. Now, because of short half-life, polonium-218 decays further at the surface of the detector where it sticks and emits an alpha particle. This alpha particle has fifty percent probability to enter the detector and producing an electrical signal. The strength of this electrical signal is proportional to the energy of the alpha particle. Subsequently further decays produce beta particles, which cannot be detected. Different isotopes produce different signals of varying strength proportional to the different alpha energies. After amplification and filtration, RAD7 sort the signals according to their strength [18]. RAD7 is an efficient instrument and it can identify one isotope (radon) in presence of another isotope (thoron) without their interference, because of its ability to distinguish the isotopes on the basis of their different alpha energy. In sniff mode, RAD7 estimate the radon concentration by polonium-218 and thoron concentration by polonium-216 [19]. This device registers the radon and thoron concentration after a pre-set time interval, automatically with the help of its LCD display. These readings can be printed with the help of a printer attached to it.

(iii) Scintillation cell

In the last fifty years, scintillation cells of different shapes and size have been designed for the estimation of radon and thoron concentration. The inner side of this cell is coated with a scintillating material, ZnS (Ag) i.e. silver activated zinc sulfide phosphor [20]. One side (bottom side) of scintillation cell is coved with a transparent glass window which is coupled with a photomultiplier tube (PMT) and ultimately connected to the counting system [21]. During the process, sample gas (radon/thoron gas) is introduced in the cell through filter paper, which prevents the entry of radon daughter products and other airborne radioactive particulates. Inside the vessel, radon daughter products will be formed from the sample air due to alpha disintegrations and later on short-lived daughter products will come in secular equilibrium with parent radon gas and give constant count rate. The light pulses will be produced when alpha particles in the cell interact with the zinc sulfide coating [22-24]. These light pulses pass through the transparent window and collected, amplified and recorded by the photomultiplier tube and their associated electronic equipment's. Scintillation cell will act as a continuous monitor if the air is pumped continuously into the cell. The number of pulses will be proportional to the concentration of radon gas filled in the cell.

3.2.3. Scintillation Based RnDuo (Smart Radon/Thoron) Monitor

Radon duo (RnDuo) is a continuous radon/thoron monitor. Technologically, it is an advanced method and portable also. It is designed by Bhabha Atomic Research Centre, Trombay, Mumbai, India for numerous applications in the studies of radon and thoron measurements [25].

(i) For Radon Measurements

For the measurement of radon, the sample gas is diffused into the scintillation cell with an active volume of 153 cm^3. During the diffusive flow, first of all sample gas passes through the "progeny filter" which eliminates the radon and thoron particulates and then pass through the "thoron discriminator" that is based on "diffusion-time delay", which prevents the entry of short-lived (55.6s) thoron (^{220}Rn) to pass through the scintillation cell. In RnDuo monitor, radon measurements depend on the detection of alpha particles emitted from the radon and it's decay products that produced inside the scintillation cell ZnS (Ag) [26]. The alpha scintillations produced in the cell due to radon and its particulates are counted continuously by the photomultiplier tube (PMT) and the associated electronics used for counting. Due to the varying concentration of radon in the cell, it is complicated to maintain the equilibrium between the radon and its decay products produced in the cell and because of this, automated continuous radon monitoring is not possible without evaluating the decay product activities. A pleasant algorithm based on the theoretical decay and growth of radon decay products is intimated in the system for the continuous measurements of radon concentration. The alpha particles obtained further processed by the microprocessor to display the radon concentration [27].

(ii) For Thoron Measurements

For the measurement of thoron, gas is collected in the cell (153 cc) by flow sampling using the inbuilt pump. During the sampling, gas will pass through the "progeny-filter" which prohibits the entry of radon and thoron daughters into the cell [28]. The inlet filter is unable to filter the radon gas and hence the sample gas may contain the radon gas. During the initial part of each ongoing cycle, a total number of alpha counts from radon, thoron and their decay products will be registered. During the latter part of every cycle, only the radon and background activity will be counted, because the sampling pump will be switched off automatically and after the five minutes thoron gas (half-life 55.6s) will be decayed sufficiently. The thoron concentration can be calculated by the difference between these two counts.

Smart RnDuo is an important technique because the measurements with the scintillation cell are not affected by the humidity. The detection limit of SMART Rn Duo lies between '8 Bqm^{-3} and 50 $MBqm^{-3}$'. So, It can be used for indoor/outdoor radon estimations in air and water also [29]. It can be used for radon survey in U-mines, seismic sites and at other geological regions but we cannot use this technique for time-integrated measurements.

3.3. PASSIVE TECHNIQUES

In passive sampling, airborne gases and vapours are collected by a physical process such as diffusion or permeation through a membrane. Passive techniques are time integrated techniques that provide integrated radon (^{222}Rn), thoron (^{220}Rn) and their daughter products concentration for a long period of time [30-31]. Passi' techniques are most reliable techniques because they provide the cumulative effect o. all the seasons during a calendar year, changing the weather and climatic conditions on the radon, thoron and their progeny concentration in the indoor environment (homes as well as workplaces). Lung cancer, after the effect of radon exposure, is associated with long-term measurement so it is necessary to estimate the radon levels for a long period of time. These techniques are favorable because they conclude the annual average radon concentration and do not require any electrical power supply for the necessary operation. Several passive techniques are reported in the literature and some of them are

3.3.1. Charcoal Canister Technique

Charcoal Canister Technique is used for the detection of radon because the activated charcoal is a good absorber of radon [32]. When sample air passes through the activated charcoal then the collected radon can be measured. This is a small sized, sealed the flat container with a dimension of the order of 10 cm filled with 25-100 g activated charcoal. This device which is filled with activated charcoal and used for the radon measurements is known as "Charcoal Canister".

The canister should be opened to allow the sample air to diffuse into the charcoal canister. The exposure time should not be less than two days (placed typically for 2-7 days) at 20 inches above from the surface of ground [33]. During sampling, radon will be trapped by the charcoal and this trapped radon decay further and deposit their progenies on the charcoal [34]. The radioactive material collected in the charcoal can be measured by gamma spectroscopy. This technique is not appropriate for a long time period because the collected radon will decay and cannot reconstruct its results even at same experimental conditions and at the same location.

3.3.2. Electret Ion Chamber

Electret radon monitor is a reliable technique for the investigators working in the field of radon concentration measurements [35-37]. It is a dielectric material that reveals the permanent electrical charge. This charge produces the electrostatic potential which is capable to collect the ions of opposite sign and drops the total electret potential [38]. Electret radon monitor is a steel chamber. The inlet filter restricts the entry of radon daughters into the chamber and allows the radon gas to diffuse into the chamber. Radiations will be emitted when radon decays further inside the chamber. These radiations ionize the gas inside the chamber volume [39-40]. The negative ions produced will be collected by the positive electret inside the chamber. Thereafter the resulting potential of the Electret is measured by a shutter method using equipment which is lightweight and battery operated [41-42]. P. Kotrappa 1983 mentioned the several advantages of Electret Dosimeter and mentioned its ability to store the information for a long period of time [43]. This technique is independent of environmental humidity.

3.3.3. Thermo-Luminescence Detector

Thermo-luminescence is a phenomenon in which electrons emit the stored energy in the form of light when they jump from higher energy state to ground state when they heated [44-45]. In this process when the crystal is irradiated to the ionizing particles then energy transferred to the electrons shift them from valence band to the conduction band. As a result, holes will be created in the valence band and electrons are free to move in the conduction band. Some of these ejected electrons get trapped in the defects of crystal and settled there in a stable position. If this crystal is heated, the energy imparted to the electrons eject them from traps and recombine with the holes present in the hole traps. Photons in the form of light will be emitted in the process of recombination of electron and hole at hole trap. At that time hole trap is known as recombination center [46].

Thermo-Luminescence Detectors are sensitive to the alpha particles and successively used for the radon measurements [47]. After the exposure, the retrieved detectors will be analyzed and photomultiplier tube (PMT) converts them into an electrical signal [48].

3.3.4. Track Etch Technique

This is a passive technique used worldwide for the radon, thoron and their progeny measurements over a long period of time [49-59]. In this technique, when ionizing particle transverse through an insulation material they transfer their energy to the electrons and produced a trail of the damaged molecule at the atomic scale (about 30 to 100 Å), known as "Latent Track". These tracks because of their small size are not visible with naked eye. These tracks can be enlarged with the chemical etching method using a suitable etchant solution. During the chemical etching process, the damaged portion will be etched at a faster rate than the undamaged portion and tracks become enlarged. These enlarged tracks can be viewed with the help of an optical microscope [60-61]. The exact changes occur at the site of damaged trail depends upon [62]:

1. Density and chemical structure of detector material.
2. Charge (Z) and the velocity of the incident particle.
3. Environmental conditions (temperature and pressure).

4. Various factors in the etching process e.g. normality, time and temperature of chemical etchant used for the etching process.

Solid State Nuclear Track Detector (SSNTD) is a widely used passive technique for time integrated monitoring in the indoor environment where the radon level is very low [63-64]. This technique is inexpensive and easy to use. Some significant features of tracks are as follows [65]:

1. The damaged trail or region of tracks is composed of displaced atoms rather than electronic defects. The tracks formed in this process are stable.
2. Tracks can be formed in insulating materials only. There is a correlation between the track formation and electrical resistivity of the material as shown in table 3.1. Only those materials whose resistivity is more than 2000 ohm-cm can store the tracks.

Materials	**Electrical Resistivity range (Ohm-cm)**
1. Track forming	
(a) Insulators	10^6–10^{20}
Silicate materials, Alkali halides, Insulating glasses and Polymers	
(b) Poor insulators: MoS_2	2×10^3–25×10^3
(c) Semiconductors: V_2O_5 glass	2×10^3–20×10^3
2. Non-track forming:	
(a) Semiconductors:	$10 - 2 \times 10^3$
Germanium (Ge), Silicon (Si)	
(b) Metals:	10^{-6}–10^{-4}
Aluminum (Al), Copper (Cu), Platinum (Pt), Tungsten (W) and Zinc (Zn)	

Table 3.1. Co-relation between Electrical resistivity and track forming/non-track forming materials [66]

3. The damaged region is very narrow of the order of 10 nm or less and its length is same as the penetration depth of the charged particle transversing through the medium.
4. Tracks will not be formed unless the energy dissipated by the charged particle does not exceed the critical value. For a different type of detectors, this value is different.

3.4. ORIGIN OF SOLID STATE NUCLEAR TRACK DETECTOR TECHNIQUE

The science of Solid State Nuclear Track Detector Technique was originated in 1958 when D. A. Young reports his first observation at British Atomic Energy Research Establishment (AERE), Harwell, England. Young was the first who observed the etch-pits in a thin film of LiF crystal [67]. Later on, these etch-pits were known as "tracks". He observed that the LiF crystal which was at a distance of 1mm from the uranium oxide film damaged due to the fission fragments of uranium nuclei. The damaged portion is chemically more reactive than the undamaged portion [68-69]. Later on after a year, E. C. H. Silk and R. S. Barnes in (1959) reported the formation of tracks in thin mica sheet [70]. They observed that the fission fragments of ^{235}U damages the mica sheet and the damaged trail can be seen under the Transmission Electron Microscope (TEM). But the tracks formed on the mica sheet were not permanent or stable and fade out after some time under the effect of the electron beam of TEM. Up to 1962, these papers remain unnoticed and then P. B. Price and R. M. Walker (1962a) working at General Electric Research and Development Centre (GERDC), Schenectady, New York carry forward the work let off by Silk and Barnes[71]. They also observed the tracks in mica [72-73]. Soon after some time, Fleischer joined their group and the team of scientists gives a new discipline in the field of SSNTDs. They report the formation of tracks in crystals of rocks due to the spontaneous fission fragments of uranium (^{238}U) present in the crust of various rocks. They also mentioned that track formation is a general phenomenon and they can etch with a suitable etchant. These tracks can also be observed in glass and plastics [74-75]. Price, Walker, and Fleischer as a team did intense work and developed a new field of Solid State Nuclear Track Detectors (SSNTDs) known as "Trackology". On the behalf of a wide range of applications and useful features of

SSNTDs, it can be concluded that hardly any area of science and technology is growing where SSNTDs does not have its potential applications [76].

In the time integrated passive technique, Solid State Nuclear Track Detectors (SSNTDs) exposed under the normal conditions, estimates the radon, thoron and their decay products concentrations. In the present study, SSNTDs were used for the measurements of radon, thoron and their progeny concentrations in the indoor environment. Though a number of detectors are available, mainly two types of detectors are in use for the measurement of radon, thoron, and their progeny concentration.

(i) CR-39 detector manufactured by Pershore Mouldings Limited, Worcestershire, England [77].

(ii) LR-115 Type II detector manufactured by Kodak Pathe, Dosirad Company, France [78].

3.4.1. CR-39 Detector

CR-39 or (Allyl-diglycol Carbonate) is very sensitive and versatile detector and it is abbreviated as Columbian Resin-39 [79]. General formula for CR-39 is ($C_{12}H_{18}O_7$) [80]. After a number of researches and laboratory experiments, it is concluded that CR-39 is a desirable Solid State Nuclear Track Detector [81]. It is widely used for the detection of alpha particles with an energy range of 1-60 MeV and proton with an energy range of 10 MeV [82-83]. Track efficiency of the CR-39 detector can be modified with its processing conditions i.e. type of etchant, temperature and etching time [84-85]. Although it is comparatively stable for environmental conditions but cannot be used for the environmental radiological assessments because of its relatively high threshold energy.

3.4.2. LR-115 Detector

The LR-115 plastic track detector used for the radon and thoron measurements is a thin film of cellulose nitrate manufactured by Kodak-Pathe, Dosirad co., Vincennes, France. Its chemical composition is {$(C_6H_8O_9N_2)_n$} [78, 86]. The structural formula of cellulose nitrate LR-115 plastic track detector is shown in Figure 3.1. The LR-115 plastic track detectors are available in two type's i. e. LR-115 Type I and LR-115 Type II detectors. The LR-115 Type II detectors are common and used for the radiological assessment in the ambient air [87]. In the present study, LR-115 Type II (peelable) plastic track detectors have been used to register the tracks due to alpha charged particle emitted from radon and thoron present in the ambient air. It is deep red colored 12 μm thin alpha sensitive layer deposited on 100 μm thick non-etchable and insensitive polyester base as shown in Figure 3.2. LR-115 Type II film is sensitive to those alpha particles emitted by radon and thoron in the surrounding environment which are in the energy range of 1.7 MeV to 4.8 MeV. They can be used to register the tracks of the proton with energy less than 100 KeV [88-89]. In LR-115 Type II plastic track detectors, 4.8 MeV is upper threshold energy that produces the tracks on the surface. LR-115 does not register the tracks due to alpha particles having a high threshold energy (6.0 MeV from ^{218}Po and 7.68 MeV from ^{214}Po) [11, 90].

H. Nakahara et al. 1980 and A. Damkjaer 1986 determined that the detection efficiency is about 50 percent for energy range between 1.5 MeV and 4.8 MeV at normal incidence [91-92]. LR-115 films are insensitive to electrons, gamma ray, X-ray, Ultraviolet or IR rays (radiations in the electromagnetic spectrum). Thus it can be utilized without any risk in presence of such types of ionizing radiations [93].

The track etching behavior of LR-115 plastic track detectors has been studied at different normality, time and temperature. The best etching condition recommended is 2.5N NaOH solution at 60°C for 90 minutes. The tracks of alpha particles produced on LR-115 films at etching condition of 2.5N NaOH solution at 60°C for 90 minutes are shown in Photograph 3.1.

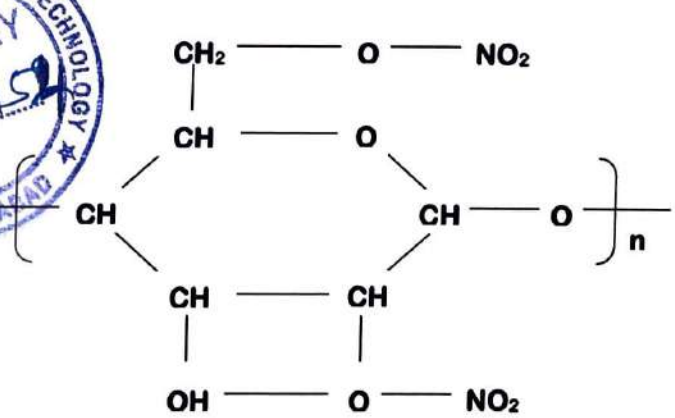


Figure 3.1: Structural formula of Cellulose Nitrate LR-115 plastic track detector

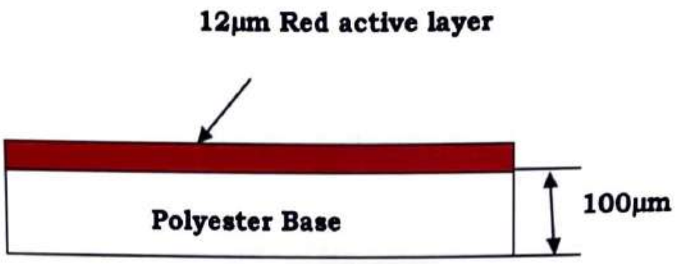
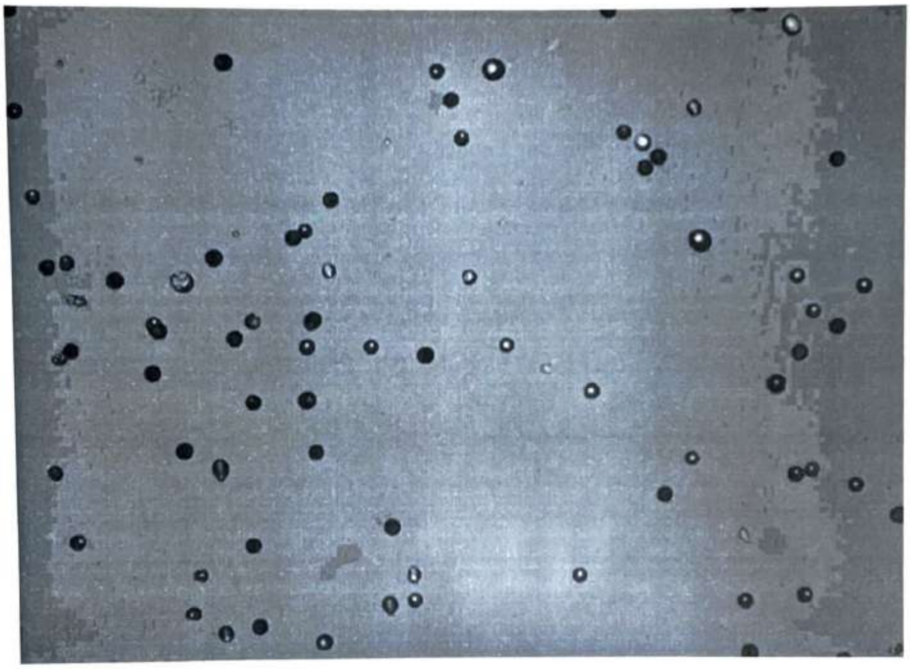


Figure 3.2: LR-115 Plastic track detector



Photograph 3.1: Tracks produced by alpha particles in the LR-115 film

3.5. ADVANTAGES OF SOLID STATE NUCLEAR TRACK DETECTORS (SSNTDS)

Many useful features of SSNTDs make them advantageous over other detectors like the bubble chamber, Spark chamber, nuclear emulsion and semiconductor detectors etc. Some of the advantages of Solid State Nuclear Track Detectors are [94-95].

1. These detectors are reasonably priced and available in various sizes as per requirement.
2. These SSNTDs are sensitive to high LET (Linear Energy Transfer) but unaffected to X-ray, beta, gamma and UV rays etc.

3. The tracks formed in Solid State Nuclear Track Detectors are stable and permanent. These detectors can be stored for a long period of time because they are neutral to the environmental affairs like temperature, pressure, and humidity etc.
4. Chemical etchants required (NaOH and KOH) for the etching process to reveal the tracks are simple and easily available.
5. High efficiency and sensitivity can be obtained when they placed in direct contact of the source.
6. The geometric flexibility of these detectors makes them useful for angular distribution measurements.
7. These detectors are safe and do not pose any health issue so that they can be used for the indoor assessments of radon and thoron concentration.
8. These are passive detectors so do not require any electrical power supply.

3.6. TWIN CUP DOSIMETER

Several methods have been developed for the measurements of radon, thoron and their progeny concentrations in the environment. Initially, the methods were developed during the studies, related to the health issues of uranium mine workers [96-97].

For the measurements of indoor radon and thoron concentrations, Solid State Nuclear Track Detectors (SSNTDs) loaded in twin cup dosimeters can be used [98-102]. In the present investigations, LR-115 Type II plastic track detectors were used for the estimations. These detectors are manufactured by Kodak Pathe, France under the trade name of LR-115 whose sensitive layer is 12 μm thick [68, 103]. BARC type Twin Cup Dosimeter used for study shown in Photograph 3.2 and arrangement of LR-115 type II detector in the pieces of 2.5 × 2.5 cm, filter paper, and semi-permeable membrane in twin cup dosimeter is shown in figure 3.3.

Photograph 3.2: Twin Cup Dosimeter used in Present Study

These dosimeters have two chambers of equal size with the central partition and length of each chamber is 4.5 cm whereas the radius is 3.1 cm [104]. The LR-115 type II detectors were exposed in three different modes as follows:

1. Membrane mode
2. Filter paper mode and
3. Bare mode

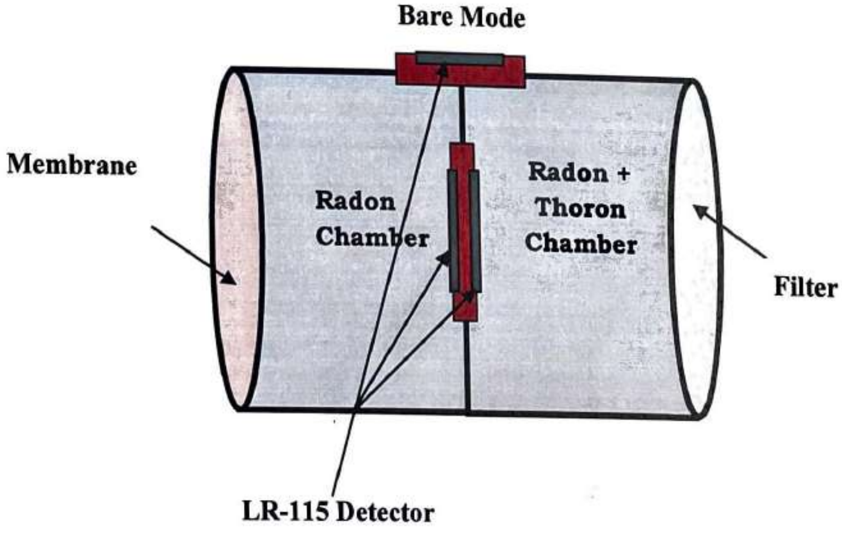


Figure 3.3: Schematic arrangement of twin cup dosimeter

The LR-115 Type II films cut into the pieces of 2.5 × 2.5 cm were placed inside both the chamber (Filter paper mode and Membrane mode) and one is placed outside the cup at bare mode. Radon and thoron concentration in Bqm^{-3} and Potential alpha Energy concentration (PAEC) of individual progeny in terms of working level (WL) units can be estimated with the exposure in these three modes.

In membrane mode, detector is placed inside the chamber, and a 25 μm thick semi-permeable membrane have permeability constants in the range of 10^{-8} to 10^{-7} cm^2s^{-1} made of latex or cellulose nitrate sandwiched between the two filter papers is placed in the lid of the chamber [103, 105-106]. This set up of the membrane allows only the radon gas to diffuse inside the chamber and suppress the entry of thoron gas. So, in this mode SSNTD-1 can register tracks only because of radon gas.

In filter mode, the lid of the chamber is covered with filter paper only. This filter paper allows both the gases (radon and thoron) to diffuse inside the chamber. So, in this mode SSNTD-2 register the tracks due to both (radon and thoron) the gases [102].

SSNTD-3 placed in the bare mode register the alpha tracks due to radon, thoron and their progenies also. The Twin Cup Dosimeters fully loaded with LR-115 Type II detectors were exposed for three months (90 days) at the locations under study. In the indoor environment, the dosimeters should be installed at those locations which are at a minimum distance of 10 cm from any surface or wall. During the exposure, detectors will register the alpha tracks for radon, thoron and their progenies in their respective modes. After the exposure for three months, the detectors were retrieved from the dosimeters and etched in 2.5N NaOH solution at 60°C for 90 minutes using constant temperature bath. After etching detectors were rinsed under cold running water and stripped from their thick polyester base. Now, the remaining thickness of the sensitive layer of the film is 7-8 μm. The etched tracks were counted using the spark counter. The process of exposure was repeated for successive three months during all the four seasons of a year to complete the annual study.

3.7 CONSTANT TEMPERATURE BATH

Constant temperature bath is a common technique used for the etching of alpha tracks on the SSNTD films which are exposed to the environment containing radon and thoron [107]. For the accurate and reliable results, time, temperature and concentration of the etchant used should be steady and controlled during the process of etching. In the present study, model PSI-CTB1constant temperature bath is used. It is a double walled water bath with three etching vessels of dimension 15 × 7 × 15 cm (l × w × h). In this design 30 SSNTD films can be etched in one cycle. It is excellent equipment with an electronic temperature controller with temperature consistency of 0.5°C (Polltech Instruments Pvt. Ltd. Mumbai). The electronic timer is also available to set the specified time required for the etching process and beep facility to alert the time have been completed. The constant temperature bath used in the present study is shown in Photograph 3.3.

Photograph 3.3: Constant Temperature Bath

3.8 SPARK COUNTER

Spark counter is specially designed counter which is most successful, inexpensive and worldwide technique [23]. Spark counter is an automatic and fast instrument used to count the alpha tracks on LR-115 films. Cross and Tommasino (1970) invent the spark counting technique which is discussed in a number of research publications [99, 108-110].

In the present study, PSI-SC1 model is used as shown in photograph 3.4. The uncertainty of this instrument is only 0.1%. In this instrument, one can set the pre-sparking and sparking voltage and a serial communication port is also provided to transfer the data to a PC. Its data storage capacity is up to 500 samples (Polltech Instruments Pvt. Ltd. Mumbai). The spark head assembly associated to spark counter has two electrodes where one electrode is known as spark head of area 1cm^2 and another electrode is grounded and a heavyweight counter that helps to hold the detectors tightly.

Photograph 3.4: Full view of Spark Counter

A block diagram of spark counter is shown here in Figure 3.4. The thin etched detectors (about 8μm thick) placed between the two electrodes of spark counter forms capacitor [111]. The aluminized Mylar film is placed on the detector in such a manner that metal face is in contact with the thin film and the grounded detector also. Heavyweight counter with a transparent window placed on the Mylar film to ensure the contact between the thin detector and the electrodes.

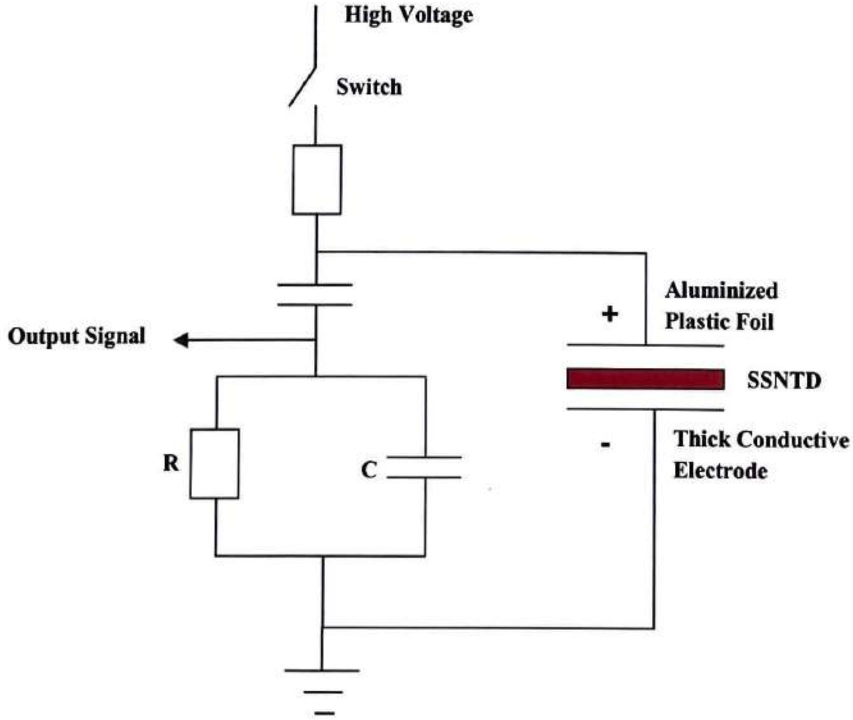


Figure 3.4: Block diagram of Spark Counter

As operating voltage is applied across the counter, it burns the aluminized Mylar film placed on the detector and produced a spark which can be observed from the window of heavyweight counter [112]. This spark takes place across the track-hole will not pass through the same hole again. In the same manner, the spark will jump one by one from one hole to another. Spark counter automatically counts the number of holes that are created on the LR-115 film. The mylar sheet is a vivid replica of counted holes. Counting efficiency of this instrument is approximately 95±5% as compared to the other optical instrument.

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CHAPTER IV

SEASONAL VARIATIONS OF RADON, THORON AND THEIR PROGENY CONCENTRATION IN THE DWELLINGS NEARBY FLY ASH DUMPING SITE AND HIGH RISE BUILDINGS IN FARIDABAD, HARYANA, INDIA

CHAPTER IV

SEASONAL VARIATIONS OF RADON, THORON AND THEIR PROGENY CONCENTRATION IN THE DWELLINGS NEARBY FLY ASH DUMPING SITE AND HIGH RISE BUILDINGS IN FARIDABAD, HARYANA, INDIA

This chapter includes the results of radon, thoron and their progeny measurements in dwellings of southern Haryana. Two case studies have been reported in this chapter. In first case study, results have been calculated in the dwellings nearby fly ash dumping site situated in Faridabad, Haryana and in second case study results have been reported for the dwellings of high rise buildings situated in Faridabad, Haryana. Both the case studies were performed during all the four seasons of a calendar year and during each season of individual case study, radon and thoron concentration, Potential Alpha Energy Concentration (PAEC) due to radon and thoron progeny, exposure due to radon and thoron progeny, inhalation dose and effective dose have been calculated and reported in this chapter. In addition to this, annual exposure due to radon and thoron and annual effective dose for the dwellers of both the case studies have also been calculated and reported in this chapter.

4.1 CASE STUDY-I

In this case study the results are incorporated for the dwellings nearby fly ash dumping site situated in Faridabad, Haryana during all the seasons of a year from January 2013- January 2014.

4.1.1 Introduction

In recent decades due to growing population, demand for industrialization increases all over the world. Apart from the need of industrialization, there is a negative impact of increasing population on the global environment and social life [1]. Most important after effect of these global processes is the generation of large quantities of industrial waste. In order to fulfill the growing demand of electricity, coal based thermal power plants are widely used all over the world and play a dominant role in future also [2-4]. Coal is largest contributor for electricity generation to the worldwide demand of energy [5]. In India, coal based thermal power plants contribute approximate 70% of the total power generated [4, 6-9]. Coal comprises the naturally occurring radio nuclides from K-40, uranium and thorium. Thermal power generation through coal combustion produces tiny particles of ash and commonly known as coal ash that causes serious environmental hazards.

Coal ash is technologically important material generated during the combustion of coal in thermal power plants [10]. Most of the coal used in India is of bituminous type and it produces huge amount of ash because it has high ash content approximated (35%- 45%) and low calorific value (3500 kcal/kg – 4000 kcal/kg) [4, 11-13]. It consists of fine particles with small size ranging from 120 micron to less than 5 micron. Coal produced two types of ashes i. e. fly ash and bottom ash that deposits under the boiler [12]. The release of fly ash from chimney to the surrounding environment can be controlled by particular devices such as electrostatic precipitator (ESP) and scrubber etc. [10] but bottom ash, a solid waste product of coal based thermal power plant deposited under the boiler is not properly managed and disposed outside the plant premises [14].

In future, upcoming demand of energy increases the production of coal ash and it cannot be ignored. So, there is no any alternate to handle the ash safely except disposal and its utilization [15]. In both the case i. e. disposal or utilization, attention have to be taken for the surrounding environment, human life and wild life as it can easily contaminate the air and ground water [16]. In India "Fly Ash Mission of Government of India" put a number of efforts for the safe disposal and utilization of fly ash on continuous basis. Due to the grateful efforts of Fly ash mission, it becomes an acceptable material for the society and now days, it can be used in agriculture, building materials, road construction materials, mine fills and metallurgy etc. [15]. In India, ash utilization is 38% but it is comparatively less than the other countries such as USA, Australia, Canada and Italy etc. The rest of the 62% of fly ash is still a problem of concern [4]. The unpleasant effects of this worldwide process are reported by a number of researchers as [6, 15, 17-18] and stated below:

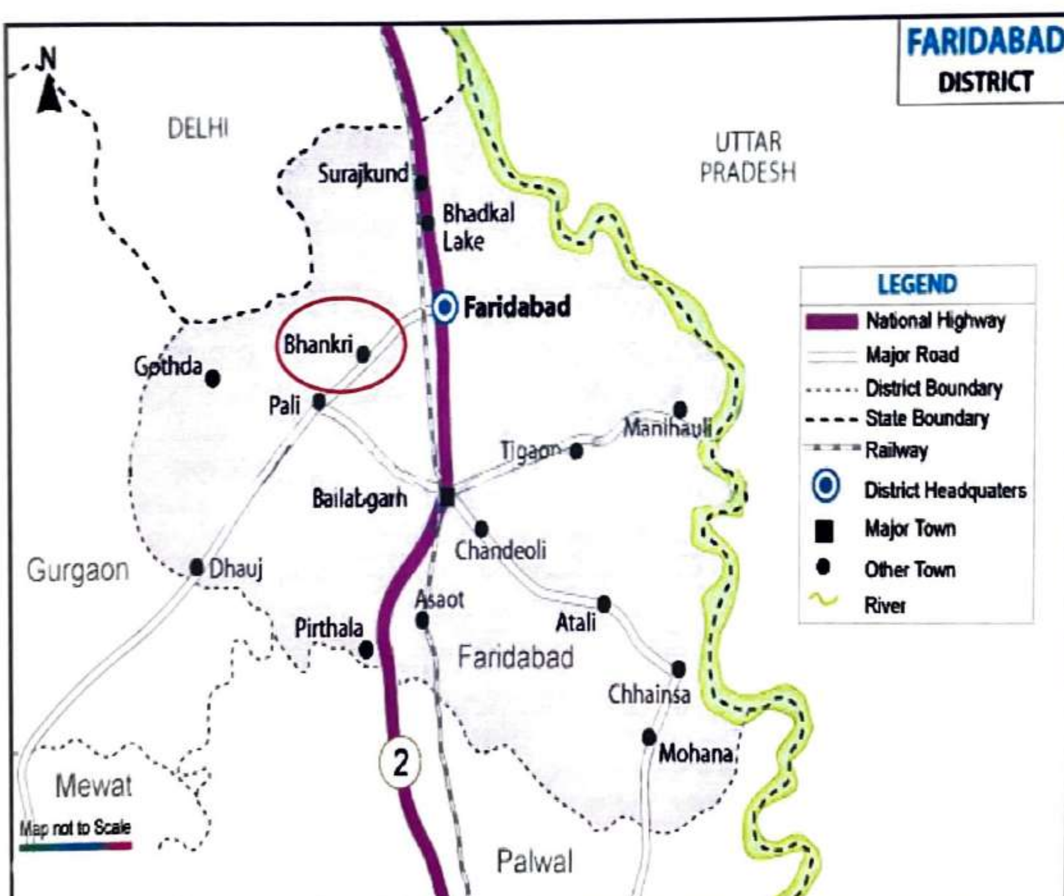
1. Management and safe disposal of huge amount of industrial waste.
2. Shortage of land, infrastructure and resources for the continuing developmental activities.

Coal ash shows a wide variation in their physio-chemical properties which depends on parent coal, combustion technique used, air/fuel ratio, burners used, and type of boiler. Concentration of metals in coal ash is approximate two times higher than the parent coal [19]. Coal ash contains enhanced level of radionuclide's and composed of oxides of iron, silicon, aluminum, magnesium, calcium, sodium and potassium [3, 20]. In India, coal based thermal power plants generates 131 million tones fly ash per annum and handling of this huge production is a major concern for environmental purpose [21-22]. This massive production of coal ash affect the surrounding environment of coal ash dumping site because it contain enhanced levels of radionuclide's along with other toxic elements. Around 10% of ash generated by thermal power plants is released in the surrounding environment from the chimney; rest of 85-90% ash is collected at the disposal sites [23]. The Environmental Protection Agency (EPA) and Barbara Gottlieb et al. predicted that population living near the disposal site has possible human health effects and much more chances of getting cancer [24-25]. Coal ash is a potential carcinogen, containing heavy metals, hazardous compounds and ^{226}Ra which decay to form chemically inert radioactive gas (^{222}Rn) radon [26]. It is a well-known fact that, long time exposure of radon, thoron and their short lived decay products leads to pathological effects like respiratory system, lung disease and occurrence of lung cancer [14, 27-28]. Several studies of different countries have been published during the recent years, which predict the health hazardous effect of radon, thoron and its progeny [29-42]. Radon (^{222}Rn) is one of the most pervasive and serious global indoor air concerns. Radon becomes an indoor air pollution problem when it penetrates into dwellings near dumping sites directly from the air and ground water contaminated due to coal ash [43]. It can cause increased risk of cancer and other disease like permanent respiratory disorder, heart damage, lung disease, kidney disease, reproductive problems, birth defects and impaired bone growth in children. Therefore, the problems related with their safe management and disposal has become a major challenge to environmentalists and scientists [14].

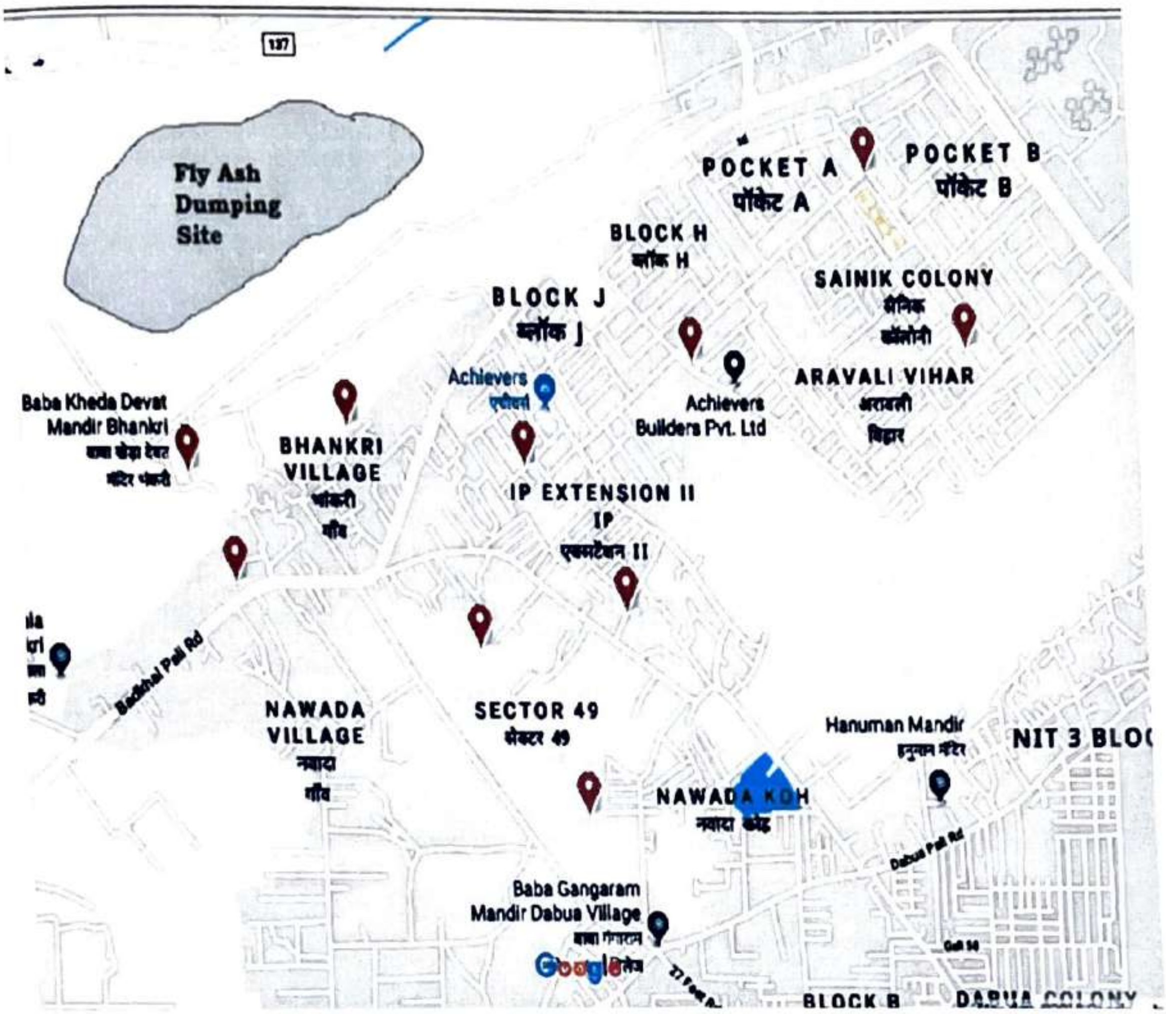
The Bhabha Atomic Research Center (BARC), Mumbai, India has initiated a monitoring program of radon (^{222}Rn) along with thoron (^{220}Rn) in the dwellings all over the country using SSNTDs based twin cup dosimeters. In the present study, measurements of indoor radon, thoron, and their progeny have been carried out for health risk assessment using twin cup dosimeters fitted with LR-115 type-II plastic track detectors (SSNTDs) in the dwellings near the fly ash dumping site of southern Haryana, India.

4.1.2 About the Study Area

In the present study the measurements were carried out in the dwellings of Faridabad situated near to the fly ash dumping site, located on the Faridabad Gurugram road, Haryana. The study area lies at 28°24′23.59" N Latitude and 77°17′ 44.95″ E Longitude. Faridabad is a district of Haryana found in the south eastern part of the state and lies just southeast of New Delhi. From the north, city is bordered by the Delhi, from the east it is connected to the Utter Pradesh; from west city is connected to Gurugram. It is positioned at an elevation of 209 meters above the sea level. City and location map are shown in photograph 4.1 and 4.2.



Photograph 4.1: Faridabad District Map



Photograph 4.2: Location Map of Dwellings near Fly Ash Dumping Site

Purpose of study was to assess the radiological impact of fly ash on the population of nearby area. For the measurements the general details are:

1. The present study was carried out from January 2013 to January 2014. The measurements were made for all the four seasons of a calendar year: winter (October to January), spring (January-April),summer (April-July) and rainy (July-October).Total covered area examined nearby fly ash dumping site situated in Faridabad is 5 km.
2. For the covered area of 5 km^2, total 10 locations were selected and every location is approximately 500 m away from the prior location. Locations are named as Faridabad fly ash dumping site 1 (FFAD-1) to Faridabad fly ash dumping site 10 (FFAD-10). Location FFAD-1 was selected inside a cave of a temple where there is no provision for ventilation and FFAD-2 was the location of dwellings nearest

to fly ash dumping site whereas FFAD-10 was the location of farthest dwellings from the fly ash dumping site.

3. At each location of the study area 10 dwellings were selected uniformly so that the collected data is true representative for the radon and thoron concentrations.
4. For a specific season, dwellings were selected for the same type of ventilation.
5. To study the appropriate effect of seasonal variation, those dwellings were selected where only fans were used in summers and no heating appliances were used during winters.
6. In every dwelling twin cup dosimeter loaded with LR-115 type II detectors were exposed for the seasonal radiological assessment and in total 100 twin cup dosimeters were installed at 10 selected locations in the area of 5 km during each season and process was repeated for every season of a year to complete annual study.

4.1.3 Experimental Technique

In the present study radon & thoron concentration, PAEC due to radon and thoron progeny, Inhalation dose, exposure due to radon and thoron progeny and annual effective dose were calculated. In this technique Twin cup dosimeters loaded with LR-115 type II Solid State Nuclear Track Detectors (SSNTDs) in the pieces of 2.5 × 2.5 cm were exposed at the selected locations for the 90 days. After the exposure for 90 days (one season) the detectors were retrieved from the twin cup dosimeters and again loaded with fresh detectors and installed at the same locations for the next 90 days (next season). In the same manner the process had been repeated during all the four seasons of a year. The retrieved detectors were etched in 2.5 N NaOH solution at 60°c for 90 minutes (detail of the technique discussed in chapter 3, under section 3.7). The tracks appeared due to the alpha particles were counted using spark counter (section 3.8).

4.1.4 Formulas Used

The radon and thoron concentration in Bqm^{-3} was estimated using track density registered with the help of following relations: [44-45]:

$$C_R\ (Bqm^{-3}) = T_m / (d \times S_m) \qquad (4.1)$$

Where T_m is track density in membrane compartment, d is number of days and S_m is sensitivity factor for membrane compartment

$S_m = (0.019 \pm 0.003\ T_r cm^{-2} d^{-1} / Bqm^{-3})$

$$C_T\ (Bqm^{-3}) = T_f - dC_R S_{rf}\ /\ (d \times S_{tf}) \qquad (4.2)$$

Where C_T is thoron concentration, T_f is track density in filter compartment, d is exposure time, S_{rf} is sensitivity factor for radon in filter compartment and S_{tf} is sensitivity factor for thoron in filter compartment. Values of S_{rf} and S_{tf} are as

$S_{rf} = (0.020 \pm 0.004\ T_r cm^{-2} d^{-1}/Bqm^{-3})$

$S_{tf} = (0.016 \pm 0.005\ T_r cm^{-2} d^{-1}/Bqm^{-3})$

From the observed values of radon and thoron concentration using equation 4.1 and 4.2, the radon and thoron daughter concentration in terms of potential alpha energy concentration (PAEC) in mWL was estimated, where WL is working level using following relation [46]:

$$C_R \text{ or } C_T\ (Bqm^{-3}) = (PAEC\ (WL) \times 3700)\ /\ F \qquad (4.3)$$

Where F is equilibrium factor and its value is 0.4 for radon and 0.1 for thoron [47].

4.1.5 Results and Discussion

In the present case study the results were calculated for radon and thoron concentration, PAEC due to radon and thoron progeny, Inhalation dose, exposure due to radon and thoron progeny and annual effective dose during all the four seasons of a calendar year and mentioned below in the tabular form according to the season.

(i) Results for Spring Season (January 2013-April 2013)

The calculated values of radon and thoron concentration and potential alpha energy concentration (PAEC) due to radon and thoron progeny from the samples collected from the dwellings nearby fly ash dumping site situated in Faridabad during the spring season (January-April) using equations 4.1-4.3 are presented in table 4.1. Table shows that the radon concentration varies from 10.30±0.31 Bqm^{-3} (farthest location) to 129.91±2.69 Bqm^{-3} (inside the cave) with an average value of 44.85±5.06 Bqm^{-3}. Similarly the thoron concentration varies from 1.67±0.06 Bqm^{-3} (farthest location) to 65.08±1.32 Bqm^{-3} (inside the cave) with an average value of 22.73±2.51 Bqm^{-3}. The graphical variations of radon and thoron concentration at different selected locations are shown in figure 4.1 and 4.2. From graphs it is clear that the maximum value of radon concentration and thoron concentration found inside the cave of a temple where there is no provision for the ventilation whereas the indoor radon and thoron concentration at the nearest location from the fly ash dumping site was found to be 76.98±1.58 Bqm^{-3} and 39.39±1.20 Bqm^{-3} respectively.

Location	Radon concentration C_R (Bqm^{-3})	Thoron concentration C_T (Bqm^{-3})	PAEC (Rn) (mWL)	PAEC (Th) (mWL)
FFAD-1	129.91±2.69	65.08±1.32	14.04±0.29	1.76±0.04
FFAD-2	76.98±1.58	39.39±1.20	8.32±0.17	1.07±0.03
FFAD-3	60.20±1.77	28.50±2.26	6.51±0.19	0.77±0.06
FFAD-4	51.64±1.21	22.05±1.42	5.58±0.13	0.60±0.04
FFAD-5	40.29±0.79	20.88±0.59	4.36±0.09	0.56±0.02
FFAD-6	30.73±1.21	17.34±0.57	3.32±0.13	0.47±0.02
FFAD-7	20.45±0.37	14.58±0.41	2.21±0.04	0.39±0.01
FFAD-8	15.30±0.25	12.18±0.33	1.65±0.03	0.33±0.01
FFAD-9	12.71±0.31	5.58±0.26	1.37±0.03	0.15±0.01
FFAD-10	10.30±0.31	1.67±0.06	1.11±0.03	0.05±0.001
Av±SE*	44.85±5.06	22.73±2.51	4.85±0.55	0.61±0.007

*SE (standard error)= $\sigma/\sqrt{N}$, where σ is SD (standard deviation) and N is no. of observations

Table 4.1: Radon and thoron concentration and PAEC due to radon and thoron progeny in the dwellings nearby fly ash dumping site during spring season

The calculated values of PAEC due to radon and thoron progeny as shown in table 4.1 varies from 1.11±0.03 mWL (farthest location) to 14.04±0.29 mWL (inside the cave) with an average value of 4.85±0.55 mWL and 0.05±0.001 mWL (farthest location) to 1.76±0.04 mWL (inside the cave) with an average value of 0.61±0.007 mWL respectively. The maximum value of PAEC due to radon and thoron progeny found inside the cave of a temple whereas the value of PAEC due to radon and thoron progeny at the nearest dwellings locations from the fly ash dumping site is 8.32±0.17 mWL and 1.07±0.03 mWL respectively.

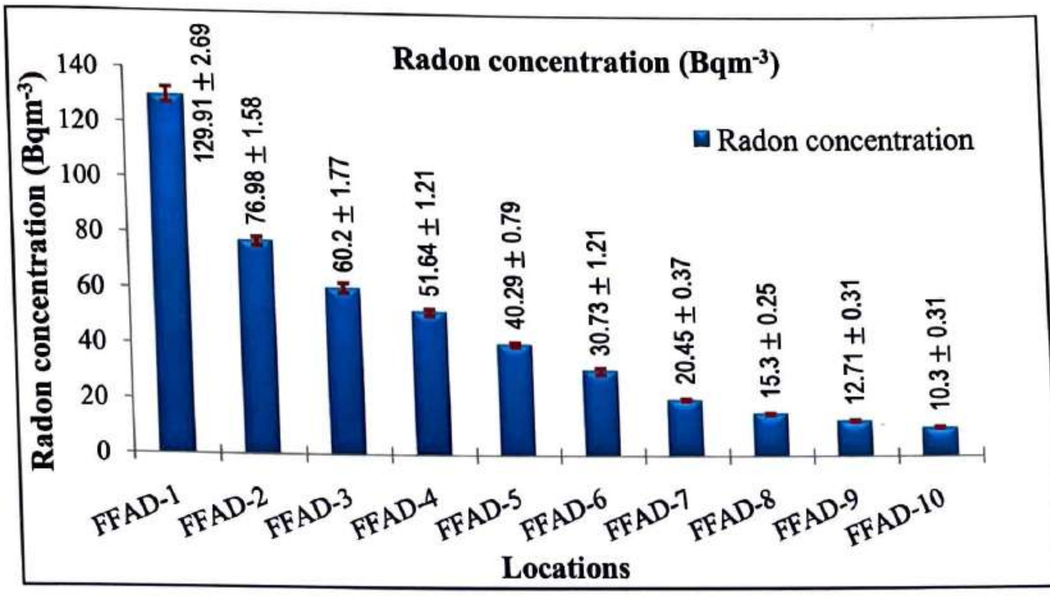


Figure 4.1: Graphical variations of radon concentration at the locations selected nearby fly ash dumping site during spring season

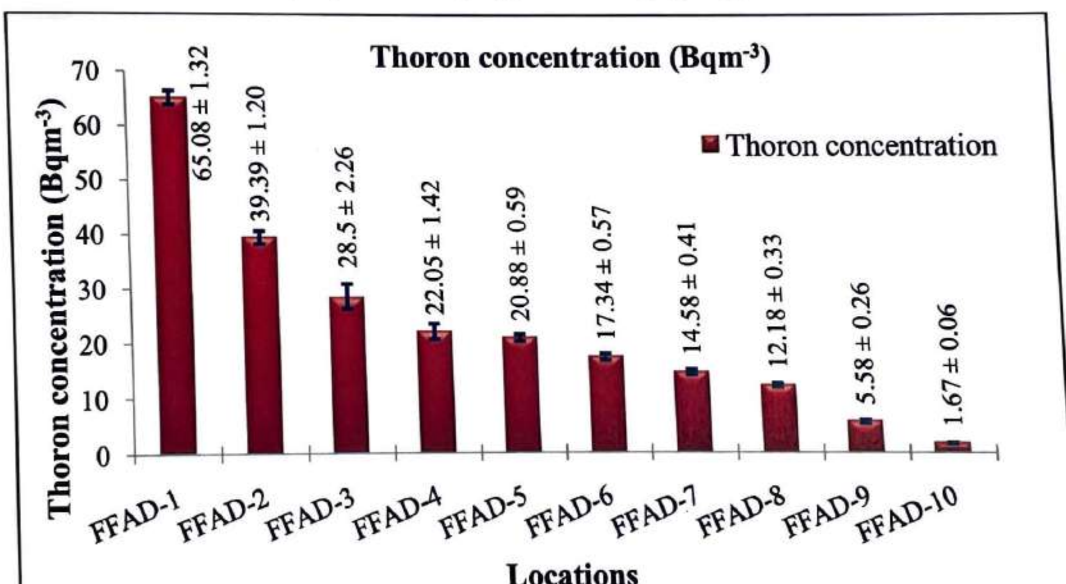


Figure 4.2: Graphical variations of thoron concentration at the locations selected nearby fly ash dumping site during spring season

The inhalation dose due to radon and thoron in mSv/y was estimated using the following formula [48]:

$$D = \{(0.17 + 9F_R)\, C_R + (0.11 + 32F_T)\, C_T\} \times 7000 \times 10^{-6} \quad (4.4)$$

Where, F_R is equilibrium factor for radon and F_T is equilibrium factor for thoron.

Annual exposure due to radon and thoron progeny was calculated by using the generic relation [49].

$$(365 \times 24 \times 0.8) / (170 \times 1000) \quad (4.5)$$

Where, the annual exposure to the general public is 0.412 WLM with a PAEC of 1 mWL. Seasonal exposure due to radon and thoron progeny was calculated from equation 4.5 by replacing 365 days to 90 days (exposure time of each season) and for the spring season the results are shown in table 4.2. The seasonal exposure due to radon and thoron daughter products varies from 11.13×10^{-3} WLM (farthest location) to 140.44×10^{-3} WLM (inside the cave) with an average value of 48.49×10^{-3} WLM and 0.45×10^{-3} WLM (farthest location) to 17.59×10^{-3} WLM (inside the cave) with an average value of 6.14×10^{-3} WLM respectively. Maximum value of exposure due to radon and thoron progeny was found inside the cave of temple (FFAD-1) nearby fly ash dumping site situated in Faridabad. The exposure due to radon and thoron in the dwellings at the nearest location from the fly ash dumping site is 83.22×10^{-3} WLM and 10.65×10^{-3} WLM respectively.

The exposure due to radon and thoron daughters was converted into effective dose by using dose conversion factors; for radon daughter the dose conversion factor for members of the public is 3.88 mSv per WLM [46], whereas for thoron daughters the conversion factor is 3.4 mSv per WLM [50]. Effective dose calculated from these generic relations and inhalation dose calculated from equations 4.4 are shown in table 4.2. The inhalation dose as shown in table varies from 0.31 mSv/y (farthest location) to 4.96 mSv/y (inside the cave) with an average value of 1.72 mSv/y. The maximum value of inhalation dose was found inside the cave of a temple whereas, the inhalation dose for the inhabitants living at the nearest location from the fly ash dumping site is 2.96 mSv/y. The cumulative effective dose calculated from the exposure due to radon and thoron daughters during the spring season for the population living nearby fly ash dumping site situated in Faridabad varies from 0.04 mSv (farthest location) to 0.60 mSv (inside the cave) with an average value of 0.21 mSv. Whereas, the effective dose for the dwellers at the nearest location from the fly ash dumping site is 0.35 mSv.

Location	Exposure due to radon progeny ($WLMx10^{-3}$)	Exposure due to thoron progeny ($WLMx10^{-3}$)	Exposure due to (Rn+Th) progeny ($WLMx10^{-3}$)	Inhalation dose D (mSv/y)	Effective dose (mSv)
FFAD-1	140.44	17.59	158.03	4.96	0.60
FFAD-2	83.22	10.65	93.86	2.96	0.35
FFAD-3	65.08	7.70	72.79	2.26	0.27
FFAD-4	55.83	5.96	61.79	1.88	0.23
FFAD-5	43.56	5.64	49.20	1.55	0.19
FFAD-6	33.22	4.69	37.91	1.22	0.14
FFAD-7	22.11	3.94	26.05	0.88	0.10
FFAD-8	16.55	3.29	19.84	0.69	0.10
FFAD-9	13.74	1.51	15.25	0.47	0.06
FFAD-10	11.13	0.45	11.58	0.31	0.04
Average	48.49	6.14	54.63	1.72	0.21

Table 4.2: Exposure due to radon and thoron progeny, inhalation dose and effective dose in the dwellings nearby the fly ash dumping site during spring season

(ii) Results for Summer Season (April 2013-July 2013)

Values of radon and thoron concentrations and potential alpha energy concentration (PAEC) due to radon and thoron progeny from the samples collected from the dwellings nearby fly ash dumping sites situated in Faridabad during the summer season (April-July) was calculated using equations 4.1-4.3 and presented in table 4.3. It shows that the radon concentration varies from 6.70±0.31 Bqm^{-3} (farthest location) to 122.67±5.27 Bqm^{-3} (inside the cave) with an average value of 37.84±4.88 Bqm^{-3}. The thoron concentration varies from 1.36±0.12 Bqm^{-3} (farthest location) to 58.78±1.71 Bqm^{-3} (inside the cave) with an average value of 18.32±2.32 Bqm^{-3}. The graphical variations of radon and thoron concentration at different selected locations are shown in figure 4.3 and 4.4 respectively. From graphs it is clear that the maximum value of radon and thoron concentration was found inside the cave of a temple (FFAD-1) and minimum values were found at the farthest location (FFAD-10) nearby fly ash dumping site. The radon and thoron concentration in the dwellings at the nearest location to the fly ash dumping site was found to be 66.38±2.55 Bqm^{-3} and 32.17±2.28 Bqm^{-3} respectively.

Location	Radon concentration C_R (Bq m^{-3})	Thoron concentration C_T (Bq m^{-3})	PAEC (Rn) (mWL)	PAEC (Th) (mWL)
FFAD-1	122.67±5.27	58.78±1.71	13.26±0.57	1.59±0.05
FFAD-2	66.38±2.55	32.17±2.28	7.18±0.28	0.87±0.06
FFAD-3	49.54±1.88	23.17±2.34	5.36±0.20	0.63±0.06
FFAD-4	40.89±2.36	16.75±1.59	4.42±0.26	0.45±0.04
FFAD-5	34.72±1.97	15.70±1.15	3.75±0.21	0.42±0.03
FFAD-6	22.85±1.50	12.98±0.49	2.47±0.16	0.35±0.01
FFAD-7	15.31±0.75	10.04±0.57	1.66±0.08	0.27±0.02
FFAD-8	10.84±0.63	8.68±0.18	1.17±0.07	0.23±0.01
FFAD-9	8.46±0.33	3.58±0.24	0.92±0.04	0.10±0.01
FFAD-10	6.70±0.31	1.36±0.12	0.72±0.03	0.04±0.01
AV±SE*	37.84±4.88	18.32±2.32	4.09±0.53	0.50±0.06

* SE (standard error)= $\sigma/\sqrt{N}$, where σ is SD (standard deviation) and N is no. of observations

Table 4.3: Radon and thoron concentration and PAEC due to radon and thoron progeny in the dwellings nearby fly ash dumping site during summer season

PAEC due to radon and thoron progeny calculated from equation 4.3 are shown in table 4.3. Table shows that the value of PAEC due to radon and thoron progeny varies from 0.72±0.03 mWL (farthest location) to 13.26±0.57 mWL (inside the cave) with an average value of 4.09±0.53 mWL and 0.04±0.01 mWL (farthest location) to 1.59±0.05 mWL (inside the cave) with an average value of 0.50±0.06 mWL respectively. The maximum value of PAEC due to radon and thoron progeny found inside the cave of a temple whereas the value of PAEC due to radon and thoron progeny for the dwellers nearest to the dumping site is 7.18±0.28 mWL and 0.87±0.06 mWL respectively.

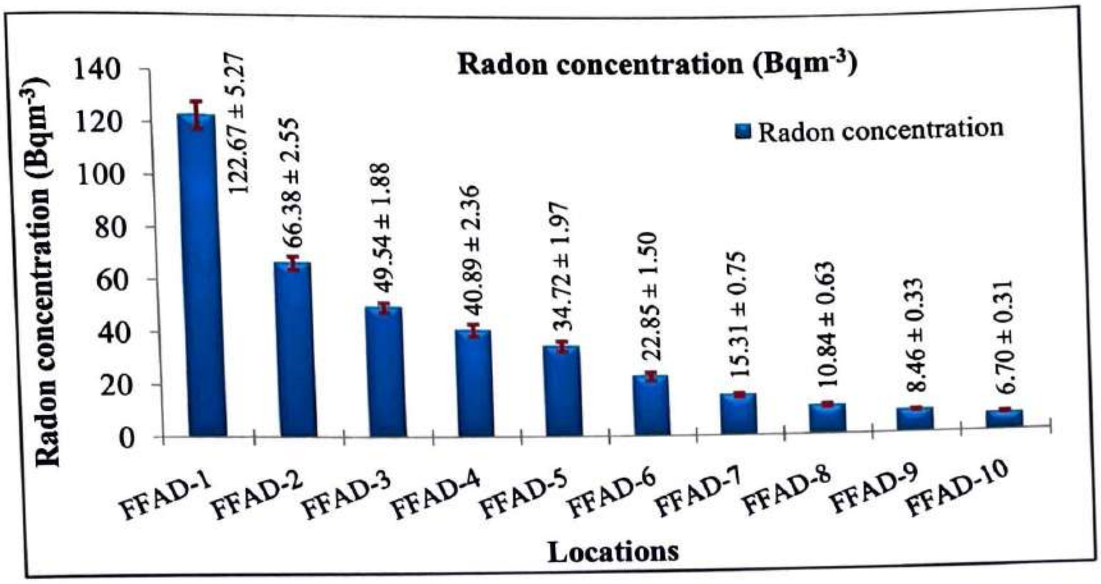


Figure 4.3: Graphical variations of radon concentration at the locations selected nearby fly ash dumping site during summer season

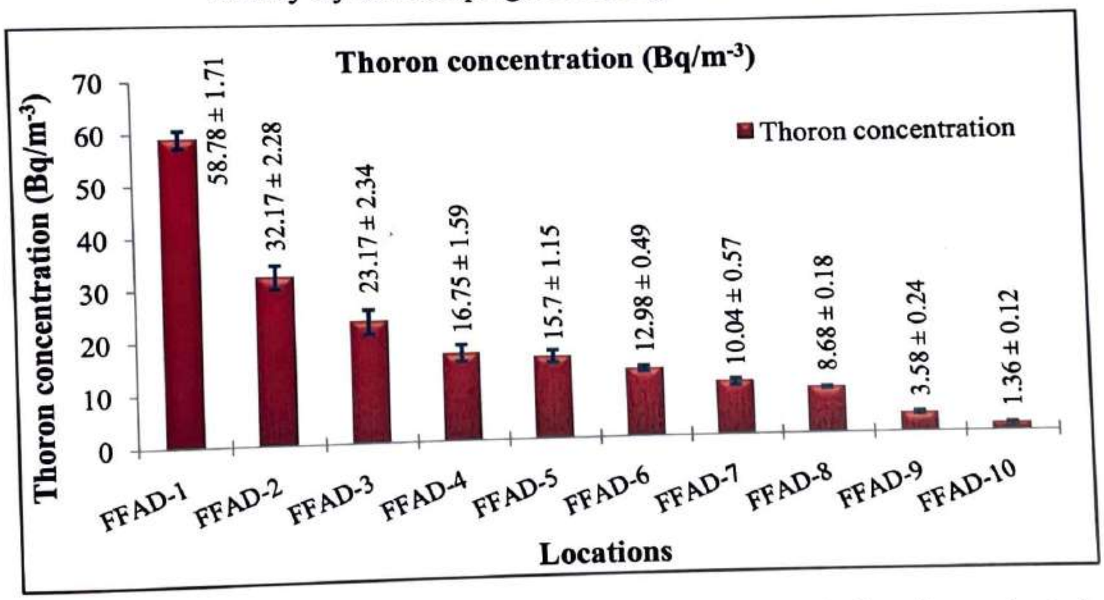


Figure 4.4: Graphical variations of thoron concentration at the locations selected nearby fly ash dumping site during summer season

Exposure due to radon and thoron progeny was calculated from equation 4.5 by replacing 365 days to 90 days (exposure time of summer season) and the results are shown in table 4.4. From table it is clear that the seasonal exposure due to radon and thoron progeny varies from 7.24×10^{-3} WLM (farthest location) to 132.61×10^{-3} WLM (inside the cave) with an average value of 40.90×10^{-3} WLM and 0.37×10^{-3} WLM (farthest location) to 15.89×10^{-3} WLM (inside the cave) with an average value of 4.95×10^{-3} WLM respectively. Maximum value of exposure due to radon and thoron progeny was found inside the cave of temple (FFAD-1) nearby fly ash dumping site situated in Faridabad. The exposure due to radon and thoron at the nearest location from the fly ash dumping site is 71.76×10^{-3} WLM and 8.69×10^{-3} WLM respectively.

The exposure due to radon and thoron daughters was converted into effective dose by using dose conversion factors; for radon daughter the dose conversion factor for members of the public is 3.88 mSv per WLM [46], whereas for thoron daughters the conversion factor is 3.4 mSv per WLM [50]. Effective dose calculated from these generic relations and inhalation dose calculated from equations 4.4 are shown in table 4.4.

Location	Exposure due to radon progeny (WLMx10^{-3})	Exposure due to thoron progeny (WLMx10^{-3})	Exposure due to (Rn+Th) progeny (WLMx10^{-3})	Inhalation dose D (mSv/y)	Effective dose (mSv)
FFAD-1	132.61	15.89	148.50	4.6	0.56
FFAD-2	71.76	8.69	80.45	2.5	0.30
FFAD-3	53.56	6.26	59.82	1.9	0.23
FFAD-4	44.21	4.53	48.74	1.5	0.18
FFAD-5	37.54	4.24	41.78	1.3	0.16
FFAD-6	24.70	3.51	28.21	0.9	0.11
FFAD-7	16.55	2.71	19.26	0.6	0.10
FFAD-8	11.72	2.34	14.06	0.5	0.10
FFAD-9	9.15	0.97	10.12	0.3	0.04
FFAD-10	7.24	0.37	7.61	0.2	0.03
Average	40.90	4.95	45.85	1.4	0.17

Table 4.4: Exposure due to radon and thoron progeny, inhalation dose and effective dose in the dwellings nearby fly ash dumping site during summer season

Table 4.4 shows that the inhalation dose varies from 0.2 mSv/y (farthest location) to 4.6 mSv/y (inside the cave) with an average value of 1.4 mSv/y. The maximum value of inhalation dose was found inside the cave of a temple (FFAD-1) whereas, the inhalation dose for the inhabitants living at the nearest location from the fly ash dumping site is 2.5 mSv/y. The cumulative effective dose calculated from the exposure due to radon and thoron daughters during the summer season for the population living nearby fly ash dumping sites situated in Faridabad varied from 0.03 mSv (farthest location) to 0.56 mSv (inside the cave) with an average value of 0.17 mSv . Whereas, the effective dose for the dwellers living in the environment nearest to the fly ash dumping site is 0.30 mSv.

(iii) Results for Rainy Season (July 2013- October 2013)

Using equations 4.1- 4.3 the calculated values of radon and thoron concentration and potential alpha energy concentration (PAEC) due to radon and thoron progeny from the samples collected from the dwellings nearby fly ash dumping sites situated in Faridabad during the rainy season (July-October) are presented in table 4.5.

Location	Radon concentration C_R (Bq m^{-3})	Thoron concentration C_T (Bq m^{-3})	PAEC (Rn) (mWL)	PAEC (Th) (mWL)
FFAD-1	133.10±1.37	72.23±1.77	14.39±0.15	1.95±0.05
FFAD-2	77.35±3.49	43.76±3.00	8.36±0.38	1.18±0.08
FFAD-3	63.23±2.48	34.76±3.49	6.84±0.27	0.94±0.09
FFAD-4	54.85±3.29	26.84±2.49	5.93±0.36	0.73±0.07
FFAD-5	49.03±3.96	23.47±1.42	5.30±0.43	0.63±0.04
FFAD-6	34.83±2.28	19.81±0.90	3.77±0.25	0.54±0.02
FFAD-7	27.79±1.34	16.74±0.96	3.01±0.15	0.45±0.03
FFAD-8	19.42±1.09	14.57±0.29	2.09±0.12	0.39±0.01
FFAD-9	14.49±0.35	7.84±0.19	1.57±0.04	0.21±0.01
FFAD-10	12.78±0.48	5.42±0.43	1.38±0.05	0.15±0.01
Av±SE*	48.69±5.02	26.54±2.74	5.26±0.54	0.72±0.07

* SE (standard error)= $\sigma/\sqrt{N}$, where σ is SD (standard deviation) and N is no. of observations

Table 4.5: Radon and thoron concentration and PAEC due to radon and thoron progeny in the dwellings nearby fly ash dumping site during rainy season

Table 4.5 shows that the radon concentration varies from 12.78±0.48 Bqm^{-3} (farthest location) to 133.10±1.37 Bqm^{-3} (inside the cave) with an average value of 48.69±5.02 Bqm^{-3}. The thoron concentration varies from 5.42±0.43 Bqm^{-3} (farthest location) to 72.23±1.77 Bqm^{-3} (inside the cave) with an average value of 26.54±2.74 Bqm^{-3}. The graphical variations of radon and thoron concentration at different selected locations are shown in figure 4.5 and 4.6 respectively. From graphs it is clear that maximum concentration was found inside the cave of a temple whereas, the radon and thoron concentration calculated from the samples collected from the dwellings nearest to the fly ash dumping site is 77.35±3.49 Bqm^{-3} and 43.76±3.00 Bqm^{-3} respectively. Results show that the maximum value of radon and thoron concentration was found inside the cave of a temple (FFAD-1) and minimum value was found at the farthest location (FFAD-10) nearby fly ash dumping site.

PAEC due to radon and thoron progeny as shown in table 4.5 calculated from equation 4.3 varies from 1.38±0.05 mWL (farthest location) to 14.39±0.15 mWL (inside the cave) with an average value of 5.26±0.54 mWL and 0.15±0.01 mWL (farthest location) to 1.95±0.05 mWL (inside the cave) with an average value of 0.72±0.07 mWL respectively. The maximum value of PAEC due to radon and thoron progeny found inside the cave of a temple (FFAD-1) whereas, for the dwellers nearest to the fly ash dumping site the PAEC due to radon and thoron progeny found to be 8.36±0.38 mWL and 1.18±0.08 mWL respectively.

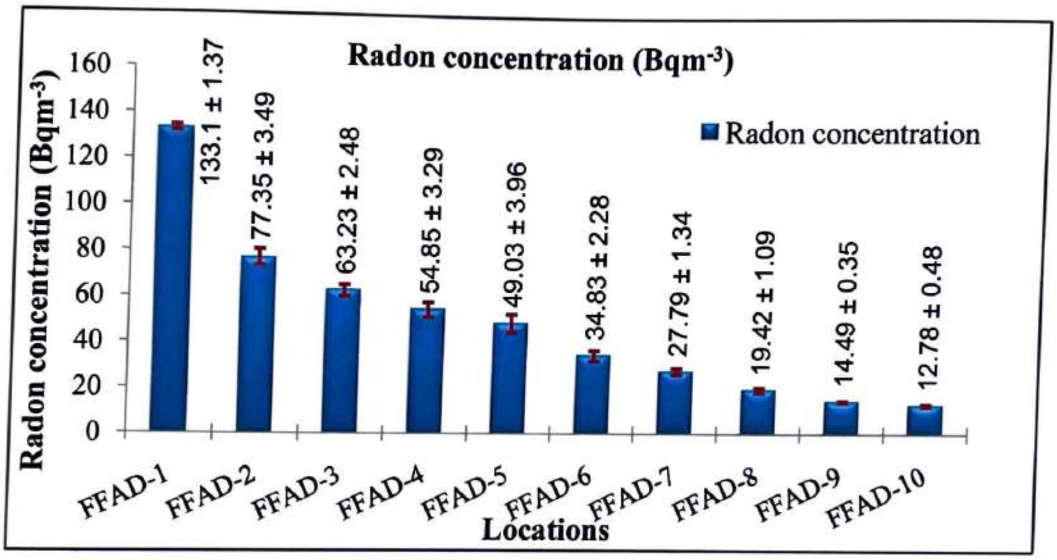


Figure 4.5: Graphical variations of radon concentration at the locations selected nearby fly ash dumping site during rainy season

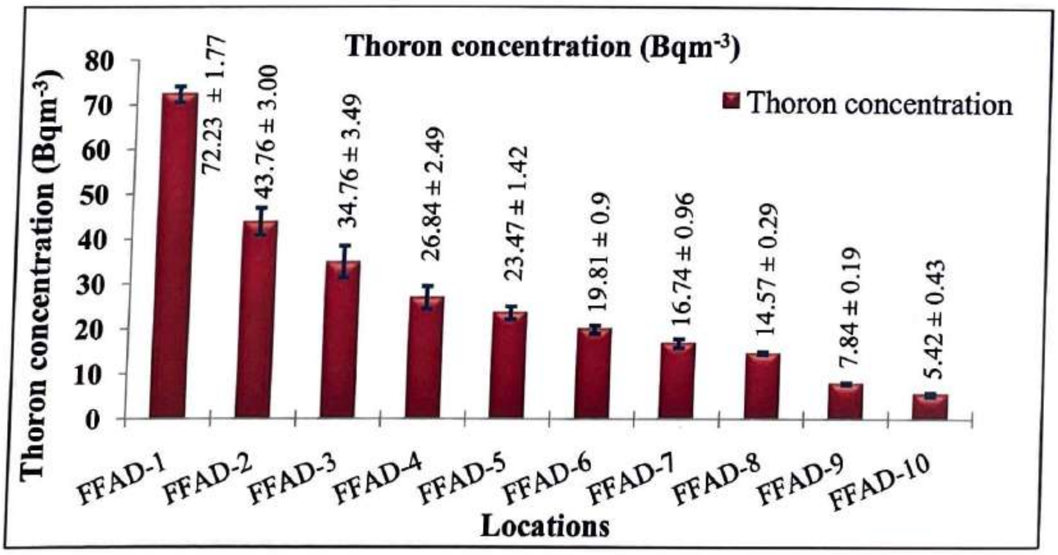


Figure 4.6: Graphical variations of thoron concentration at the locations selected nearby fly ash dumping site during rainy season

Exposure due to radon and thoron progeny during the rainy season was calculated from equation 4.5 by replacing 365 days to 90 days (exposure time of the season) and the results are shown in table 4.6. The seasonal exposure due to radon and thoron progeny varies from 13.82×10^{-3} WLM (farthest location) to 143.89×10^{-3} WLM (inside the cave) with an average value of 52.63×10^{-3} WLM and 1.47×10^{-3} WLM (farthest location) to 19.52×10^{-3} WLM (inside the cave) with an average value of 7.17×10^{-3} WLM respectively. Maximum value of exposure due to radon and thoron progeny was found inside the cave of temple (FFAD-1) nearby fly ash dumping site situated in Faridabad. The exposure due to radon and thoron at the nearest location from the fly ash dumping site is 83.62×10^{-3} WLM and 11.83×10^{-3} WLM respectively.

Location	Exposure due to radon progeny ($WLMx10^{-3}$)	Exposure due to thoron progeny ($WLMx10^{-3}$)	Exposure due to (Rn+Th) progeny ($WLMx10^{-3}$)	Inhalation dose D (mSv/y)	Effective dose (mSv)
FFAD-1	143.89	19.52	163.41	5.21	0.61
FFAD-2	83.62	11.83	95.55	3.07	0.36
FFAD-3	68.38	9.39	77.75	2.49	0.29
FFAD-4	59.29	7.26	66.55	2.08	0.25
FFAD-5	53.01	6.34	59.35	1.85	0.22
FFAD-6	37.65	5.35	43.00	1.38	0.16
FFAD-7	30.05	4.52	34.57	1.23	0.13
FFAD-8	20.99	3.94	24.93	0.85	0.10
FFAD-9	15.66	2.12	17.78	0.57	0.07
FFAD-10	13.82	1.47	15.29	0.47	0.06
Average	52.63	7.17	59.80	1.91	0.22

Table 4.6: Exposure due to radon and thoron progeny, inhalation dose and effective dose in the dwellings nearby fly ash dumping site during rainy season

The exposure due to radon and thoron daughters was converted into effective dose by using dose conversion factors; for radon daughters the dose conversion factor for members of the public is 3.88 mSv per WLM [46], whereas for thoron daughters the conversion factor is 3.4 mSv per WLM [50]. Effective dose calculated from these generic relations and inhalation dose calculated from equations 4.4 are shown in table 4.6. The inhalation dose varies from 0.47 mSv/y (farthest location) to 5.21 mSv/y (inside the cave) with an average value of 1.91 mSv/y. The maximum value of inhalation dose was found inside the cave of a temple (FFAD-1) whereas, the inhalation dose for the inhabitants living at the nearest location from the fly ash dumping site is 3.07 mSv/y as shown in table 4.6. The cumulative effective dose calculated from the exposure due to radon and thoron daughters during the rainy season for the population living nearby fly ash dumping site situated in Faridabad varies from 0.06 mSv (farthest location) to 0.61 mSv (inside the cave) with an average value of 0.22 mSv. Whereas, the effective dose for the dwellers living in the environment nearest to the fly ash dumping site is 0.36 mSv.

(iv) Results for Winter Season (October 2013- January 2014)

The calculated values of radon and thoron concentration and potential alpha energy concentration (PAEC) due to radon and thoron progeny from the samples collected from the dwellings nearby fly ash dumping sites situated in Faridabad during the winter season (October 2013- January 2014) using equations 4.1- 4.3 are presented in table 4.7.

Location	Radon concentration C_R (Bqm^{-3})	Thoron concentration C_T (Bqm^{-3})	PAEC (Rn) (mWL)	PAEC (Th) (mWL)
FFAD-1	139.79±2.93	78.37±2.16	15.11±0.32	2.12±0.06
FFAD-2	82.41±1.69	43.91±1.83	8.91±0.18	1.19±0.05
FFAD-3	69.84±1.91	36.79±1.03	7.55±0.21	0.99±0.03
FFAD-4	58.66±2.17	30.66±1.69	6.34±0.24	0.83±0.05
FFAD-5	53.93±3.25	27.12±0.86	5.83±0.35	0.73±0.02
FFAD-6	41.38±1.66	24.87±1.05	4.47±0.18	0.67±0.03
FFAD-7	36.72±0.50	21.40±0.79	3.97±0.05	0.58±0.02
FFAD-8	26.94±0.41	18.06±0.41	2.91±0.05	0.49±0.01
FFAD-9	16.32±0.44	11.83±0.36	1.76±0.05	0.32±0.01
FFAD-10	17.63±0.57	7.85±0.41	1.91±0.06	0.21±0.01
AV±SE*	54.36±5.05	30.09±2.75	5.88±0.55	0.81±0.07

* SE (standard error)= $\sigma/\sqrt{N}$, where σ is SD (standard deviation) and N is no. of observations

Table 4.7: Radon and thoron concentration and PAEC due to radon and thoron progeny in the dwellings nearby fly ash dumping site during winter season

Table 4.7 shows that the radon concentration varies from 17.63±0.57 Bqm^{-3} (farthest location) to 139.79±2.93 Bqm^{-3} (inside the cave) with an average value of

54.36±5.05 Bqm^{-3}. The thoron concentration varies from 7.85±0.41 Bqm^{-3} (farthest location) to 78.37±2.16 Bqm^{-3} (inside the cave) with an average value of 30.09±2.75 Bqm^{-3}. The graphical variations of radon and thoron concentration at different selected locations are shown in figure 4.7 and 4.8 respectively. From figure it is clear that the maximum value of radon and thoron concentration was found inside the cave of a temple (FFAD-1) and minimum value was found at the farthest location (FFAD-10) from the fly ash dumping site. Whereas, the radon and thoron concentration calculated from the samples collected from the dwellings nearest to the fly ash dumping site is 82.41±1.69 Bqm^{-3} and 43.91±1.83 Bqm^{-3} respectively.

PAEC due to radon and thoron progeny calculated from equation 4.3 are shown in table 4.7. From table it is clear that PAEC due to radon and thoron progeny varies from 1.91±0.06 mWL (farthest location) to 15.11±0.32 mWL (inside the cave) with an average value of 5.88±0.55 mWL and 0.21±0.01 mWL (farthest location) to 2.12±0.06 mWL (inside the cave) with an average value of 0.81±0.07 mWL respectively. The maximum value of PAEC due to radon and thoron progeny found inside the cave of a temple (FFAD-1) whereas, the value of PAEC due to radon and thoron progeny for the dwellers nearest to the fly ash dumping site is 8.91±0.18 mWL and 1.19±0.05 mWL respectively.

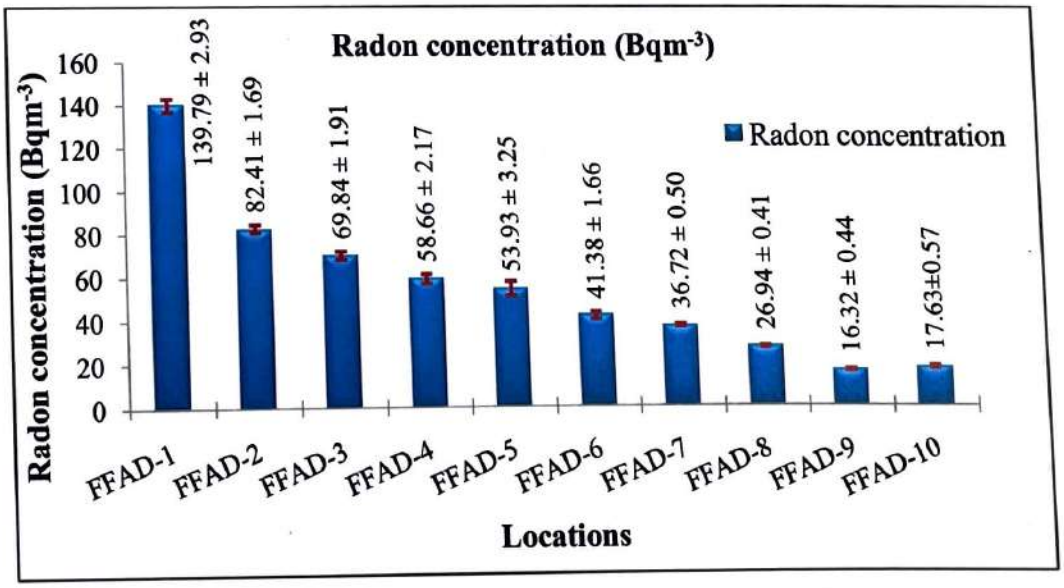


Figure 4.7: Graphical variations of radon concentration at the locations selected nearby fly ash dumping site during winter season

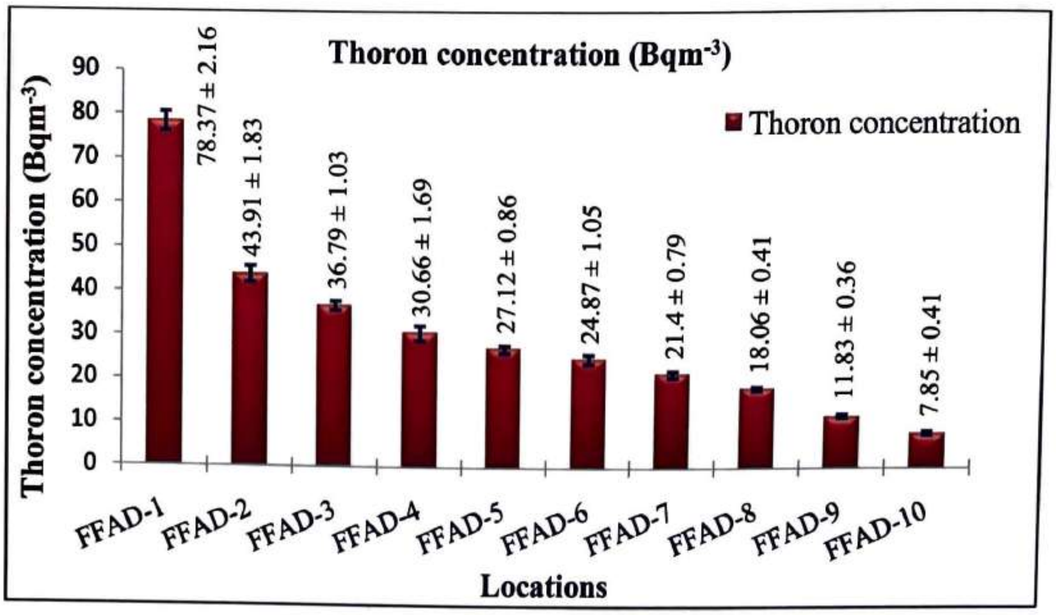


Figure 4.8: Graphical variations of thoron concentration at the locations selected nearby fly ash dumping site during winter season

Exposure due to radon and thoron progeny during the winter season was calculated from equation 4.5 for duration of 90 days (exposure time of the season) and the results are shown in table 4.8. The seasonal exposure due to radon and thoron progeny varies from 19.06×10^{-3} WLM (farthest location) to 151.13×10^{-3} WLM (inside the cave) with an average value of 58.77×10^{-3} WLM and 2.12×10^{-3} WLM (farthest location) to 21.18×10^{-3} WLM (inside the cave of a temple) with an average value of 8.13×10^{-3} WLM respectively. Maximum value of exposure due to radon and thoron progeny was found inside the cave of temple (FFAD-1) nearby fly ash dumping site situated in Faridabad. The exposure due to radon and thoron at the nearest location from the fly ash dumping site is 89.10×10^{-3} WLM and 11.87×10^{-3} WLM respectively.

The exposure due to radon and thoron daughters was converted into effective dose by using dose conversion factors; for radon daughter the dose conversion factor for members of the public is 3.88 mSv per WLM [46], whereas for thoron daughters the conversion factor is 3.4 mSv per WLM [50]. Effective dose calculated from these generic relations, and inhalation dose calculated from equations 4.4 are shown in table 4.8.

Location	Exposure due to radon progeny (WLMx10^{-3})	Exposure due to thoron progeny (WLMx10^{-3})	Exposure due to (Rn+Th) progeny (WLMx10^{-3})	Inhalation dose D (mSv/y)	Effective dose (mSv)
FFAD-1	151.13	21.18	172.31	5.53	0.65
FFAD-2	89.10	11.87	100.97	3.21	0.38
FFAD-3	75.50	9.94	85.44	2.71	0.32
FFAD-4	63.41	8.29	71.70	2.27	0.27
FFAD-5	58.31	7.33	65.64	2.06	0.25
FFAD-6	44.74	6.72	51.46	1.68	0.19
FFAD-7	39.70	5.78	45.48	1.47	0.17
FFAD-8	29.12	4.88	34.00	1.34	0.13
FFAD-9	17.64	3.20	20.84	0.71	0.10
FFAD-10	19.06	2.12	21.18	0.65	0.10
Av±SE*	58.77	8.13	66.90	2.14	0.25

* SE (standard error)= $\sigma/\sqrt{N}$, where σ is SD (standard deviation) and N is no. of observations

Table 4.8: Exposure due to radon and thoron progeny, inhalation dose and effective dose in the dwellings nearby fly ash dumping site during winter season

The inhalation dose varies from 0.65 mSv/y (farthest location) to 5.53 mSv/y (inside the cave) with an average value of 2.14 mSv/y. The maximum value of inhalation dose was found inside the cave of a temple (FFAD-1) whereas, the inhalation dose for the population living at the nearest location from the fly ash dumping site is 3.21 mSv/y as shown in table 4.8. The cumulative effective dose calculated from the exposure due to radon and thoron daughters during the winter season for the population living nearby fly ash dumping site situated in Faridabad varies from 0.10 mSv (farthest location) to 0.65 mSv (inside the cave) with an average value of 0.25 mSv . Whereas, the effective dose for the dwellers living in the environment nearest to the fly ash dumping site is 0.38 mSv.

Radon and thoron concentration in the dwellings nearby fly ash dumping site during all the four seasons of a year are represented in table 4.9.

Location	Seasonal variations in radon conc.(C_R) (Bqm^{-3})				Seasonal variations in thoron conc.(C_T) (Bqm^{-3})			
	Winter	Spring	Summer	Rainy	Winter	Spring	Summer	Rainy
FFAD-1	139.79 ±2.93	129.91 ±2.69	122.67 ±5.27	133.10 ±1.37	78.37 ±2.16	65.08 ±1.32	58.78 ±1.71	72.23 ±1.77
FFAD-2	82.41 ±1.69	76.98 ±1.58	66.38 ±2.55	77.35 ±3.49	43.91 ±1.83	39.39 ±1.20	32.17 ±2.28	43.76 ±3.00
FFAD-3	69.84 ±1.91	60.20 ±1.77	49.54 ±1.88	63.23 ±2.48	36.79 ±1.03	28.50 ±2.26	23.17 ±2.34	34.76 ±3.49
FFAD-4	58.66 ±2.17	51.64 ±1.21	40.89 ±2.36	54.85 ±3.29	30.66 ±1.69	22.05 ±1.42	16.75 ±1.59	26.84 ±2.49
FFAD-5	53.93 ±3.25	40.29 ±0.79	34.72 ±1.97	49.03 ±3.96	27.12 ±0.86	20.88 ±0.59	15.70 ±1.15	23.47 ±1.42
FFAD-6	41.38 ±1.66	30.73 ±1.21	22.85 ±1.50	34.83 ±2.28	24.87 ±1.05	17.34 ±0.57	12.98 ±0.49	19.81 ±0.90
FFAD-7	36.72 ±0.50	20.45 ±0.37	15.31 ±0.75	27.79 ±1.34	21.40 ±0.79	14.58 ±0.41	10.04 ±0.57	16.74 ±0.96
FFAD-8	26.94 ±0.41	15.30 ±0.25	10.84 ±0.63	19.42 ±1.09	18.06 ±0.41	12.18 ±0.33	8.68 ±0.18	14.57 ±0.29
FFAD-9	16.32 ±0.44	12.71 ±0.31	8.46 ±0.33	14.49 ±0.35	11.83 ±0.36	5.58 ±0.26	3.58 ±0.24	7.84 ±0.19
FFAD-10	17.63 ±0.57	10.30 ±0.31	6.70 ±0.31	12.78 ±0.48	7.85 ±0.41	1.67 ±0.06	1.36 ±0.12	5.42 ±0.43
AV±SE*	54.36 ±5.05	44.85 ±5.06	37.84 ±4.88	48.69 ±5.02	30.09 ±2.75	22.73 ±2.51	18.32 ±2.32	26.54 ±2.74

* SE (standard error)= $\sigma/\sqrt{N}$, where σ is SD (standard deviation) and N is no. of observations

Table 4.9: Seasonal variations of radon and thoron concentration in the dwellings nearby Fly ash dumping sites situated in Faridabad, Haryana

As shown in table 4.9 maximum value of radon concentration is 139.79±2.93 Bqm^{-3} (inside the cave of a temple) during winters (October-January) and the minimum value is 6.70±0.31 Bqm^{-3} (farthest location) during summer (April-July). The maximum value of radon concentration for the dwellers living at the nearest location from the fly ash dumping site is 82.41±2.93 Bqm^{-3} (FFAD-2) during winter.

The maximum and minimum value of thoron concentration is 78.37±2.16 Bqm^{-3} (inside the cave of a temple) during winter (October-January) and 1.36±0.12 Bqm^{-3} (farthest location) during summer (April-July) respectively. The maximum and minimum value of thoron concentration for the dwellers living at the nearest location from the fly ash dumping site is 43.91±1.83 Bqm^{-3} (FFAD-2) during winter. Graphical variations of minimum and maximum values of radon and thoron concentration during all the four seasons of a year are shown in figure 4.9 and figure 4.10

respectively. From graphs it is clear that maximum values of radon and thoron concentration is during the winter and it is because, the ventilation falls during winter especially in the night when temperature falls considerably and dwellers remain the doors and windows closed frequently to maintain their thermal comfort. Minimum values of radon and thoron concentration is during summer as shown in figure and it is because dwellers remain the doors and windows open and in addition to this fans results in proper air exchange [51].

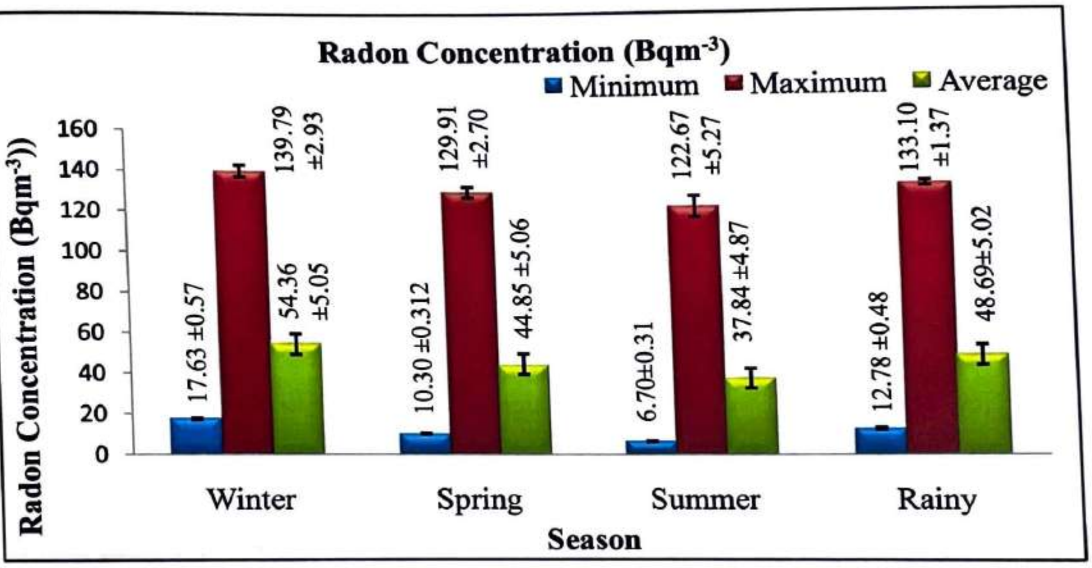


Figure 4.9: Graphical variations of radon concentration in the dwellings nearby Fly ash dumping sites situated in Faridabad, Haryana during all the seasons of a year

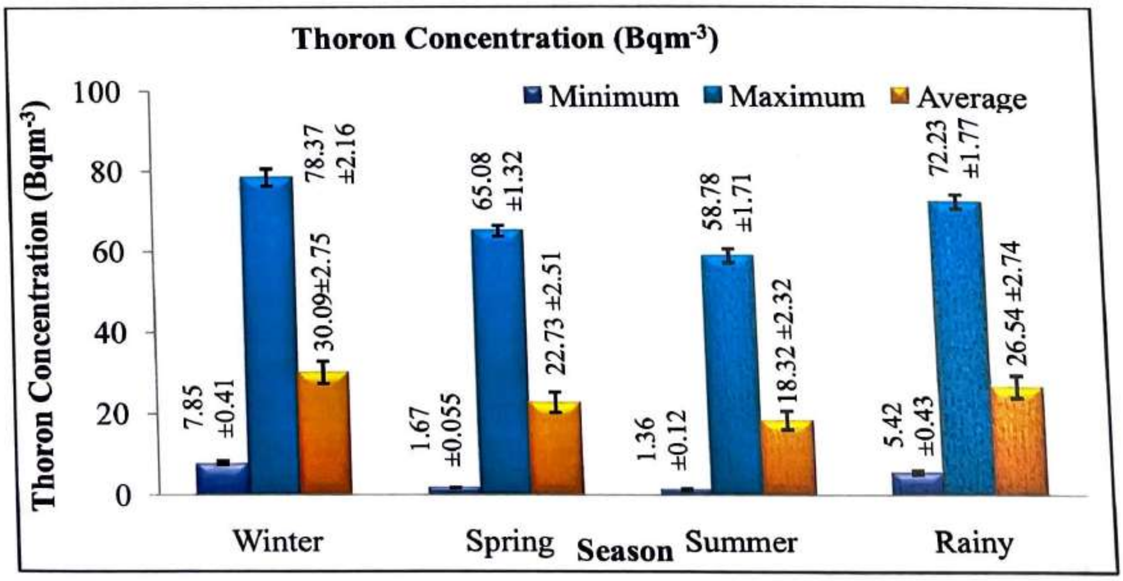


Figure 4.10: Graphical variations of thoron concentration in the dwellings nearby Fly ash dumping sites situated in Faridabad, Haryana during all the seasons of a year

Seasonal variation of Potential Alpha Energy Concentration (PAEC) due to radon and thoron progeny nearby fly ash dumping site situated in Faridabad are shown in table 4.10. Maximum value of PAEC due to radon progeny during all the four seasons of a year was found to be 15.11±0.32 mWL during the winters (October-January) and minimum value was found to be 0.72±0.03 mWL during the summer (April-July). Whereas, maximum value of PAEC due to thoron progeny during all the four seasons of a year was found to be 2.12±0.06 mWL during winters (October-January) and minimum value was found to be 0.04±0.01 mWL during summer (April-July).

Location	Seasonal variations of PAEC (Rn) mWL				Seasonal variations of PAEC (Th) mWL			
	Winter	Spring	Summer	Rainy	Winter	Spring	Summer	Rainy
FFAD-1	15.11 ±0.32	14.04 ±0.29	13.26 ±0.57	14.39 ±0.15	2.12 ±0.06	1.76 ±0.04	1.59 ±0.05	1.95 ±.05
FFAD-2	8.91 ±0.18	8.32 ±0.17	7.18 ±0.28	8.36 ±0.38	1.19 ±0.05	1.07 ±0.03	0.87 ±0.06	1.18 ±0.08
FFAD-3	7.55 ±0.21	6.51 ±0.19	5.36 ±0.20	6.84 ±0.27	0.99 ±0.03	0.77 ±0.06	0.63 ±0.06	0.94 ±0.09
FFAD-4	6.34 ±0.24	5.58 ±0.13	4.42 ±0.26	5.93 ±0.36	0.83 ±0.05	0.60 ±0.04	0.45 ±0.04	0.73 ±0.07
FFAD-5	5.83 ±0.35	4.36 ±0.09	3.75 ±0.21	5.30 ±0.43	0.73 ±0.02	0.56 ±0.02	0.42 ±0.03	0.63 ±0.04
FFAD-6	4.47 ±0.18	3.32 ±0.13	2.47 ±0.16	3.77 ±0.25	0.67 ±0.03	0.47 ±0.02	0.35 ±0.01	0.54 ±0.02
FFAD-7	3.97 ±0.05	2.21 ±0.04	1.66 ±0.08	3.01 ±0.15	0.58 ±0.02	0.39 ±0.01	0.27 ±0.02	0.45 ±0.03
FFAD-8	2.91 ±0.05	1.65 ±0.03	1.17 ±0.07	2.09 ±0.12	0.49 ±0.01	0.33 ±0.01	0.23 ±0.01	0.39 ±0.01
FFAD-9	1.76 ±0.05	1.37 ±0.03	0.92 ±0.04	1.57 ±0.04	0.32 ±0.01	0.15 ±0.01	0.10 ±0.01	0.21 ±0.01
FFAD-10	1.91 ±0.06	1.11 ±0.03	0.72 ±0.03	1.38 ±0.05	0.21 ±0.01	0.05 ±0.001	0.04 ±0.01	0.15 ±0.01
AV±SE*	5.88 ±0.55	4.85 ±0.55	4.09 ±0.53	5.26 ±0.54	0.81 ±0.07	0.61 ±0.07	0.50 ±0.06	0.72 ±0.07

* SE (standard error)= $\sigma/\sqrt{N}$, where σ is SD (standard deviation) and N is no. of observations

Table 4.10: Seasonal variations of PAEC due to radon and thoron progeny in the dwellings nearby fly ash dumping site situated in Faridabad, Haryana

Variation in the exposure due to radon and thoron progeny in WLM calculated from the equation 4.5 on the seasonal basis in the dwellings nearby fly ash dumping site situated in Faridabad are shown in table 4.11. The maximum value of exposure due to radon daughters is 151.13×10^{-3} WLM during winter (October-January) whereas, minimum value is 7.24×10^{-3} WLM during summer (April-July) season. Similarly, maximum exposure due to thoron daughters is 21.18×10^{-3} WLM during winter (October-January) and minimum value is 0.37×10^{-3} WLM during summer (April-July).

Location	Seasonal variation of exposure due to radon progeny (WLMx10^{-3})				Seasonal variation of exposure due to thoron progeny (WLMx10^{-3})			
	Winter	Spring	Summer	Rainy	Winter	Spring	Summer	Rainy
FFAD-1	151.13	140.44	132.61	143.89	21.18	17.59	15.89	19.52
FFAD-2	89.10	83.22	71.76	83.62	11.87	10.65	8.69	11.83
FFAD-3	75.50	65.08	53.56	68.38	9.94	7.70	6.26	9.39
FFAD-4	63.41	55.83	44.21	59.29	8.29	5.96	4.53	7.26
FFAD-5	58.31	43.56	37.54	53.01	7.33	5.64	4.24	6.34
FFAD-6	44.74	33.22	24.70	37.65	6.72	4.69	3.51	5.35
FFAD-7	39.70	22.11	16.55	30.05	5.78	3.94	2.71	4.52
FFAD-8	29.12	16.55	11.72	20.99	4.88	3.29	2.34	3.94
FFAD-9	17.64	13.74	9.15	15.66	3.20	1.51	0.97	2.12
FFAD-10	19.06	11.13	7.24	13.82	2.12	0.45	0.37	1.47
Average	58.77	48.49	40.90	52.63	8.13	6.14	4.95	7.17

Table 4.11: Seasonal variations of exposure due to radon and thoron progeny in the dwellings nearby fly ash dumping site situated in Faridabad, Haryana

Annual exposure as a cumulative effect of exposure during all the four seasons of a year from table 4.11 due to radon and thoron daughters both is shown in table 4.12.

Location	Annual exposure due to Radon (WLMx10^{-3})	Annual exposure due to Thoron (WLMx10^{-3})	Annual exposure due to (Rn+Th) (WLMx10^{-3})	Annual effective dose (mSv)
FFAD-1	568.07	74.18	642.25	2.46
FFAD-2	327.70	43.04	370.74	1.42
FFAD-3	262.52	33.29	295.81	1.13
FFAD-4	222.74	26.04	248.78	0.95
FFAD-5	192.42	23.55	215.97	0.83
FFAD-6	140.31	20.27	160.58	0.61
FFAD-7	108.41	16.95	125.36	0.48
FFAD-8	78.38	14.45	92.83	0.35
FFAD-9	56.19	7.80	63.99	0.24
FFAD-10	51.25	4.41	55.66	0.21
Average	200.79	26.39	227.18	0.87

Table 4.12: Annual exposure due to radon and thoron progeny and annual effective dose in the dwellings nearby fly ash dumping site situated in Faridabad, Haryana

The annual exposure due to radon progeny varies from 51.25×10^{-3} WLM to 568.07×10^{3} WLM with an average value of 200.79×10^{-3} WLM. Annual exposure due to thoron progeny varies from 4.41×10^{-3} WLM to 74.18×10^{-3} WLM with an average value of 26.39×10^{-3} WLM. Annual exposure due to radon and thoron daughters was converted into annual effective dose by using dose conversion factors; for radon daughters 3.88 mSv per WLM [46] is dose conversion factor for the members of the public, whereas for thoron daughters the conversion factor is 3.4 mSv per WLM [50]. Annual effective dose varies from 2.46 mSv to 0.21 mSv with an average value of 0.87 mSv.

Variations in the inhalation dose for the dwellers living nearby fly ash dumping site situated in Faridabad during all the four seasons of a year are shown in table 4.13. The maximum inhalation dose is 5.53 mSv/y during winter (October-January) and minimum value of inhalation dose is 0.2 mSv/y during summer (April-July). Maximum values of inhalation dose were found inside the cave of a temple whereas; maximum value for the dwellers living at the nearest location from the fly ash dumping site is 3.21 mSv/y (FFAD-2) during winter (October-January).

Location	Seasonal Inhalation dose (mSv/y)			
	Winter	Spring	Summer	Rainy
FFAD-1	5.53	4.96	4.6	5.21
FFAD-2	3.21	2.96	2.5	3.07
FFAD-3	2.71	2.26	1.9	2.49
FFAD-4	2.27	1.88	1.5	2.08
FFAD-5	2.06	1.55	1.3	1.85
FFAD-6	1.68	1.22	0.9	1.38
FFAD-7	1.47	0.88	0.6	1.23
FFAD-8	1.34	0.69	0.5	0.85
FFAD-9	0.71	0.47	0.3	0.57
FFAD-10	0.65	0.31	0.2	0.47
Average	2.14	1.72	1.4	1.91

Table 4.13: Seasonal variations of inhalation dose in dwellings nearby fly ash dumping site situated in Faridabad, Haryana

Effective dose for the inhabitants during all the seasons of a calendar year and annual effective dose calculated from annual exposure due to radon and thoron daughters is shown in table 4.14. Maximum effective dose (0.65 mSv) was found during winters and minimum dose (0.03 mSv) was found in summers as shown in figure 4.11.

Location	Effective dose on seasonal basis (mSv)				Annual effective dose (mSv)
	Winter	Spring	Summer	Rainy	
FFAD-1	0.65	0.60	0.56	0.61	2.46
FFAD-2	0.38	0.35	0.30	0.36	1.42
FFAD-3	0.32	0.27	0.23	0.29	1.13
FFAD-4	0.27	0.23	0.18	0.25	0.95
FFAD-5	0.25	0.19	0.16	0.22	0.83
FFAD-6	0.19	0.14	0.11	0.16	0.61
FFAD-7	0.17	0.10	0.10	0.13	0.48
FFAD-8	0.13	0.10	0.10	0.10	0.35
FFAD-9	0.10	0.06	0.04	0.07	0.24
FFAD-10	0.10	0.04	0.03	0.06	0.21
Average	0.25	0.21	0.17	0.22	0.87

Table 4.14: Seasonal variations of effective dose and annual effective dose in dwellings nearby fly ash dumping site situated in Faridabad, Haryana

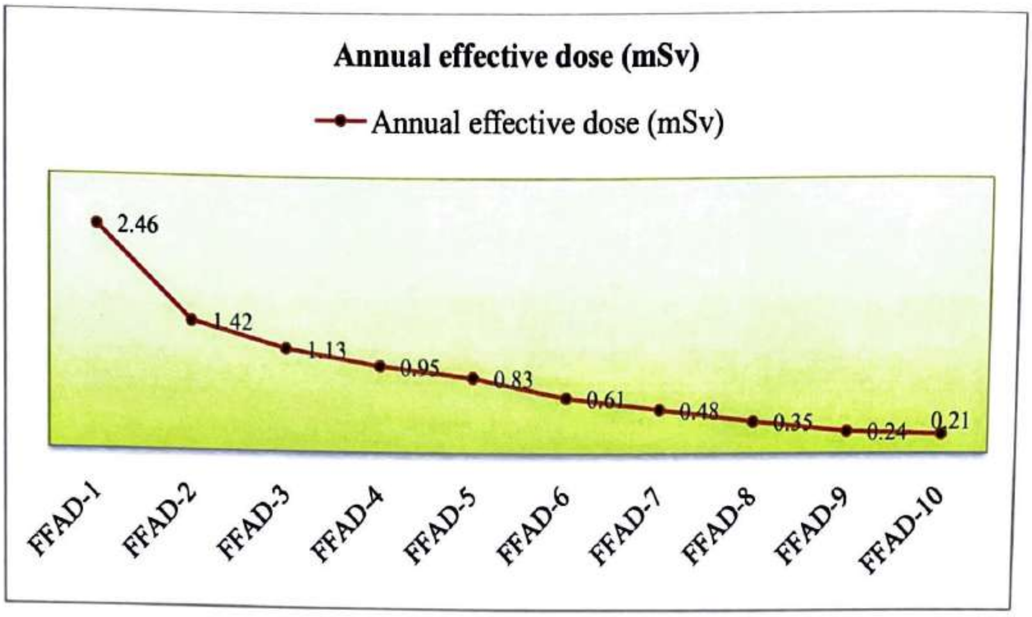


Figure 4.11: Graphical variations of annual effective dose in the dwellings nearby fly ash dumping site situated in Faridabad, Haryana during all the seasons of a year

4.1.6. Conclusion

- Huge combustion of coal produce large quantity of fly ash and the problems related with their safe management and disposal has become a major challenge to environmentalists and scientists. This study was carried out for radon, thoron and their progeny measurements in dwellings near the fly ash dumping site situated in Faridabad during all the four seasons of a calendar year.
- Results indicate that there is variation in radon and thoron concentration during the different seasons of a year. The maximum values of radon and thoron concentration were found in winter season which is normally expected, because the dwellers remains the doors and windows of their house closed to maintain the thermal comfort and minimum values were found during summer because of proper exchange rate of air.
- The highest value of radon and thoron concentration was found to be 139.79±6.55 Bqm^{-3} and 78.37±2.16 Bqm^{-3} during winter, inside the cave of a temple (FFAD-1) nearby the dumping site because there is no any provision for ventilation.
- Dwellings nearest to the dumping site (FFAD-2) have higher concentration of radon and thoron as compared to other dwellings and maximum value of radon and thoron concentration for the nearest dwellers was found to be 76.98±1.58 Bqm^{-3}and 39.39±1.20 Bqm^{-3} respectively as shown in table 4.9.

- As the distance of dwellings from the dumping site increases the radon and thoron concentration decrease. Data reveal that the radon and thoron concentrations for the dwellings nearest to the dumping site (FFAD-2) are within permissible levels of 100 Bqm^{-3} as recommended by various regulatory bodies. Variation in the concentration during the different seasons is because of different ventilation conditions, house structure and their distances from the dumping sites.

4.2 CASE STUDY-II

In the second case study of this chapter the results are incorporated for the dwellings in high rise buildings situated in Faridabad, Haryana during all the seasons of a year from January 2014-January 2015.

4.2.1. Introduction

As the developments in trade, science and technology is going to be progressive, simultaneously there is a progression in Indian population also. This evolution in the population and technology changes the life style of peoples and turned them towards the modern Indian civilization [52]. In the modern life style, population is floating towards the nearby cities, and the agriculture which was main source of occupation slowly changing their way in the field of industry and commerce. All over the India, need of higher education and jobs in the corporate society is also an attraction for the population to migrate towards the urban area [53]. All these factors populate the Indian cities and demands for the urban expansion but, little possibility of horizontal expansion creates the unavoidable space problem. So, Vertical expansion is an alternate to fulfill the growing demand of housing. The buildings with vertical expansion are known as high rise buildings, tall buildings or Towers. In the ancient time high rise buildings was constructed for temples and churches etc. But, in this modern era high rise buildings are in fashion for residential and commercial purposes. There are some reasons to adopt the style of high rise building (Towers) and they are as follows [54]:

1. Pressure on limited available land to fulfill the demand of housing in urban society.
2. Sky touching price of lands

3. Restriction on the usage of agricultural and its adjacent land
4. Attraction towards the modern life style and
5. To provide the accommodation to as much people as possible.

Construction of vertical buildings or Towers in the developed countries (United State, Germany, France, China, United Kingdom, Japan and Canada etc.) was started from the early twentieth century whereas, In India a developing country it starts from the second half of the century and most of the vertical buildings was in Mumbai [52]. D. M. Sundrani reported that all over the world the largest building is Burj Khalifa situated in Dubai and its height is 828 meter [55]. Saudi Arabia planned for Kingdom Tower whose height is 1000 meter to beat the height of Burj Khalifa.

In India, a building larger than 23 m (7 to 10 stories) is considered as high-rise building. The Mumbai Municipal Corporation categorizes a building as high rise if its height is 30 m (nine floors). In the early years, height of tallest building in Pune was 36 meter and later on PMC (Pune Municipal Corporation) permitted the construction of 100 meter Tower. Now, developers planned for Gateway Tower 1 whose height is 150 meter. In India, Mumbai is experiencing an immense construction with thousands of vertical buildings. More than 2500 vertical buildings were constructed by this time and a number of buildings are under construction [53]. So it is clear that In India, trend of high rise buildings is very common to fulfill the demand of urban expansion.

From the above stated literature it is clear that in India cities, high rise buildings are only alternate to fulfill the growing demand of housing and that's why people spent most of their time in high rise structure for the domestic and commercial purposes. Unlikely the horizontal or detached houses, the vertical buildings are closely packed and poorly ventilated. Lawrence reported that the study of indoor residential environment is the only factor important to the quality of life and health [56]. So, health and hygiene point of view study of radon and thoron estimation of these buildings is necessary.

It was little possible that the elevated level of radon and thoron concentration was found in the vertical apartments but it is very common. A survey in high rise buildings situated in Hong Kong beep an alarm for the estimation of indoor radon, thoron and their progeny levels [57-59] and it is well known that radon is second leading cause of lung cancer after smoking [60].

Radon is present everywhere in the natural environment because it comes from the decay chain of uranium which is present in the earth's crust. Half- life of radon is 3.824 days and because of its long half- life it's not a problem in itself, but its progeny contributes a major part of natural radiation dose to general population. Radioactive breakdown of uranium in soil, rock and water leads to its formation naturally. In the outdoor air, radon concentration is low and not of any concern but inside the buildings it can accumulate up to high concentration. Indoor radon and thoron concentration changes from one apartment to another apartment and it can be affected by various parameters such as [61].

1. Soil under the building
2. Building materials used for construction
3. Design of building
4. Life style of occupants
5. Local geology
6. Wind speed and Weather
7. Height above the ground
8. Behavior of inhabitant either smoker or non-smoker and
9. Ventilation conditions

Among all of them soil and building material are two main sources of indoor radon and thoron concentration and it can easily migrate in the building through different routes such as cracks in the concrete blocks, major joints and loose fittings [62]. A number of researchers show that building material used in the construction is a leading contributor for indoor radon accumulation in high rise buildings [63-65]. Although major exposure is due to radon emanation but F. Steinhäusler reported that thoron emanation from building materials cannot be ignored and researcher renew their interest and report the thoron exposure from building materials [66-69]. Whereas, in some other countries, entry of soil gas is a key source of indoor radon concentration mainly in low rise residential apartments [70-71].

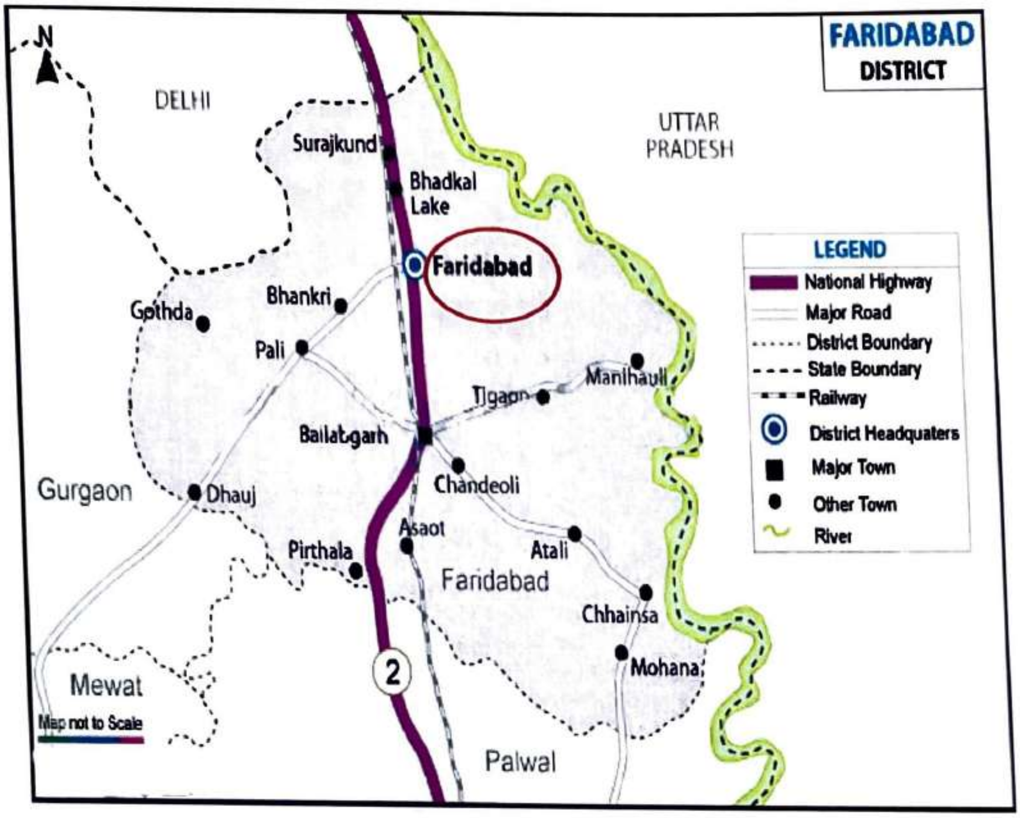
Sooner or later ventilation rate of any building also plays an important role to the indoor radon level and therefore the observation of ventilation condition in high rise buildings becomes an important issue for researcher to check the indoor air quality [72].

From the above stated literature it is clear that there are various parameters that sound for the radiological estimations in high rise buildings. So, Health and hygiene point of view, in the second case study of this chapter, radon, thoron and their progeny levels were estimated in dwellings of high rise buildings situated in Faridabad (southern Haryana), India during all the four seasons of a year. This study was necessary because Faridabad is the largest city and one of the major industrial and educational hubs of Haryana so there is a lot of migration from surrounding areas to this region. To fulfill the needs of growing population, in the last decade there has been an upsurge in the establishment of high rise buildings in the region.

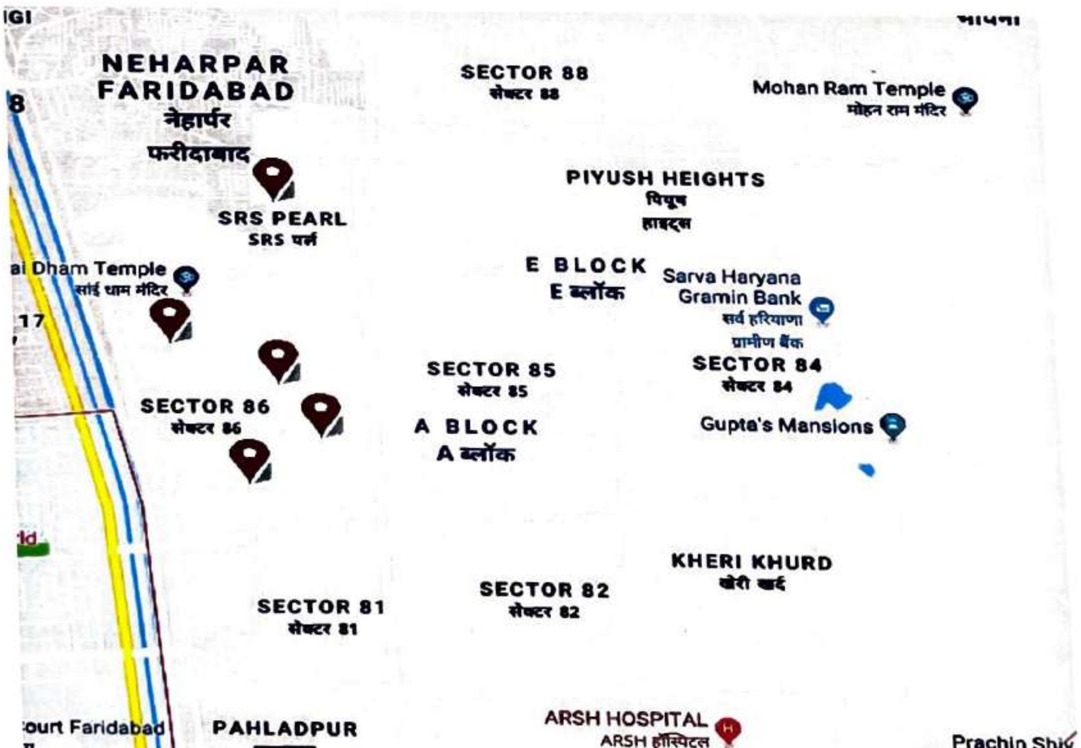
4.2.2 About The Study Area

In the present case study the measurements were carried in the dwellings of high rise buildings developed newly in the Greater Faridabad, Haryana. This area is developed between the Agra Canal and Yamuna River and usually known as Neharpar Faridabad. The study area lies at 28°25′15.96" N Latitude and 77°18′ 28.08″ E Longitude. It is bordered by Delhi to its North, from North East to Noida, from east to Greater Noida and connected to Gurugram from its west. The general details about the study are:

1. The study was carried out for all the four seasons of a calendar year: winter (October-January), spring (January-April), summer (April-July) and rainy (July-October). Duration of the present study was from January 2014 to January 2015.
2. In the present study, total five high rise buildings (towers) were selected from ground to the ninth floor in the same society. To represent the precise data, dwellings were selected on the uniformity of same ventilation condition and same building materials. For an individual season data of 50 dwellings were collected.
3. In every dwelling twin cup dosimeters loaded with LR-115 type II detectors were exposed for the seasonal assessment of radiological exposure and in total 150 Twin cup dosimeters (3 at each floor) were installed in the dwellings of high rise buildings during the study of every season and procedure was repeated for all the four seasons of a year. City and location map are shown in photograph 4.3 and 4.4.



Photograph 4.3: Faridabad District Map



Photograph 4.4: Location Map of Dwellings of High Rise Buildings

4.2.3 Experimental Technique

For the measurements of radon and thoron concentration, PAEC due to radon and thoron progeny, inhalation dose, annual exposure due to radon and thoron progeny and annual effective dose; track etch technique using Solid State Nuclear Track Detector was used. Detail of this technique has been discussed in chapter 3 under section 3.8.

4.2.4 Formulas used

The radon and thoron concentration was calculated using equations 4.1 and 4.2 and Potential Alpha Energy concentration due to radon and thoron progeny was calculated using equation 4.3 of this chapter under the subsection 4.1.4. The inhalation dose due to radon and thoron in mSv/y was estimated using the equation 4.4 under the section 4.1.5 of this chapter.

4.2.5 Results and Discussion

In the present case study the results were calculated for radon and thoron concentration, PAEC due to radon and thoron progeny, Inhalation dose, exposure due to radon and thoron progeny and annual effective dose during all the four seasons of a calendar year and mentioned below in the tabular form according to the season.

(i) Results for spring season (January 2014-April 2014)

The calculated values of radon and thoron concentration and potential alpha energy concentration (PAEC) due to radon and thoron progeny from the samples collected from the dwellings of high rise buildings situated in Faridabad during the spring season (January 2014-April 2014) using equations 4.1- 4.3 discussed under section 4.1.4 in this chapter are presented in table 4.15. The radon concentration varies from 12.15±0.24 Bqm^{-3} (at ninth floor) to 47.79±0.67 Bqm^{-3} (at ground floor) with an average value of 25.03±1.75 Bqm^{-3}. The thoron concentration varies from 6.79±0.66 Bqm^{-3} (at ninth floor) to 22.55±1.07 Bqm^{-3} (at ground floor) with an average value of 11.78±0.72 Bqm^{-3}. The graphical variations of radon and thoron concentration at different selected locations are shown in figure 4.12 and figure 4.13 respectively.

Location	Radon concentration C_R (Bq m^{-3})	Thoron concentration C_T (Bq m^{-3})	PAEC (Rn) (mWL)	PAEC (Th) (mWL)
G-0	47.79±0.67	22.55±1.07	5.17±0.07	0.61±0.03
G-1	40.75±0.71	17.28±0.68	4.41±0.08	0.47±0.02
G-2	36.93±0.40	14.89±0.10	3.99±0.04	0.40±0.03
G-3	29.41±0.34	12.43±0.75	3.18±0.04	0.34±0.02
G-4	22.72±0.57	10.32±0.96	2.46±0.06	0.28±0.03
G-5	16.84±0.24	9.35±0.32	1.82±0.03	0.25±0.01
G-6	15.79±0.44	8.68±0.63	1.71±0.05	0.23±0.02
G-7	14.59±0.58	8.06±0.77	1.58±0.06	0.22±0.02
G-8	13.35±0.37	7.40±0.52	1.44±0.04	0.20±0.01
G-9	12.15±0.24	6.79±0.66	1.31±0.03	0.18±0.02
Av±SE*	25.03±1.75	11.78±0.72	2.71±0.19	0.32±0.02

* SE (standard error)= $\sigma/\sqrt{N}$, where σ is SD (standard deviation) and N is no. of observations

Table 4.15: Radon and thoron concentration and PAEC due to radon and thoron progeny in the dwellings of high rise buildings during spring season

Table 4.15 shows that PAEC due to radon and thoron progeny varies from 1.31±0.03 mWL (at ninth floor) to 5.17±0.07 mWL (at ground floor) with an average value of 2.71±0.19 mWL and 0.18±0.02 mWL (at ninth floor) to 0.61±0.03 mWL (at ground floor) with an average value of 0.32±0.02 mWL respectively.

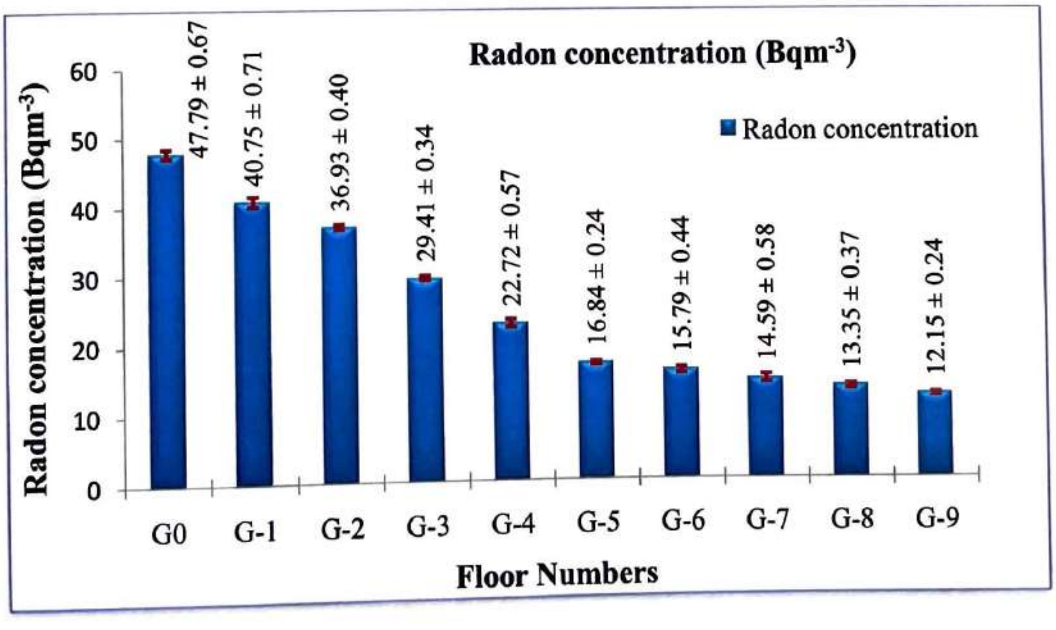


Figure 4.12: Graphical variations of radon concentration in the dwellings of high rise buildings during spring season

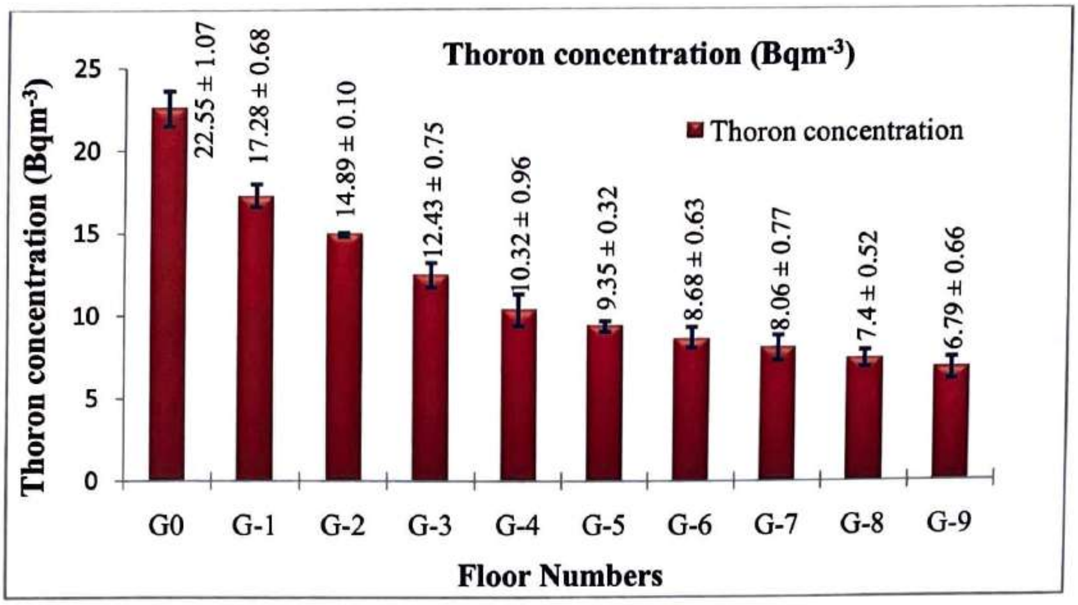


Figure 4.13: Graphical variations of thoron concentration in the dwellings of high rise buildings during spring season

From the observations and graphical representation it is clear that maximum value of radon and thoron concentration and PAEC due to radon and thoron progeny was found at the ground floor of each building and this is due to the vicinity of ground floor to the soil and poor exchange rate of air as compared to the other floors of the tower.

The annual exposure to the general public is 0.412 WLM with a PAEC of 1 mWL. In seasonal study, exposure due to radon and thoron progeny was calculated from equation 4.5 for duration of 90 days (exposure time of each season) and for the spring season the results are shown in table 4.16. The seasonal exposure due to radon and thoron progeny varies from 13.13×10^{-3} WLM (at ninth floor) to 51.66×10^{-3} WLM (at ground floor) with an average value of 27.06×10^{-3} WLM and 1.83×10^{-3} WLM (at ninth floor) to 6.09×10^{-3} WLM (at ground floor) with an average value of 3.18×10^{-3} WLM respectively.

The exposure due to radon and thoron progeny was converted into effective dose by using dose conversion factors; 3.88 mSv per WLM for radon daughter [46], whereas for thoron daughters the conversion factor is 3.4 mSv per WLM [50]. Effective dose calculated from these generic relations and inhalation dose calculated from equations 4.4 are shown in table 4.16. The inhalation dose varies from 0.48 mSv/y (at ninth floor) to 1.79 mSv/y (at ground floor) with an average value of 0.94 mSv/y. The cumulative effective dose calculated from the exposure due to radon and thoron daughters during the spring season varies from 0.06 mSv (at ninth floor) to 0.22 mSv (at ground floor) with an average value of 0.12 mSv. Whereas, the effective dose for the dwellers of ground floor is 0.19 mSv.

Location	Exposure due to radon (Rn) ($WLM x 10^{-3}$)	Exposure due to thoron (Th) ($WLM x 10^{-3}$)	Exposure due to (Rn+Th) ($WLM x 10^{-3}$)	Inhalation dose D (mSv/y)	Effective dose (mSv)
G-0	51.66	6.09	57.75	1.79	0.22
G-1	44.05	4.67	48.72	1.48	0.19
G-2	39.92	4.02	43.94	1.33	0.17
G-3	81.80	3.36	35.16	1.07	0.33
G-4	24.56	2.79	27.35	0.84	0.11
G-5	18.20	2.53	20.73	0.66	0.08
G-6	17.07	2.35	19.42	0.62	0.07
G-7	15.77	2.18	17.95	0.57	0.07
G-8	14.43	2.00	16.43	0.53	0.06
G-9	13.13	1.83	14.96	0.48	0.06
Average	27.06	3.18	30.24	0.94	0.12

Table 4.16: Exposure due to radon and thoron progeny, inhalation dose and effective dose in the dwellings of high rise buildings during spring season

(ii) Results for summer season (April 2014-July 2014)

The calculated values of radon and thoron concentration and potential alpha energy concentration (PAEC) due to radon and thoron progeny from the samples collected from the dwellings of high rise buildings situated in Faridabad during the summer season (April 2014-July 2014) are presented in table 4.17. The radon concentration varies from 8.68±0.57 Bqm^{-3} (at ninth floor) to 35.65±0.95 Bqm^{-3} (at ground floor) with an average value of 20.89±1.26 Bqm^{-3}. Similarly the thoron concentration varies from 5.21±0.53 Bqm^{-3} (at ninth floor) to 17.91±0.49 Bqm^{-3} (at ground floor) with an average value of 10.66±0.61 Bqm^{-3}. The graphical variations of radon and thoron concentration at different selected locations are shown in figure 4.14 and figure 4.15.

Location	Radon concentration C_R (Bq m^{-3})	Thoron concentration C_T (Bq m^{-3})	PAEC (Rn) (mWL)	PAEC (Th) (mWL)
G--0	35.65±0.95	17.91±0.49	3.85±0.10	0.48±0.01
G-1	30.18±1.26	14.89±0.70	3.26±0.14	0.40±0.02
G-2	27.62±1.51	12.77±1.13	2.99±0.16	0.35±0.03
G-3	24.41±0.28	12.29±0.64	2.64±0.03	0.33±0.02
G-4	21.99±1.20	10.72±1.49	2.38±0.13	0.29±0.04
G-5	18.34±0.58	9.20±1.29	1.98±0.06	0.25±0.04
G-6	16.69±0.69	8.58±0.41	1.80±0.07	0.23±0.01
G-7	13.55±0.44	8.19±0.56	1.46±0.05	0.22±0.02
G-8	11.81±0.47	6.84±0.30	1.28±0.05	0.19±0.01
G-9	8.68±0.57	5.21±0.53	0.94±0.06	0.14±0.01
AV±SE*	20.89±1.26	10.66±0.61	2.26±0.14	0.29±0.02

* SE (standard error)= $\sigma/\sqrt{N}$, where σ is SD (standard deviation) and N is no. of observations

Table 4.17: Radon and thoron concentration and PAEC due to radon and thoron progeny in the dwellings of high rise buildings during summer season

From table 4.17 it is clear that the calculated values of PAEC due to radon and thoron progeny varies from 0.94±0.06 mWL (at ninth floor) to 3.85±0.10 mWL (at ground floor) with an average value of 2.26±0.14 mWL and 0.14±0.01 mWL (at ninth floor) to 0.48±0.01 mWL (at ground floor) with an average value of 0.29±0.02 mWL respectively. From the observations it is clear that maximum value of radon and thoron concentration was found at the ground floor of each building and this is due to the vicinity of ground floor to the soil and poor exchange rate of air as compared to the other floors of the tower. Radon and thoron concentration during summer season found comparatively less than the spring season as shown in table 4.15. This is because of the fact that the dwellers kept their doors and windows open during summer season for proper exchange of air.

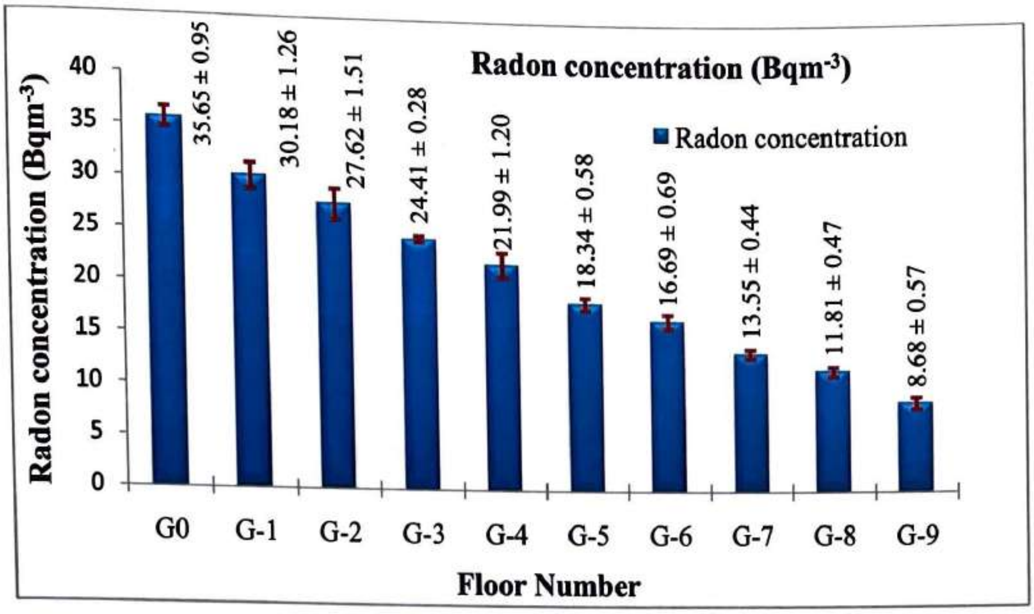


Figure 4.14: Graphical variations of radon concentration in the dwellings of high rise buildings during summer season

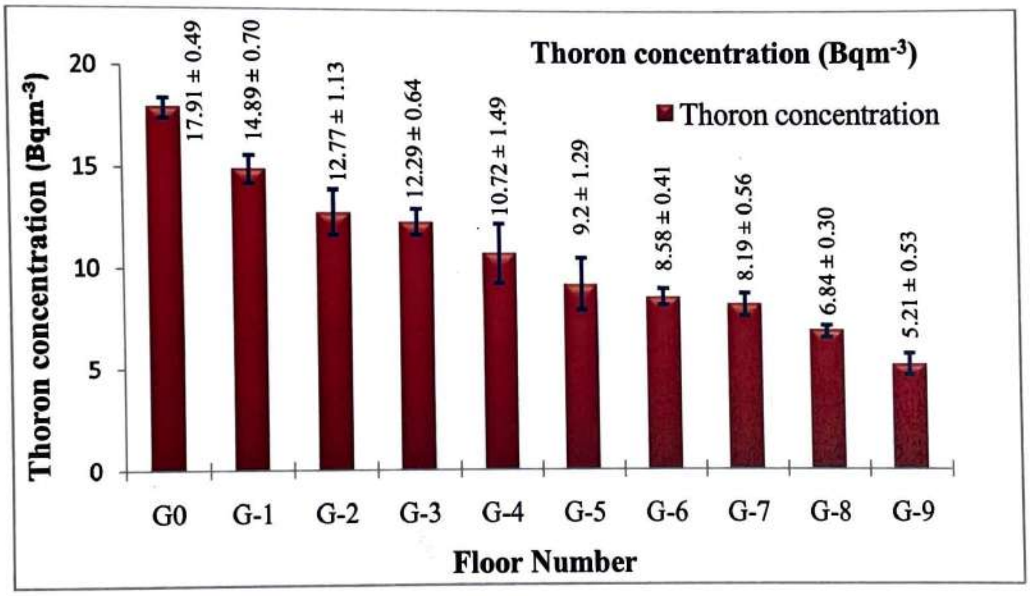


Figure 4.15: Graphical variation of thoron concentration in the dwellings of high rise buildings during summer season

In seasonal study, exposure due to radon and thoron progeny was calculated from equation 4.5 for duration of 90 days (exposure time of each season) and for the spring season the results are shown in table 4.18. The annual exposure to the general public is 0.412 WLM with a PAEC of 1 mWL. The seasonal exposure due to radon and thoron progeny varies from 9.39×10^{-3} WLM (at ninth floor) to 38.54×10^{-3} WLM (at ground floor) with an average value of 22.59×10^{-3} WLM and 1.41×10^{-3} WLM (at ninth floor) to 4.84×10^{-3} WLM (at ground floor) with an average value of 2.88×10^{-3} WLM respectively.

Location	Exposure due to Radon (Rn) (WLMx10^{-3})	Exposure due to Thoron (Th) (WLMx10^{-3})	Exposure due to (Rn+Th) (WLMx10^{-3})	Inhalation dose D (mSv/y)	Effective dose (mSv)
G-0	38.54	4.84	43.88	1.36	0.17
G-1	32.63	4.03	36.66	1.15	0.14
G-2	29.86	3.45	33.31	1.03	0.13
G-3	26.39	3.32	29.71	0.93	0.11
G-4	23.77	2.90	26.67	0.83	0.10
G-5	19.82	2.49	22.31	0.70	0.09
G-6	18.04	2.32	20.36	0.64	0.08
G-7	14.64	2.21	16.85	0.55	0.06
G-8	12.77	1.85	14.62	0.47	0.06
G-9	9.39	1.41	10.80	0.35	0.04
Average	22.59	2.88	25.47	0.80	0.10

Table 4.18: Exposure due to radon and thoron progeny, inhalation dose and effective dose in the dwellings of high rise buildings during summer season

The exposure due to radon and thoron progeny was converted into effective dose by using dose conversion factors; for radon daughter the dose conversion factor for members of the public is 3.88 mSv per WLM [46], whereas for thoron daughters the conversion factor is 3.4 mSv per WLM [50]. Effective dose calculated from these generic relations and inhalation dose calculated from equations 4.4 are shown in table 4.18. The inhalation dose varies from 0.35 mSv/y (at ninth floor) to 1.36 mSv/y (at ground floor) with an average value of 0.80 mSv/y. The cumulative effective dose calculated from the exposure due to radon and thoron daughters during the summer season for the dwellers of high rise buildings situated in Faridabad varies from 0.04 mSv (at ninth floor) to 0.17 mSv (at ground floor) with an average value of 0.10 mSv

(iii) Results for rainy season (July 2014-October 2014)

The calculated values of radon and thoron concentration and potential alpha energy concentration (PAEC) due to radon and thoron progeny from the samples collected from the dwellings of high rise buildings situated in Faridabad during the rainy season (July 2014-October 2014) are presented in table 4.19. The radon concentration varies from 14.16±0.56 Bqm^{-3} (at ninth floor) to 62.82±0.88 Bqm^{-3} (at ground floor) with an average value of 30.51±2.35 Bqm^{-3}. The thoron concentration varies from 7.68±0.26 Bqm^{-3} (at ninth floor) to 28.85±0.53 Bqm^{-3} (at ground floor) with an average value of 14.38±1.08 Bqm^{-3}. The graphical variations of radon and thoron concentration at different selected locations are shown in figure 4.16 and figure 4.17.

Location	Radon concentration C_R (Bq m^{-3})	Thoron concentration C_T (Bq m^{-3})	PAEC (Rn) (mWL)	PAEC (Th) (mWL)
G-0	62.82±0.88	28.85±0.53	6.79±0.10	0.78±0.01
G-1	53.10±0.90	24.12±0.21	5.74±0.09	0.65±0.01
G-2	42.76±0.34	18.56±0.43	4.62±0.04	0.50±0.01
G-3	35.01±1.66	16.12±3.63	3.79±0.18	0.42±0.10
G-4	26.80±0.72	13.27±0.99	2.90±0.08	0.36±0.03
G-5	19.76±0.6	10.12±0.50	2.14±0.07	0.27±0.01
G-6	18.11±0.40	9.01±0.72	1.96±0.04	0.24±0.01
G-7	17.26±0.78	8.98±0.35	1.87±0.08	0.24±0.01
G-8	15.35±0.60	7.12±1.02	1.66±0.06	0.19±0.03
G-9	14.16±0.56	7.68±0.26	1.53±0.06	0.21±0.01
Av±SE*	30.51±2.35	14.38±1.08	3.30±0.25	0.39±0.03

* SE (standard error)= $\sigma/\sqrt{N}$, where σ is SD (standard deviation) and N is no. of observations

Table 4.19: Radon and thoron concentration and PAEC due to radon and thoron progeny in the dwellings of high rise buildings during rainy season

From table 4.19 it is clear that the calculated values of PAEC due to radon and thoron progeny varies from 1.53±0.06 mWL (at ninth floor) to 6.79±0.10 mWL (at ground floor) with an average value of 3.30±0.25 mWL and 0.21±0.01 mWL (at ninth floor) to 0.78±0.01 mWL (at ground floor) with an average value of 0.39±0.03 mWL respectively. From the observations it is clear that results are within the safety limits of 100 Bqm^{-3} given by World Health Organization (WHO).

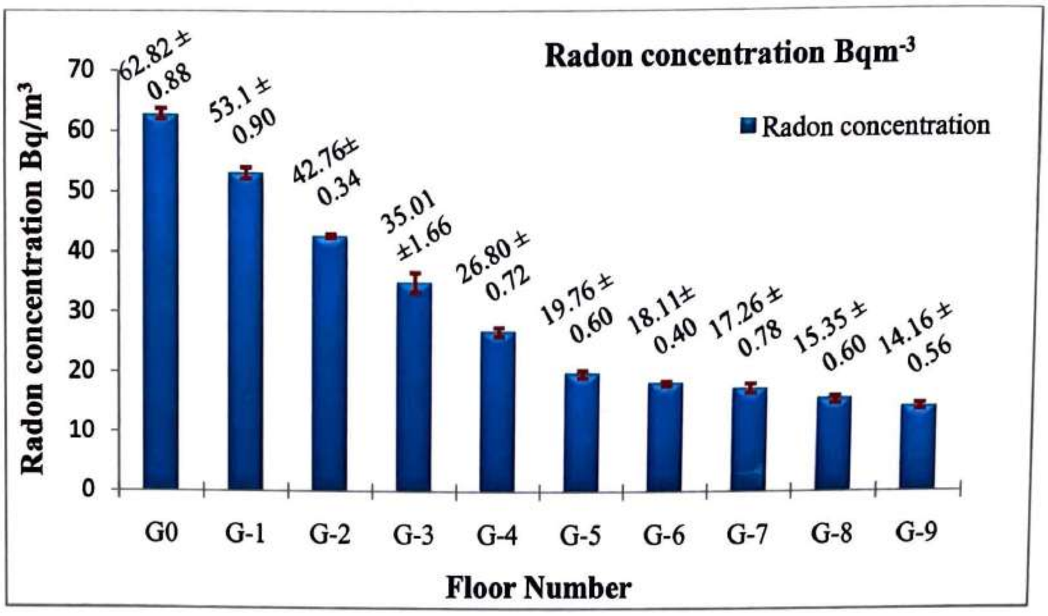


Figure 4.16: Graphical variations of radon concentration in the dwellings of high rise buildings during rainy season

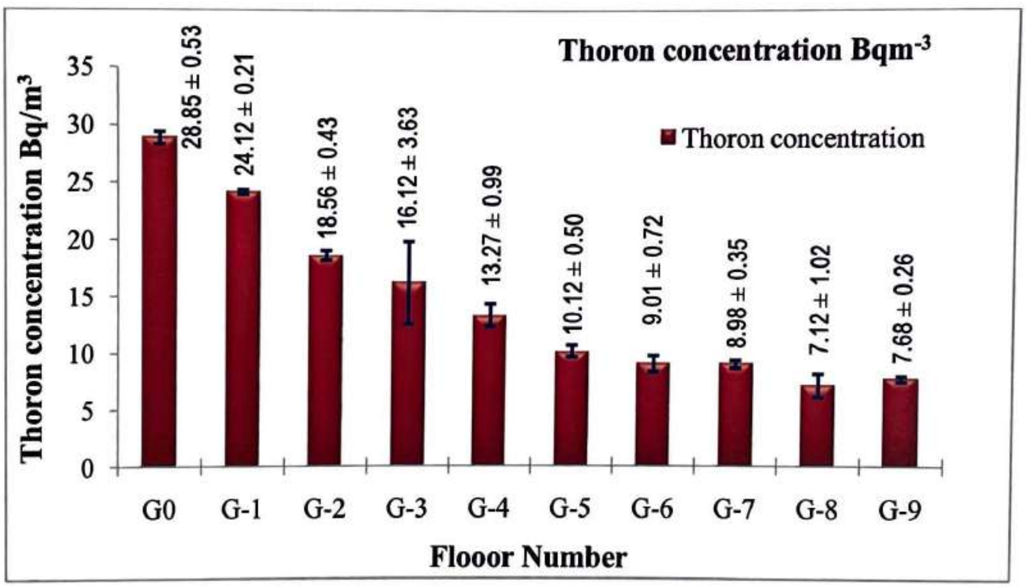


Figure 4.17: Graphical variations of thoron concentration in the dwellings of high rise buildings during rainy season

In seasonal study, exposure due to radon and thoron progeny was calculated from equation 4.5 for duration of 90 days (exposure time of each season) and for the rainy season the results are shown in table 4.20. The annual exposure to the general public is 0.412 WLM with a PAEC of 1 mWL. The seasonal exposure due to radon and thoron progeny varies from 15.31×10^{-3} WLM (at ninth floor) to 67.92×10^{-3} WLM (at ground floor) with an average value of 32.99×10^{-3} WLM and 2.08×10^{-3} WLM (at ninth floor) to 7.80×10^{-3} WLM (at ground floor) with an average value of 3.89×10^{-3} WLM respectively.

The exposure due to radon and thoron progeny was converted into effective dose by using dose conversion factors; for radon daughter the dose conversion factor for members of the public is 3.88 mSv per WLM [46], whereas for thoron daughters the conversion factor is 3.4 mSv per WLM [50]. Effective dose calculated from these generic relations and inhalation dose calculated from equations 4.4 are shown in table 4.20. The inhalation dose varies from 0.55 mSv/y (at ninth floor) to 2.34 mSv/y (at ground floor) with an average value of 1.14 mSv/y. The cumulative effective dose calculated from the exposure due to radon and thoron daughters during the summer season for the dwellers of high rise buildings situated in Faridabad varies from 0.06 mSv (at ninth floor) to 0.29 mSv (at ground floor) with an average value of 0.14 mSv.

Location	Exposure due to radon progeny (WLMx10^{-3})	Exposure due to thoron Progeny (WLMx10^{-3})	Exposure due to (Rn+Th) progeny (WLMx10^{-3})	Inhalation dose D (mSv/y)	Effective dose (mSv)
G-0	67.92	7.80	75.72	2.34	0.29
G-1	57.40	6.52	63.92	1.97	0.25
G-2	46.23	5.02	51.25	1.57	0.20
G-3	37.85	4.36	42.21	1.30	0.16
G-4	28.97	3.59	32.56	1.02	0.13
G-5	21.36	2.74	24.10	0.76	0.10
G-6	19.58	2.43	22.01	0.69	0.08
G-7	18.66	2.43	21.09	0.67	0.08
G-8	16.60	1.92	18.52	0.57	0.07
G-9	15.31	2.08	17.39	0.55	0.06
Average	32.99	3.89	36.88	1.14	0.14

Table 4.20: Exposure due to radon and thoron progeny, inhalation dose and effective dose in the dwellings of high rise buildings during rainy season

(iv) Results for winter season (October 2014-January 2015)

The calculated values of radon and thoron concentration and Potential Alpha Energy Concentration (PAEC) due to radon and thoron progeny from the samples collected from the dwellings of high rise buildings situated in Faridabad during the winter season (October 2014-January 2015) are presented in table 4.21. The radon concentration varies from 19.57±0.54 Bqm^{-3} (at ninth floor) to 78.38±0.71 Bqm^{-3} (at ground floor) with an average value of 36.27±3.01 Bqm^{-3}. The thoron concentration varies from 9.49±1.12 Bqm^{-3} (at ninth floor) to 37.08±1.74 Bqm^{-3} (at ground floor) with an average value of 17.44±1.48 Bqm^{-3}. The graphical variations of radon and thoron concentration at different selected locations are shown in figure 4.18 and figure 4.19.

Location	Radon concentration C_R (Bq m^{-3})	Thoron concentration C_T (Bq m^{-3})	PAEC (Rn) (mWL)	PAEC (Th) (mWL)
G-0	78.38±0.71	37.08±1.74	8.47±0.08	1.00±0.05
G-1	69.22±2.02	35.25±1.64	7.48±0.22	0.95±0.04
G-2	47.85±0.68	22.13±0.86	5.17±0.07	0.60±0.02
G-3	37.95±0.54	17.28±0.32	4.10±0.06	0.47±0.01
G-4	30.14±0.88	14.78±0.91	3.26±0.10	0.40±0.03
G-5	22.12±0.31	10.67±0.13	2.39±0.03	0.29±0.004
G-6	20.73±0.58	9.23±0.11	2.24±0.06	0.27±0.003
G-7	19.15±0.77	9.33±0.16	2.07±0.08	0.25±0.004
G-8	17.55±0.23	8.47±0.10	1.90±0.03	0.23±0.003
G-9	19.57±0.54	9.49±1.12	2.12±0.06	0.26±0.03
AV±SE*	36.27±3.01	17.44±1.48	3.92±0.33	0.47±0.04

* SE (standard error)= $\sigma/\sqrt{N}$, where σ is SD (standard deviation) and N is no. of observations

Table 4.21: Radon and thoron concentration and PAEC due to radon and thoron progeny in the dwellings of high rise buildings during winter Season

From table 4.21 it is clear that the calculated values of PAEC due to radon and thoron progeny varies from 2.12±0.06 mWL (at ninth floor) to 8.47±0.08 mWL (at ground floor) with an average value of 3.92±0.33 mWL and 0.26±0.03 mWL (at ninth floor) to 1.00±0.05 mWL (at ground floor) with an average value of 0.47±0.04 mWL respectively.

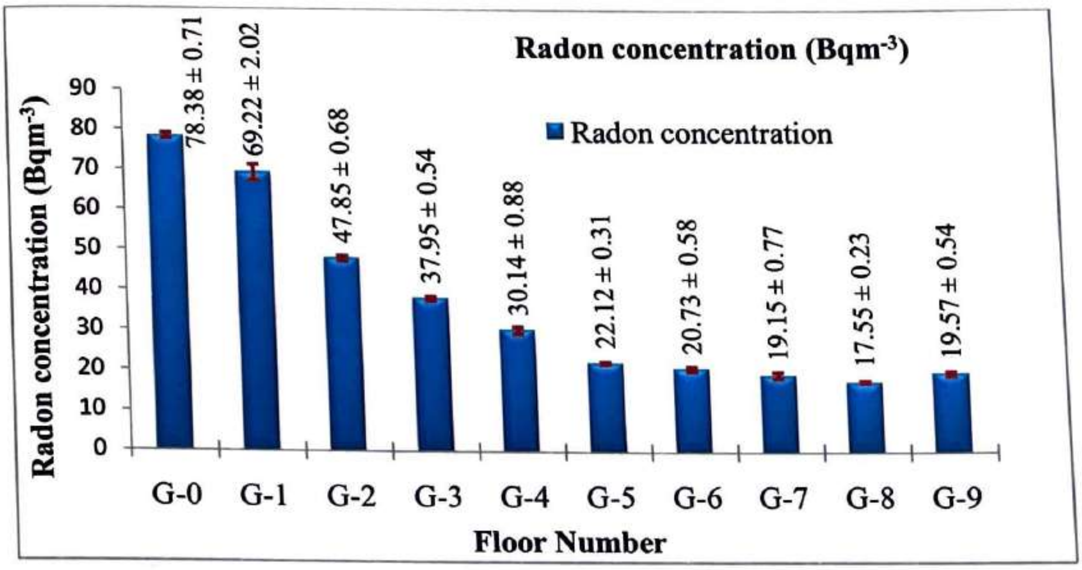


Figure 4.18: Graphical variations of radon concentration in the dwellings of high rise buildings during winter season

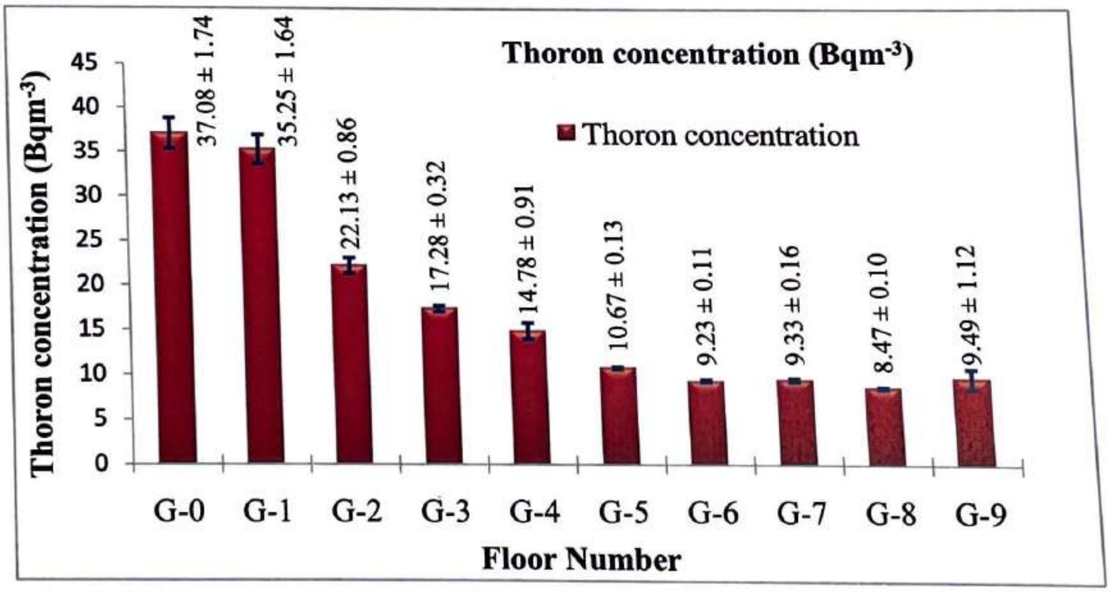


Figure 4.19: Graphical variations of thoron concentration in the dwellings of high rise buildings during winter season

In seasonal study, exposure due to radon and thoron progeny was calculated from equation 4.5 for duration of 90 days (exposure time of each season) and for the winter season the results are shown in table 4.22. The annual exposure to the general public is 0.412 WLM with a PAEC of 1 mWL. The seasonal exposure due to radon and thoron progeny varies from 21.16×10^{-3} WLM (at ninth floor) to 84.74×10^{-3} WLM (at ground floor) with an average value of 39.21×10^{-3} WLM and 2.57×10^{-3} WLM (at ninth floor) to 10.02×10^{-3} WLM (at ground floor) with an average value of 4.71×10^{-3} WLM respectively.

Location	Exposure due to radon progeny (WLMx10^{-3})	Exposure due to thoron progeny (WLMx10^{-3})	Exposure due to (Rn+Th) progeny (WLMx10^{-3})	Inhalation dose D (mSv/y)	Effective dose (mSv)
G-0	84.74	10.02	94.76	2.94	0.36
G-1	74.83	9.53	84.36	2.67	0.32
G-2	51.73	5.98	57.71	1.78	0.22
G-3	41.03	4.67	45.70	1.41	0.18
G-4	32.58	3.99	36.57	1.14	0.14
G-5	23.91	2.88	26.79	0.84	0.10
G-6	22.41	2.68	25.09	0.78	0.10
G-7	20.71	2.52	23.23	0.73	0.09
G-8	18.97	2.29	21.26	0.66	0.08
G-9	21.16	2.57	23.73	0.74	0.09
Average	39.21	4.71	43.92	1.37	0.17

Table 4.22: Exposure due to radon and thoron progeny, inhalation dose and effective dose in the dwellings of high rise buildings during winter season

The exposure due to radon and thoron progeny was converted into effective dose by using dose conversion factors; for radon daughter the dose conversion factor for members of the public is 3.88 mSv per WLM [46], whereas for thoron daughters the conversion factor is 3.4 mSv per WLM [50]. Effective dose calculated from these generic relations and inhalation dose calculated from equations 4.4 are shown in table 4.22. The inhalation dose varies from 0.74 mSv/y (at ninth floor) to 2.94 mSv/y (at ground floor) with an average value of 1.37 mSv/y. The cumulative effective dose calculated from the exposure due to radon and thoron daughters during the summer season for the dwellers of high rise buildings situated in Faridabad varies from 0.09 mSv (at ninth floor) to 0.36 mSv (at ground floor) with an average value of 0.17 mSv.

Radon and thoron concentration in the dwellings of high rise buildings situated in Faridabad during all the four seasons (winter, spring, summer and rainy) of a year are represented in table 4.23.

Location	Seasonal variations in radon concentration (C_R) (Bqm^{-3})				Seasonal variations in thoron concentration (C_T) (Bqm^{-3})			
	Winter	Spring	Summer	Rainy	Winter	Spring	Summer	Rainy
G-0	78.38 ±0.71	47.79 ±0.67	35.65 ±0.95	62.82 ±0.88	37.08 ±1.74	22.55 ±1.07	17.91 ±0.49	28.85 ±0.53
G-1	69.22 ±2.02	40.75 ±0.71	30.18 ±1.26	53.10 ±0.90	35.25 ±1.64	17.28 ±0.68	14.89 ±0.70	24.12 ±0.21
G-2	47.85 ±0.68	36.93 ±0.40	27.62 ±1.51	42.76 ±0.34	22.13 ±0.86	14.89 ±0.10	12.77 ±1.13	18.56 ±0.43
G-3	37.95 ±0.54	29.41 ±0.34	24.41 ±0.28	35.01 ±1.66	17.28 ±0.32	12.43 ±0.75	12.29 ±0.64	16.12 ±3.63
G-4	30.14 ±0.88	22.72 ±0.57	21.99 ±1.20	26.80 ±0.72	14.78 ±0.91	10.32 ±0.96	10.72 ±1.49	13.27 ±0.99
G-5	22.12 ±0.31	16.84 ±0.24	18.34 ±0.58	19.76 ±0.61	10.67 ±0.13	9.35 ±0.32	9.20 ±1.29	10.12 ±0.50
G-6	20.73 ±0.58	15.79 ±0.44	16.69 ±0.69	18.11 ±0.40	9.23 ±0.11	8.68 ±0.63	8.58 ±0.41	9.01 ±0.72
G-7	19.15 ±0.77	14.59 ±0.58	13.55 ±0.44	17.26 ±0.78	9.33 ±0.16	8.06 ±0.77	8.19 ±0.56	8.98 ±0.35
G-8	17.55 ±0.23	13.35 ±0.37	11.81 ±0.47	15.35 ±0.60	8.47 ±0.10	7.40 ±0.52	6.84 ±0.30	7.12 ±1.02
G-9	19.57 ±0.54	12.15 ±0.24	8.68 ±0.57	14.16 ±0.56	9.49 ±1.12	6.79 ±0.66	5.21 ±0.53	7.68 ±0.26
AV±SE *	36.27 ±3.01	25.03 ±1.75	20.89 ±1.26	30.51 ±2.35	17.44 ±1.48	11.78 ±0.72	10.66 ±0.61	14.38 ±1.08

* SE (standard error)= $\sigma/\sqrt{N}$, where σ is SD (standard deviation) and N is no. of observations

Table 4.23: Seasonal variations in radon and thoron concentration in dwellings of high rise buildings situated in Greater Faridabad, Haryana

Maximum value of radon concentration is 78.38±0.71 Bqm^{-3} (at ground floor) during winters (October-January) whereas; minimum value is 8.68±0.57 Bqm^{-3} (at ninth floor) during summer (April-July). Similarly, maximum value of thoron concentration is 37.08±1.74 Bqm^{-3} (at ground floor) during winter (October-January) whereas; minimum value of thoron concentration is 5.21±0.53 Bqm^{-3} (at ninth floor) during summer (April-July). Maximum values of radon and thoron concentration was found during the winter. This is because of the fact that, dwellers kept their doors closed because of fall in temperature and it reduces the ventilation rate and increases the radon and thoron concentration. Minimum values of radon and thoron concentration was found during summer because of proper air exchange. Graphical variations of radon and thoron concentration during all the four seasons of a year are shown in figure 4.20 and figure 4.21.

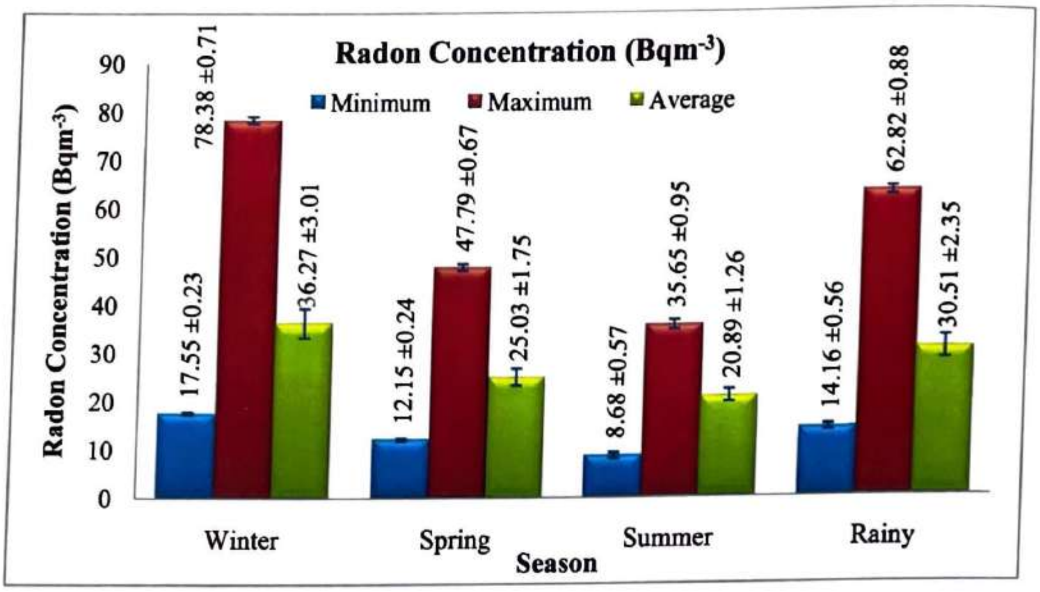


Figure 4.20: Graphical variations of radon concentration in the dwellings of high rise buildings situated in Greater Faridabad, Haryana during all the seasons of a year

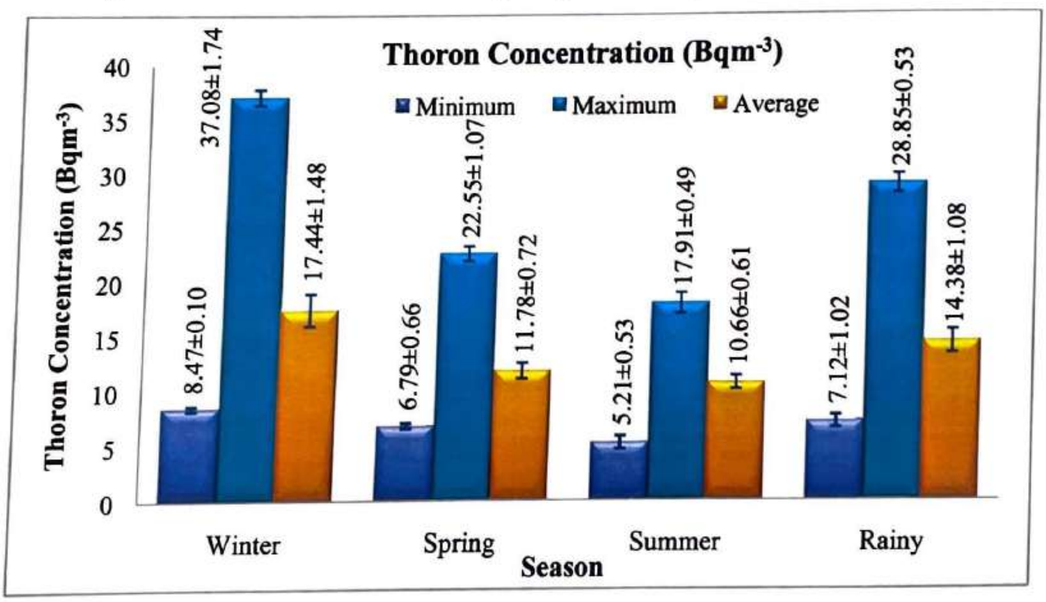


Figure 4.21: Graphical variations of thoron concentration in the dwellings of high rise buildings situated in Greater Faridabad, Haryana during all the seasons of a year

Seasonal variations of Potential Alpha Energy Concentration (PAEC) due to radon and thoron progeny in the dwellings of high rise buildings situated in Faridabad are shown in table 4.24. Maximum value of PAEC due to radon progeny was found to be 8.47±0.08 mWL during the winters (October-January) and minimum observed value was 0.94±0.06 mWL during the summer (April-July). The maximum value of PAEC due to thoron progeny was found to be 1.00±0.05 mWL during winters (October-January) and minimum value was 0.14±0.01 mWL during summer (April-July).

Location	Seasonal variations of PAEC (Rn) mWL				Seasonal variations of PAEC (Th) mWL			
	Winter	Spring	Summer	Rainy	Winter	Spring	Summer	Rainy
G-0	8.47 ±0.08	5.17 ±0.07	3.85 ±0.10	6.79 ±0.10	1.00 ±0.05	0.61 ±0.03	0.48 ±0.01	0.78 ±0.01
G-1	7.48 ±0.22	4.41 ±0.08	3.26 ±0.14	5.74 ±0.09	0.95 ±0.04	0.47 ±0.02	0.40 ±0.02	0.65 ±0.01
G-2	5.17 ±0.07	3.99 ±0.04	2.99 ±0.16	4.62 ±0.04	0.60 ±0.02	0.40 ±0.03	0.35 ±0.03	0.50 ±0.01
G-3	4.10 ±0.06	3.18 ±0.04	2.64 ±0.03	3.79 ±0.18	0.47 ±0.01	0.34 ±0.02	0.33 ±0.02	0.42 ±0.10
G-4	3.26 ±0.10	2.46 ±0.06	2.38 ±0.13	2.90 ±0.08	0.40 ±0.03	0.28 ±0.03	0.29 ±0.04	0.36 ±0.03
G-5	2.39 ±0.03	1.82 ±0.03	1.98 ±0.06	2.14 ±0.07	0.29 ±0.004	0.25 ±0.01	0.25 ±0.04	0.27 ±0.01
G-6	2.24 ±0.06	1.71 ±0.05	1.80 ±0.07	1.96 ±0.04	0.27 ±0.003	0.23 ±0.02	0.23 ±0.01	0.24 ±0.01
G-7	2.07 ±0.08	1.58 ±0.06	1.46 ±0.05	1.87 ±0.08	0.25 ±0.004	0.22 ±0.02	0.22 ±0.02	0.24 ±0.01
G-8	1.90 ±0.03	1.44 ±0.04	1.28 ±0.05	1.66 ±0.06	0.23 ±0.003	0.20 ±0.01	0.19 ±0.01	0.19 ±0.03
G-9	2.12 ±0.06	1.31 ±0.03	0.94 ±0.06	1.53 ±0.06	0.26 ±0.03	0.18 ±0.02	0.14 ±0.01	0.21 ±0.01
AV±SE *	3.92 ±0.33	2.71 ±0.19	2.26 ±0.14	3.30 ±0.25	0.47 ±0.04	0.32 ±0.02	0.29 ±0.02	0.39 ±0.03

* SE (standard error)= $\sigma/\sqrt{N}$, where σ is SD (standard deviation) and N is no. of observations

Table 4.24: Seasonal variations of Potential Alpha Energy Concentration (PAEC) due to radon and thoron progeny in the dwellings of high rise buildings situated in Greater Faridabad, Haryana

Variation in the exposure due to radon and thoron progeny in WLM calculated from the equation 4.5 on the seasonal basis in the dwellings of high rise buildings situated in Faridabad are shown in table 4.25. From table it is clear that the maximum value of exposure due to radon daughters is 84.74×10^{-3} WLM during winter (October-January) whereas, minimum value is 9.39×10^{-3} WLM during summer (April-July) season. Similarly, maximum exposure due to thoron daughters is 10.02×10^{-3} WLM during winter (October-January) and minimum value of exposure due to thoron is 1.41×10^{-3} WLM during summer (April-July).

Location	Seasonal variation of exposure due to radon progeny (WLM x10^{-3})				Seasonal variation of exposure due to thoron progeny (WLM x10^{-3})			
	Winter	Spring	Summer	Rainy	Winter	Spring	Summer	Rainy
G-0	84.74	51.66	38.54	67.92	10.02	6.09	4.84	7.80
G-1	74.83	44.05	32.63	57.40	9.53	4.67	4.03	6.52
G-2	51.73	39.92	29.86	46.23	5.98	4.02	3.45	5.02
G-3	41.03	81.80	26.39	37.85	4.67	3.36	3.32	4.36
G-4	32.58	24.56	23.77	28.97	3.99	2.79	2.90	3.59
G-5	23.91	18.20	19.82	21.36	2.88	2.53	2.49	2.74
G-6	22.41	17.07	18.04	19.58	2.68	2.35	2.32	2.43
G-7	20.71	15.77	14.64	18.66	2.52	2.18	2.21	2.43
G-8	18.97	14.43	12.77	16.60	2.29	2.00	1.85	1.92
G-9	21.16	13.13	9.39	15.31	2.57	1.83	1.41	2.08
Av	39.21	27.06	22.59	32.99	4.71	3.18	2.88	3.89

Table 4.25: Seasonal variations of exposure due to radon and thoron progeny in the dwellings of high rise buildings situated in greater Faridabad, Haryana

Annual exposure as a cumulative effect of exposure during all the four seasons of a year from table 4.25 due to radon and thoron daughters both is shown in table 4.26.

Location	Annual exposure due to radon progeny (WLMx10^{-3})	Annual exposure due to thoron progeny (WLMx10^{-3})	Annual exposure due to (Rn+Th) progeny (WLMx10^{-3})	Annual effective dose (mSv)
G-0	242.86	28.75	271.61	1.04
G-1	208.91	24.75	233.66	0.90
G-2	167.74	18.47	186.21	0.72
G-3	187.07	15.71	202.78	0.78
G-4	109.88	13.27	123.15	0.48
G-5	83.29	10.64	93.93	0.37
G-6	77.10	9.78	86.88	0.33
G-7	69.78	9.34	79.12	0.30
G-8	62.77	8.06	70.83	0.27
G-9	58.99	7.89	66.88	0.25
Average	121.85	14.66	136.51	0.53

Table 4.26: Annual Exposure due to radon and thoron progeny and annual effective dose in the dwellings of high rise buildings situated in greater Faridabad, Haryana

Table shows that annual exposure due to radon varies from 58.99×10^{-3} WLM to 242.86×10^{-3} WLM with an average value of 121.85×10^{-3} WLM. Annual exposure due to thoron varies from 7.89×10^{-3} WLM to 28.75×10^{-3} WLM with an average value of 14.66×10^{-3} WLM. Annual exposure due to radon and thoron daughters was converted into annual effective dose by using dose conversion factors; for radon daughters 3.88 mSv per WLM [46] is dose conversion factor for the members of the public, whereas for thoron daughters the conversion factor is 3.4 mSv per WLM [50]. Annual effective dose varies from 0.25 mSv to 1.04 mSv with an average value of 0.52 mSv.

Variations in the inhalation dose for the dwellers living in high rise buildings situated in Faridabad during all the four seasons of a year are shown in table 4.27.

Location	Seasonal variation of inhalation dose (mSv/y)			
	Winter	Spring	Summer	Rainy
G-0	2.94	1.79	1.36	2.34
G-1	2.67	1.48	1.15	1.97
G-2	1.78	1.33	1.03	1.57
G-3	1.41	1.07	0.93	1.30
G-4	1.14	0.84	0.83	1.02
G-5	0.84	0.66	0.70	0.76
G-6	0.78	0.62	0.64	0.69
G-7	0.73	0.57	0.55	0.67
G-8	0.66	0.53	0.47	0.57
G-9	0.74	0.48	0.35	0.55
Average	1.37	0.94	0.80	1.14

Table 4.27: Seasonal variations of inhalation dose in dwellings of high rise buildings situated in Greater Faridabad, Haryana

From table 4.27 it is clear that the maximum inhalation dose is 2.94 mSv/y during winter (at ground floor) and minimum value of inhalation dose is 0.35 mSv/y during summer (at ninth floor).

Annual effective dose as cumulative quantity of all the seasons of a year for the dwellers living in high rise buildings situated in Faridabad is shown in table 4.28. From table it is clear that the maximum value of annual effective dose is 1.04 mSv/y (at ground floor) and minimum value of annual effective dose is 0.256 mSv/y (at ninth floor). Graphical variations of annual effective dose for dwellers of high rise buildings situated in greater Faridabad during all the seasons of a year are shown in figure 4.22.

Location	Seasonal Effective dose (mSv)				Annual effective dose (mSv)
	Winter	Spring	Summer	Rainy	
G-0	0.36	0.22	0.17	0.29	1.04
G-1	0.32	0.19	0.14	0.25	0.90
G-2	0.22	0.17	0.13	0.20	0.72
G-3	0.18	0.33	0.11	0.16	0.78
G-4	0.14	0.11	0.10	0.13	0.48
G-5	0.10	0.08	0.09	0.10	0.37
G-6	0.10	0.07	0.08	0.08	0.33
G-7	0.09	0.07	0.06	0.08	0.30
G-8	0.08	0.06	0.06	0.07	0.27
G-9	0.09	0.06	0.04	0.06	0.25
Average	0.17	0.12	0.10	0.14	0.53

Table 4.28: Seasonal variations of effective dose in dwellings of high rise buildings situated in Faridabad, Haryana

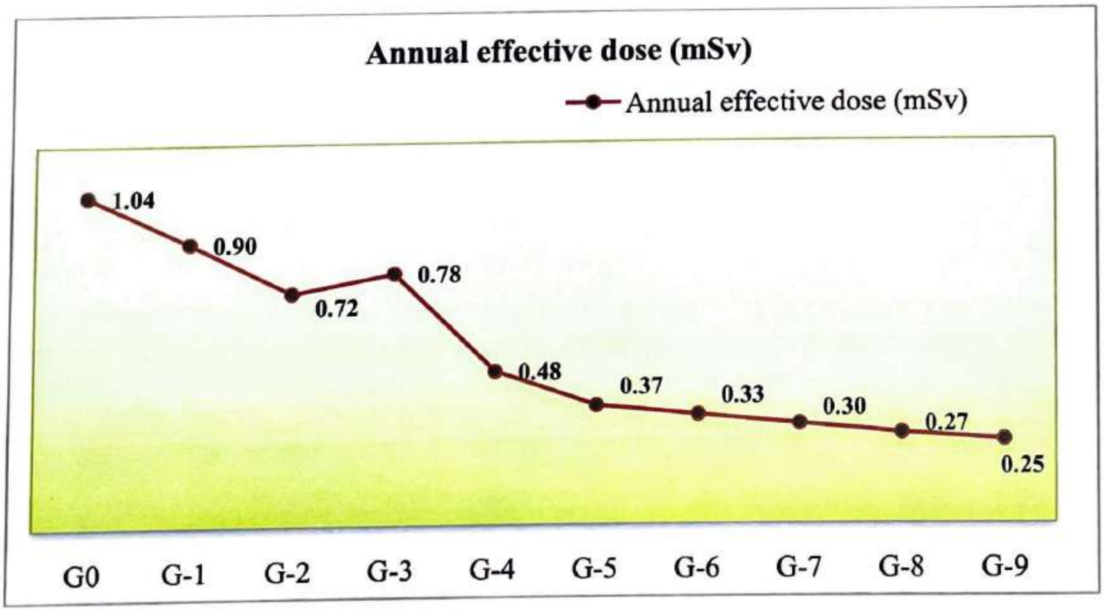


Figure 4.22: Graphical variations of annual effective dose for dwellers of high rise buildings situated in Greater Faridabad during all the seasons of a year

4.2.6 Conclusion

- Urban expansion of Indian cities promoted high rise buildings for housing and workplaces. High rise buildings are adopted at a fast rate because of cost of land and pressure on agricultural land for horizontal expansion.
- In the ancient time elevated radon levels were found in the low rise buildings but now it is common in high rise buildings also.
- Present study shows the variations in the results in two categories first is according to the height of the building and second is according to the different seasons of a year.
- Maximum results were found at the ground floors of the towers during the winter season and minimum values were found at the ninth floor (top floor of the present study) of the towers during summers.
- Maximum value of radon and thoron concentration was found to be 78.38±0.71 Bqm^{-3} and 37.08±1.74 Bqm^{-3} respectively at ground floor of the towers during winter and minimum value of radon and thoron concentration was found to be 8.68±0.57 Bqm^{-3} and 5.21±0.53 Bqm^{-3} at ninth floor of the towers during summers.
- An inverse relation was found in the height of the buildings and radon concentration mean that as the height of the building increases radon concentration decreases.
- The measurements indicate that results are below the action level (100 Bqm^{-3}) as recommended by various regulatory bodies.

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CHAPTER V

SEASONAL VARIATIONS IN RADON, THORON AND THEIR PROGENY CONCENTRATION AT THE DIFFERENT WORK PLACES OF DELHI-NCR AND FARIDABAD, HARYANA, INDIA

CHAPTER V

SEASONAL VARIATIONS IN RADON, THORON AND THEIR PROGENY CONCENTRATION AT THE DIFFERENT WORK PLACES OF DELHI-NCR AND FARIDABAD, HARYANA, INDIA

Two case studies have been reported in this chapter which includes the calculated results of radon, thoron and their progeny measurements at the workplaces of Delhi NCR and Haryana, India. First case study was carried out for the employees working in the multi-storied malls with multiple basements selected at Delhi NCR and Faridabad, Haryana, India and second case study was conducted in the premises of coal based thermal power plants of Delhi NCR and Haryana, India. Both the case studies were made during all the four seasons of a year and during each season of individual case study, radon and thoron concentration, Potential Alpha Energy Concentration (PAEC) due to radon and thoron progeny, exposure due to radon and thoron progeny, inhalation dose and effective dose have been calculated and reported in this chapter. In addition to this annual exposure due to radon and thoron progeny and annual effective dose for the workers of both the case studies have also been calculated and reported in this chapter.

5.1 CASE STUDY-I

In this case study the results are incorporated for the multi-storied malls selected in Delhi NCR and district Faridabad Haryana (India) during all the seasons of a year from October 2012 to October 2013.

5.1.1 Introduction

Radiation is ubiquitous and low levels of background radiation exist around us for they are present from the time when the earth was formed and it exists in various geological formations in soils, rocks, plants, water and air to which all are exposed since inception [1-3]. The various sources include cosmic rays which come from outer space and from the surface of the sun, terrestrial radio nuclides which occurs in the earth's crust, building materials, air, water, foods and in the human body itself. The exposures vary depending on the geology and location of the area and also as a result of human activities and practices viz. technologically enhanced naturally occurring radioactive materials (TENORMs), particularly in building materials, phosphate fertilizers, coal etc. Radon and thoron, which are a topic of public health concern, have been found to be ubiquitous air pollutants in homes and in the environment of work places i.e. thermal power plants, refineries, LPG bottling plants, underground stores, schools, banks, multi-storied malls, building and offices etc., to which all persons are exposed [4]. Radon monitoring has become a global phenomenon owing to its health hazard effects on population. Indoor ^{222}Rn exposure of the population depends in a complex way on the characteristics of the soil, material and structure of the building, meteorology, the design, ventilation conditions and occupants' behavior, which strongly influence the indoor levels of the radioactive gas radon and its decay products. Risk projections imply that radon is the second most common leading cause of lung cancer after smoking [5]. A relationship between lung cancer and inhalation of radon has been demonstrated [6]. Recent epidemiological evidence suggests that inhalation of radon and its decay products in domestic environments could also be a cause of lung cancer [7-8]. Recent researches from different countries have been published, which predict the radiological impact of indoor radon, thoron and their progeny as a worldwide problem and a significant risk factor for lung cancer [9-16]. The level of risk depends on the concentration of radon and length of exposure. It has been already estimated that if the level of radon concentration is above the 100 Bq/m^3 it leads to an approximately 16% increased chance of developing lung cancer [17]

Measurement of radon, thoron and their progeny is important because the radiation dose to human population due to radon and its progeny contributes more than 50% of the dose from all sources of radiation, both naturally occurring and manmade [18]. As poorer ventilation allows radon to build up, therefore, in the areas which are in contact with soil like mines, underground buildings and basements etc., require greater attention and calls for radon-thoron dosimetry because of the deleterious health effects on account of exposure [19]. In the present investigation, radon-thoron and their progeny dosimetry in the basements of multi-storied malls has been carried out as it is very important from radiation protection point of view. Radon being heavier than air is not normally a problem in the upper floors of buildings but may be a cause of concern in the basements owing to poorer ventilation and needed particular attention for the basement employees as compared to the other floors workers [20]. Depending upon the nature of soil and building materials used, the radon may accumulate in basements and can pose serious health hazards to the people. Therefore, in the present study, seasonal variation of radon-thoron and their progeny in the ambient air in the multi-storied malls of Delhi NCR and Faridabad, Haryana (India) has been carried out and its seasonal variation has also been studied.

5.1.2 About The Study Area

In the study the measurements were carried out in Delhi National Capital Region (NCR) including District Faridabad, Haryana (India). The study area lies at 28° 25' 16" N Latitude and 77° 18' 28" E Longitude. It has an average elevation of 198 meters. It is bordered by the Yamuna to the east and Aravali Hills towards the west and southwest.

Photograph 5.1: Location map of Multi-storied Malls in Delhi NCR and Haryana

1. The measurements were conducted from October 2012 to October 2013 during all the four seasons of a year: winter (October to January), spring (January-April), summer (April-July) and rainy (July-October).

2. Total fifteen malls were selected for the present study and to maintain the uniformity total seven floors from third basement to third floor including ground floor were selected from every mall for the radiological assessments.
3. The selected locations are represented as: third basement (B3), second basement (B2), first basement (B1), ground floor (G0), first floor (F1), second floor (F2) and third floor (F3).
4. Three locations were selected at each floor of the every mall at the same uniformity so that the results are representable collectively.
5. At every location twin cup dosimeters loaded with LR-115 type II detectors were exposed for the seasonal radiological assessment and in total 315 twin cup dosimeters were installed during the study of each season and the process was repeated for all the four seasons of a year.

5.1.3 Experimental Technique

In the present study radon and thoron concentration, PAEC due to radon and thoron progeny, inhalation dose, annual exposure due to radon and thoron progeny and annual effective dose were calculated with track etch technique using Solid State Nuclear Track Detectors. In this technique Twin cup dosimeters loaded with LR-115 type II Solid State Nuclear Track Detectors in the pieces of 2.5 × 2.5 cm were exposed at the selected locations during all the four seasons of a year. The detail of this technique has been discussed in chapter 3 under section 3.8.

5.1.4 Formulas Used

The radon and thoron concentration was calculated using equations 4.1 and 4.2 and Potential Alpha Energy Concentration due to radon and thoron progeny was calculated using equation 4.3 of fourth chapter under the subsection 4.1.4. The inhalation dose due to radon and thoron in mSv/y was estimated using the equation 4.4 under the section 4.1.5 of fourth chapter.

5.1.5 Results and Discussion

In the present case study the results were calculated for radon and thoron concentration and Potential Alpha Energy Concentration (PAEC) due to radon and thoron progeny and inhalation dose during all the four seasons, from the samples collected from the multi-storied malls situated in Delhi NCR and district Faridabad Haryana (India) using equations 4.1- 4.3 discussed under section 4.1.4 in fourth chapter. The exposure due to radon and thoron progeny was calculated from equation 4.5 as discussed in chapter 4 under section 4.1.5 for duration of 90 days (exposure time of each season). The exposure due to radon and thoron progeny was converted into effective dose by using dose conversion factors; for radon daughter the dose conversion factor is 3.88 mSv per WLM [7], whereas for thoron daughters the conversion factor is 3.4 mSv per WLM for members of the public [21]. The calculated results for all the parameters are elaborated in the tabular form and explained separately for all the seasons of a calendar year.

(i) Results for winter season (October 2012-January2013)

The calculated values of radon and thoron concentration and potential alpha energy concentration (PAEC) due to radon and thoron progeny are presented in table 5.1.From table it is clear that radon concentration varies from 13.68±0.46 Bqm^{-3} at the third floor of the malls to 87.97±1.79 Bqm^{-3} at the third basement of the malls with an average value of 45.37±4.69 Bqm^{-3}. The thoron concentration varies from 7.66±0.89 Bqm^{-3} at the third floor of the malls to 29.21±2.64 Bqm^{-3} at the third basement of the malls with an average value of 21.40±1.67 Bqm^{-3} during winter season (October-January).

Locations	Radon Concentration C_R (Bqm^{-3})	Thoron Concentration C_T (Bqm^{-3})	PAEC (Rn) mWL	PAEC (Th) mWL
B3	87.97±1.79	29.21±2.64	9.51±0.19	0.79±0.07
B2	78.51±1.41	28.78±3.80	8.49±0.15	0.78±0.10
B1	54.08±0.93	29.20±1.75	5.85±0.10	0.79±0.05
G0	42.89±1.01	27.28±0.63	4.64±0.11	0.74±0.02
F1	24.83±1.39	15.64±0.62	2.68±0.15	0.42±0.02
F2	17.83±0.56	10.85±0.46	1.93±0.06	0.29±0.01
F3	13.68±0.46	7.66±0.89	1.48±0.05	0.21±0.02
AV±SE*	45.37±4.69	21.40±1.67	4.91±0.51	0.58±0.05

*SE is (standard error) $=\sigma/\sqrt{N}$, where σ is SD (standard deviation) and N is number of observations

Table 5.1: Radon and thoron concentration and PAEC due to radon and thoron progeny in multi-storied malls during winter season

Table 5.1 shows that Potential Alpha Energy Concentration (PAEC) due to radon and thoron progeny varies from 1.48±0.05 mWL at the third floor of the malls to

9.51±0.19 mWL at the third basement of the malls with an average value of 4.91±0.51 mWL and 0.21±0.02 mWL at the third floor of the malls to 0.79±0.07 mWL with an average value of 0.58±0.05 mWL at the third basement of the malls during winter (October-January) respectively. Minimum values of radon, thoron concentration and PAEC due to radon and thoron progeny were found to be at the third floor of the malls whereas the maximum values were found in the third basement of the malls. The variations in radon and thoron concentration are shown in figure 5.1 and 5.2.

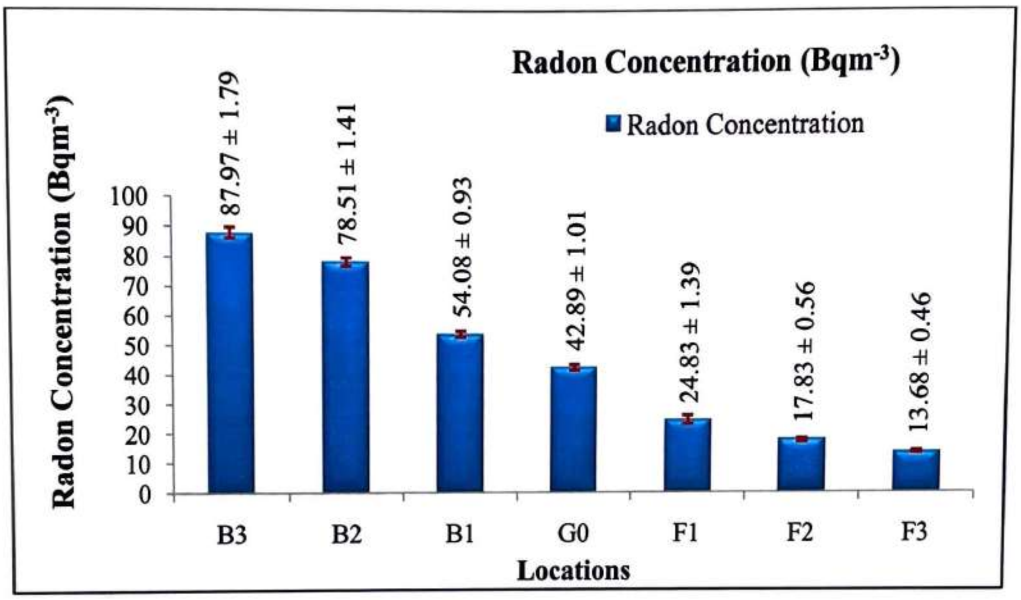

Figure 5.1: Graphical variations of radon concentration in multi-storied malls during winter season

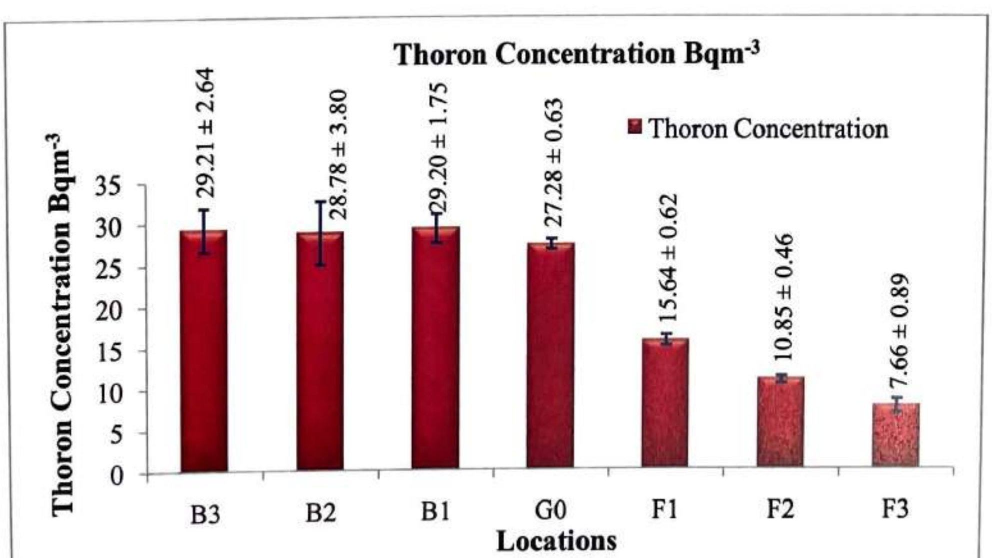

Figure 5.2: Graphical variations of thoron concentration in multi-storied malls during winter season

Graphs reveals that the minimum value of radon and thoron concentration was found at the third floor of the malls (top floor selected in the present study) because of its distance from the ground and comparatively better ventilation as compared to the other floors of the malls whereas the maximum value was found at the third basement of the malls (lowest floor considered in the present study) because of poor ventilation and the vicinity of multiple surfaces to the ground rather than other floors of the building

The results for annual exposure to the workers of the multi-storied malls during the winter season are shown in table 5.2. The exposure due to radon and thoron progeny varies from 15.08×10^{-3} WLM (at third floor of the malls) to 97.01×10^{-3} WLM (in third basement of malls) with an average value of 50.03×10^{-3} WLM and 2.11×10^{-3} WLM (at third floor of the malls) to 8.05×10^{-3} WLM (in third basement of malls) with an average value of 6.12×10^{-3} WLM respectively during winter (October-January).

Results for effective dose and inhalation dose are shown in table 5.2. It shows that the inhalation dose varies from 0.54 mSv/y (at third floor of the malls) to 3.01 mSv/y (in the third basement of the malls) with an average value of 1.70 mSv/y. Effective dose for the winter season varies from 0.06 mSv (at third floor of the malls) to 0.40 mSv (in the third basement of the malls) with an average value of 0.21 mSv.

Locations	Exposure due to radon progeny (WLMx10^{-3})	Exposure due to thoron progeny (WLMx10^{-3})	Exposure due to (Rn+Th) progeny (WLMx10^{-3})	Inhalation Dose (mSv/y)	Effective dose (mSv)
B3	97.01	8.05	105.06	3.01	0.40
B2	86.57	7.93	94.50	2.75	0.36
B1	59.65	8.05	67.70	2.11	0.25
G0	47.30	7.52	54.82	1.77	0.21
F1	27.38	4.31	31.69	1.02	0.12
F2	19.67	2.99	22.66	0.73	0.09
F3	15.08	2.11	17.19	0.54	0.06
Average	50.03	5.90	55.93	1.70	0.21

Table 5.2: Exposure due to radon and thoron progeny, inhalation dose and effective dose in multi-storied malls during winter season

(ii) Results for Spring Season (January 2013-April 2013)

During the spring season, the results calculated for radon and thoron concentration and Potential Alpha Energy Concentration (PAEC) due to radon and thoron progeny from the samples collected from the multi-storied malls situated in Delhi NCR and district Faridabad Haryana (India) are listed in table 5.3. From table it is clear that radon concentration varies from 7.54±0.25 Bqm^{-3} (at the third floor of the malls) to 54.06±1.10 Bqm^{-3} (in the third basement of the malls) with an average value of 27.79±2.96 Bqm^{-3}. The thoron concentration varies from 6.60±0.59 Bqm^{-3} (at the third floor of the malls) to 22.84±1.38 Bqm^{-3} (in the third basement of the malls) with an average value of 15.12±1.21 Bqm^{-3} during spring season (January-April).

Location	Radon Concentration C_R (Bqm^{-3})	Thoron Concentration C_T (Bqm^{-3})	PAEC (Rn) mWL	PAEC (Th) mWL
B3	54.06±1.10	22.84±1.38	5.85±0.12	0.62±0.04
B2	49.13±0.88	20.76±1.75	5.31±0.10	0.56±0.05
B1	33.31±0.57	19.56±1.12	3.60±0.06	0.53±0.03
G0	26.59±0.62	19.91±0.45	2.87±0.07	0.54±0.01
F1	14.80±0.83	8.50±0.35	1.60±0.090	0.23±0.01
F2	10.32±0.33	7.49±0.31	1.12±0.04	0.20±0.01
F3	7.54±0.25	6.60±0.59	0.82±0.03	0.18±0.02
Av±SE*	27.79±2.96	15.12±1.21	3.00±0.32	0.41±0.03

SE* is (standard error) = $\sigma/\sqrt{N}$, where σ is SD (standard deviation) and N is total number. of observations

Table 5.3: Radon and thoron concentration and PAEC due to radon and thoron progeny in multi-storied malls during spring season

The Potential Alpha Energy Concentration (PAEC) due to radon progeny as shown in table 5.3 varies from 0.82±0.03 mWL (in the third floor of the malls) to 5.85±0.12 mWL (at the third basement of the malls) with an average value of 3.00±0.32 mWL and PAEC due to thoron progeny varies from 0.18±0.02 mWL (at the third floor of the malls) to 0.62±0.04 mWL (in the third basement of the malls) with an average value of 0.41±0.03 mWL during Spring (January-April). Minimum values of radon, thoron concentration and PAEC due to radon and thoron progeny were found at the third floor of the malls whereas the maximum values were found in the third basement of the malls.

The variations in radon and thoron concentration are shown in figure 5.3 and 5.4. Graphs shows that the minimum values of radon and thoron concentration were found at the third floor of the malls (top floor selected in the present study) whereas maximum value were found at the third basement of the malls (lowest floor considered in the present study) because the floors above the ground have low level of radon and thoron concentration as compared to the floors near the ground.

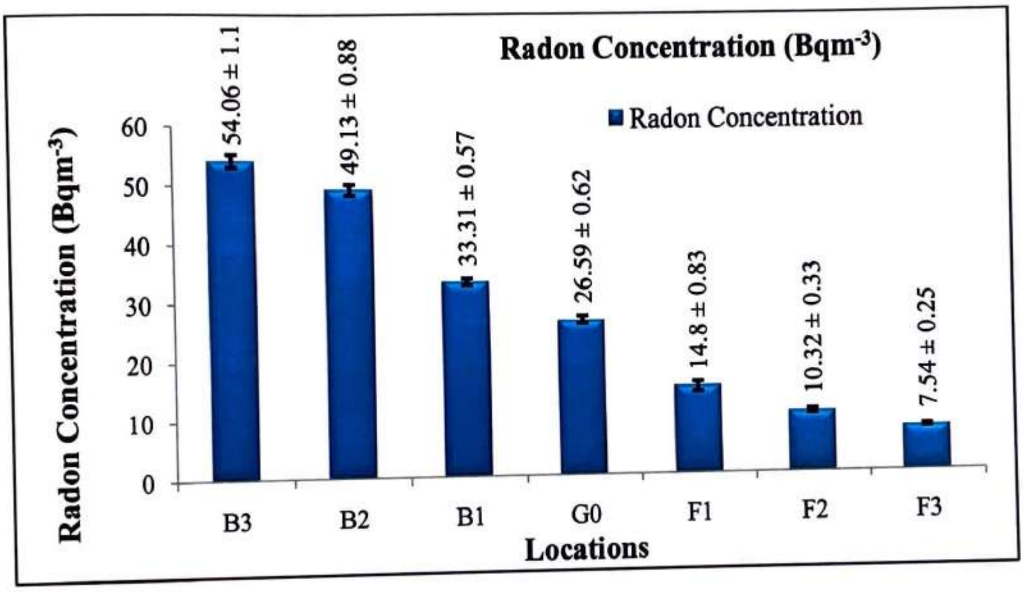

Figure 5.3: Graphical variations of radon concentration in multi-storied malls during spring season

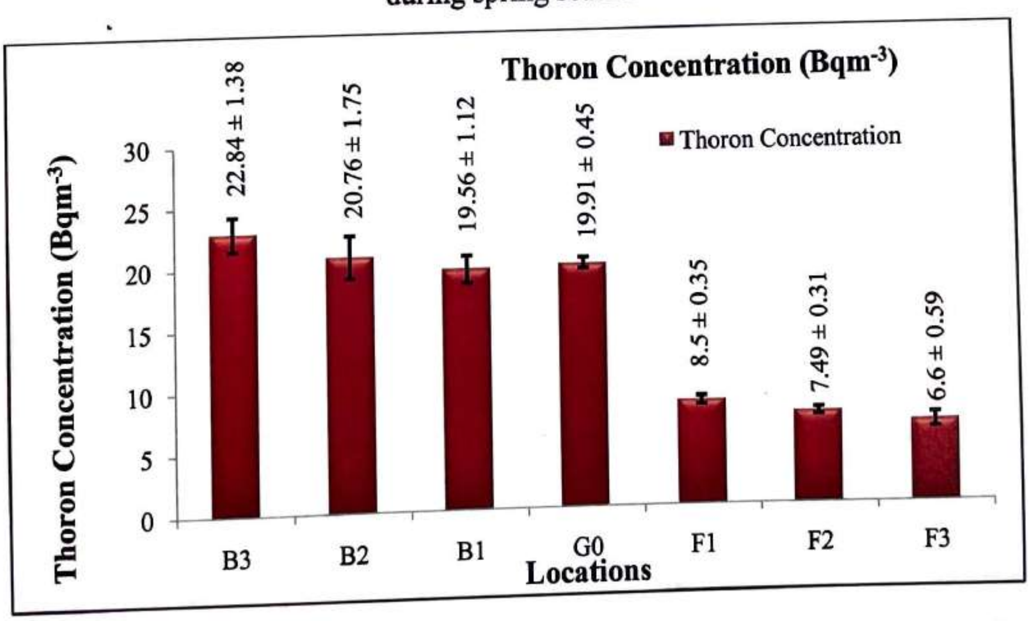

Figure 5.4: Graphical variations of thoron concentration in multi-storied malls during spring season

The results for annual exposure to the workers of multi-storied malls during the spring season are shown in table 5.4. The exposure due to radon progeny varies from 8.32×10^{-3} WLM (at third floor of the malls) to 59.62×10^{-3} WLM (in third basement of malls) with an average value of 30.65×10^{-3} WLM and exposure due to thoron progeny varies from 1.82×10^{-3} WLM (at third floor of the malls) to 6.30×10^{-3} WLM (in third basement of malls) with an average value of 4.17×10^{-3} WLM during spring (January-April).

Results for effective dose and inhalation dose are shown in table 5.4. Table 5.4 shows that the inhalation dose varies from 0.35 mSv/y (at third floor of the malls) to 1.96 mSv/y (in the third basement of the malls) with an average value of 1.09 mSv/y. Effective dose calculated in mSv varies from 0.04 mSv (at third floor of the malls) to 0.25 mSv (in the third basement of the malls) with an average value of 0.13 mSv. Minimum value of effective dose due to radon and thoron progeny was found at the third floor of the malls whereas the maximum value was found in the environment of third basement of the malls because of poor exchange rate of air and the vicinity of multiple surfaces to the ground.

Locations	Exposure due to radon progeny (WLMx10^{-3})	Exposure due to thoron progeny (WLMx10^{-3})	Exposure due to (Rn+Th) progeny (WLMx10^{-3})	Inhalation Dose (mSv/y)	Effective dose (mSv)
B3	59.62	6.30	65.92	1.96	0.25
B2	54.18	5.72	59.90	1.79	0.23
B1	36.73	5.39	42.12	1.34	0.16
G0	29.32	5.49	34.81	1.17	0.13
F1	16.32	2.34	18.66	0.59	0.07
F2	11.38	2.06	13.44	0.45	0.05
F3	8.32	1.82	10.14	0.35	0.04
Average	30.65	4.17	34.82	1.09	0.13

Table 5.4: Exposure due to radon and thoron progeny, inhalation dose and effective dose in multi-storied malls during spring season

(iii) Results for the summer season (April 2013-July 2013)

The results calculated for radon and thoron concentration and Potential Alpha Energy Concentration (PAEC) due to radon and thoron progeny from the samples collected from the multi-storied malls situated in Delhi NCR and district Faridabad Haryana (India) are listed in table 5.5. From table 5.5 it is clear that radon concentration varies from 5.09±0.33 Bqm^{-3} (at the third floor of the malls) to 38.42±1.47 Bqm^{-3} (in the third basement of the malls) with an average value of 18.45±1.95 Bqm^{-3}. The thoron concentration varies from 3.06±0.21 Bqm^{-3} (at the third floor of the malls) to 18.31±1.22 Bqm^{-3} (in the third basement of the malls) with an average value of 10.64±0.94 Bqm^{-3}.

Table 5.5 shows that potential alpha energy concentration (PAEC) due to radon progeny varies from 0.55±0.04 mWL (at the third floor of the malls) to 4.15±0.16 mWL (at the third basement of the malls) with an average value of 1.99±0.21 mWL and PAEC due to thoron progeny varies from 0.08±0.01 mWL (at the third floor of the malls) to 0.50±0.03 mWL (in the third basement of the malls) with an average value of 0.29±0.03 mWL during summer season (April-July). Minimum values of radon, thoron concentration and PAEC due to radon and thoron progeny were found to be at the third floor of the malls whereas the maximum values were found in the third basement of the malls.

Location	Radon Concentration C_R (Bqm^{-3})	Thoron Concentration C_T (Bqm^{-3})	PAEC (Rn) mWL	PAEC (Th) mWL
B3	38.42±1.47	18.31±1.22	4.15±0.16	0.50±0.03
B2	29.07±0.91	15.60±0.52	3.14±0.10	0.42±0.01
B1	23.40±0.94	13.42±0.73	2.53±0.10	0.36±0.02
G0	16.21±0.77	12.23±0.61	1.75±0.08	0.33±0.02
F1	10.96±0.85	7.34±0.68	1.19±0.09	0.20±0.02
F2	7.29±0.67	4.57±0.35	0.79±0.07	0.12±0.01
F3	5.09±0.33	3.06±0.21	0.55±0.04	0.08±0.01
Av±SE*	18.45±1.95	10.64±0.94	1.99±0.21	0.29±0.03

SE* is (standard error) = $\sigma/\sqrt{N}$, where σ is SD (standard deviation) and N is total number. of observations

Table 5.5: Radon and thoron concentration and PAEC due to radon and thoron progeny in multi-storied malls during summer season

The variations in radon and thoron concentration are shown in figure 5.5 and 5.6. Graphs reveals that the maximum value of radon and thoron concentration was found at the third basement of the malls (lowest floor considered in the present study) because of poor ventilation and the vicinity of multiple surfaces to the ground rather than other floors of the building whereas minimum value of radon and thoron concentration was found at the third floor of the malls (top floor selected in the present study) because the indoor radon concentration changes with the operation of A.C (mechanical ventilation system) at the floors which are above the ground during the summer season as compared to the basements where the air conditioners (AC) were not installed [22].

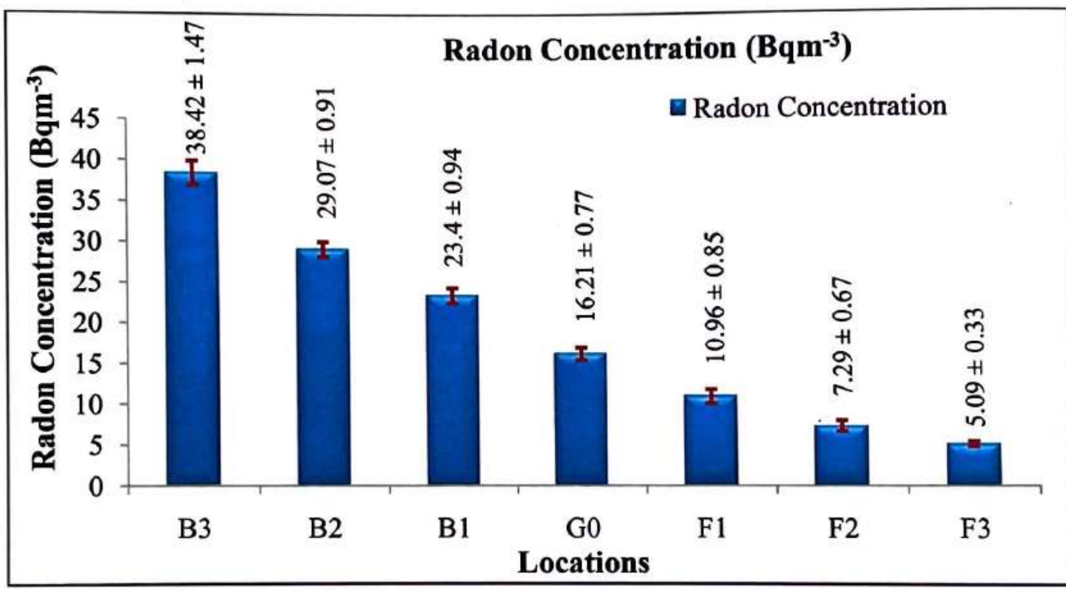

Figure 5.5: Graphical variations of radon concentration in multi-storied malls during summer season

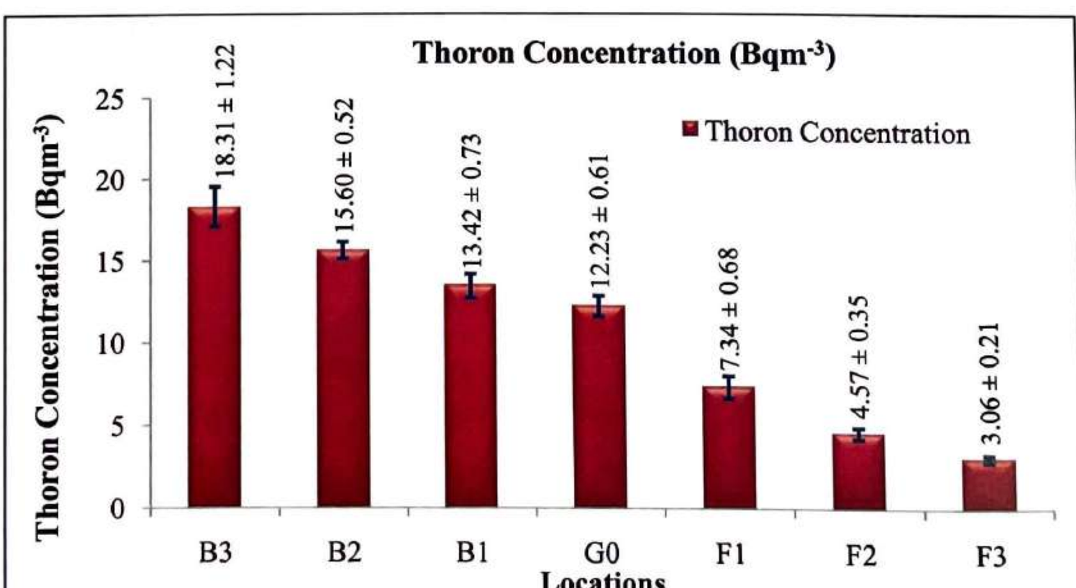

Figure 5.6: Graphical variations of thoron concentration in multi-storied malls during summer season

The results for annual exposure due to radon and thoron progeny during the summer season are shown in table 5.6. The exposure due to radon progeny varies from 5.61×10^{-3} WLM (at third floor of the malls) to 42.37×10^{-3} WLM (in third basement of malls) with an average value of 20.34×10^{-3} WLM and due to thoron progeny varies from 0.83×10^{-3} WLM (at third floor of the malls) to 5.05×10^{-3} WLM (in third basement of malls) with an average value of 2.93×10^{-3} WLM during summer (April-July).

Locations	Exposure due to radon progeny ($WLMx10^{-3}$)	Exposure due to thoron progeny ($WLMx10^{-3}$)	Exposure due to (Rn+Th) progeny ($WLMx10^{-3}$)	Inhalation Dose (mSv/y)	Effective dose (mSv)
B3	42.37	5.05	47.42	1.44	0.18
B2	32.06	4.30	36.36	1.13	0.14
B1	25.81	3.70	29.51	0.93	0.11
G0	17.87	3.37	21.24	0.71	0.08
F1	12.09	2.02	14.11	0.46	0.05
F2	8.04	1.26	9.30	0.30	0.04
F3	5.61	0.83	6.44	0.20	0.02
Average	20.34	2.93	23.27	0.74	0.09

Table 5.6: Exposure due to radon and thoron progeny, inhalation dose and effective dose in multi-storied malls during summer season

The seasonal effective dose and inhalation dose are shown in table 5.6. Table shows that the inhalation dose varies from 0.20 mSv/y (at third floor of the malls) to 1.44 mSv/y (in the third basement of the malls) with an average value of 0.74 mSv/y. Effective dose for the inhabitants of high rise buildings in the summer season varies from 0.02 mSv (at third floor of the malls) to 0.18 mSv (in the third basement of the malls) with an average value of 0.09 mSv. Minimum value of effective dose due to radon and thoron progeny was found at the third floor of the malls whereas the maximum value was found in the environment of third basement of the malls because of poor exchange rate of air and the vicinity to the soil under the ground.

(iv) Results for the rainy season (July 2013-October 2013)

During the rainy season, results for radon and thoron concentration and Potential Alpha Energy Concentration (PAEC) due to radon and thoron progeny from the samples collected from the multi-storied malls situated in Delhi NCR and district

Faridabad Haryana (India) are listed in table 5.7. From table it is clear that radon concentration varies from 8.84±0.62 Bqm^{-3} (at the third floor of the malls) to 60.76±2.32 Bqm^{-3} (in the third basement of the malls) with an average value of 32.66±2.97 Bqm^{-3} similarly, the thoron concentration varies from 5.70±0.41 Bqm^{-3} (at the third floor of the malls) to 27.13±1.86 Bqm^{-3} (in the third basement of the malls) with an average value of 16.33±1.41 Bqm^{-3}.

Location	Radon Concentration C_R (Bqm^{-3})	Thoron Concentration C_T (Bqm^{-3})	PAEC (Rn) mWL	PAEC (Th) mWL
B3	60.76±2.32	27.13±1.86	6.57±0.25	0.73±0.05
B2	47.03±1.47	25.09±0.83	5.08±0.16	0.68±0.02
B1	42.39±1.70	16.10±1.16	4.58±0.18	0.46±0.03
G0	31.92±1.52	21.16±1.06	3.45±0.17	0.57±0.03
F1	24.19±1.86	10.66±1.16	2.62±0.20	0.29±0.03
F2	14.33±1.31	7.61±0.58	1.55±0.14	0.21±0.02
F3	8.84±0.62	5.70±0.41	0.96±0.07	0.15±0.01
Av±SE*	32.66±2.97	16.33±1.41	3.53±0.32	0.44±0.04

Table 5.7: Radon and thoron concentration and PAEC due to radon and thoron progeny in multi-storied malls during rainy season

Table 5.7 shows that potential alpha energy concentration (PAEC) due to radon progeny varies from 0.96±0.07 mWL (at the third floor of the malls) to 6.57±0.25 mWL (at the third basement of the malls) with an average value of 3.53±0.32 mWL and PAEC due to thoron progeny varies from 0.15±0.01 mWL (at the third floor of the malls) to 0.73±0.05 mWL (in the third basement of the malls) with an average value of 0.44±0.04 mWL during rainy season (July-October). Minimum values of radon and thoron concentration and PAEC due to radon and thoron progeny were found to be at the third floor of the malls whereas the maximum values were found in the third basement of the malls.

The variations in radon and thoron concentration are shown in figure 5.7 and 5.8. Graphs reveal that the maximum value was found at the third basement of the malls (lowest floor considered in the present study) whereas minimum value of radon and thoron concentration was found at the third floor of the malls (top floor selected in the present study).

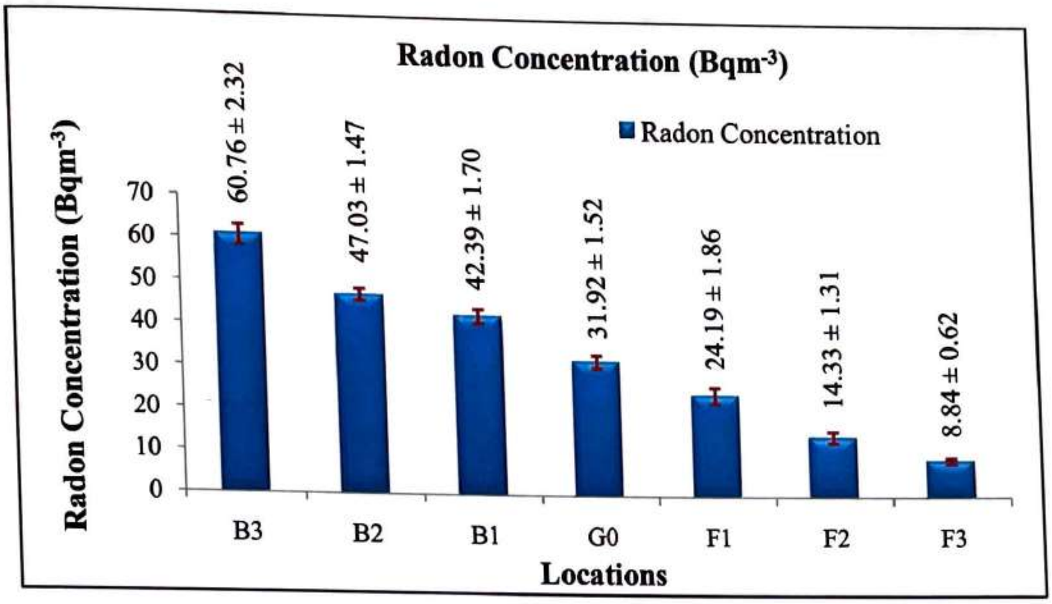

Figure 5.7: Graphical variations of radon concentration in multi-storied malls during rainy season

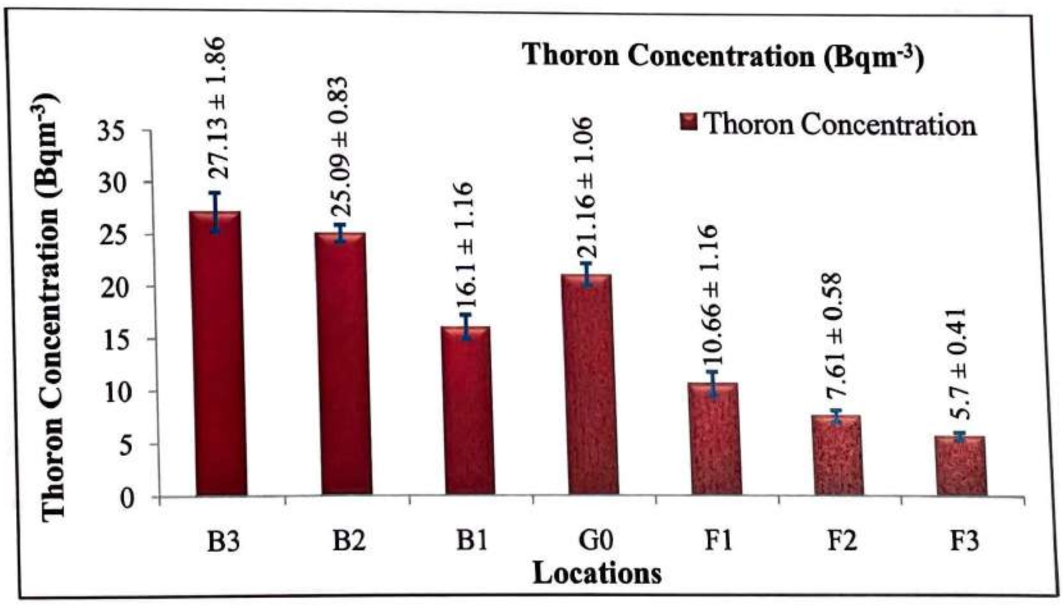

Figure 5.8: Graphical variations of thoron concentration in multi-storied malls during rainy season

The results for exposure due to radon and thoron progeny are shown in table 5.8. The exposure due to radon progeny varies from 9.75×10^{-3} WLM (at third floor of the malls) to 67.00×10^{-3} WLM (in third basement of malls) with an average value of 36.01×10^{-3} WLM and due to thoron progeny varies from 1.57×10^{-3} WLM (at third floor of the malls) to 7.48×10^{-3} WLM (in third basement of malls) with an average value of 4.50×10^{-3} WLM during rainy season (July-October).

Locations	Exposure due to Radon progeny ($WLMx10^{-3}$)	Exposure due to thoron progeny ($WLMx10^{-3}$)	Exposure due to (Rn+Th) progeny ($WLMx10^{-3}$)	Inhalation Dose (mSv/y)	Effective dose (mSv)
B3	67.00	7.48	74.48	2.24	0.28
B2	51.86	6.92	58.77	1.83	0.22
B1	46.75	4.69	51.44	1.52	0.19
G0	35.19	5.83	41.02	1.34	0.15
F1	26.67	2.94	29.61	0.89	0.11
F2	15.80	2.10	17.90	0.56	0.07
F3	9.75	1.57	11.32	0.37	0.04
Average	36.01	4.50	40.51	1.25	0.15

Table 5.8: Exposure due to radon and thoron progeny, inhalation dose and effective dose in multi-storied malls during rainy Season

The exposure due to radon and thoron progeny and inhalation dose are shown in table 5.8. Table shows that the inhalation dose varies from 0.37 mSv/y (at third floor of the malls) to 2.24 mSv/y (in the third basement of the malls) with an average value of 1.25 mSv/y. Effective dose during the rainy season varies from 0.04 mSv (at third floor of the malls) to 0.28 mSv (in the third basement of the malls) with an average value of 0.15 mSv. Minimum value of effective dose due to radon and thoron progeny was found at the third floor of the malls whereas the maximum value was found in the environment of third basement of the malls because of poor exchange rate of air and the multiple surfaces are in contact with soil under the ground.

Variation in radon and thoron activity with respect to the weather is a well-known fact and seasonal variations in radon and thoron concentration in multi-storied malls selected in Delhi NCR and district Faridabad Haryana, (India) during all the four seasons (winter, spring, summer and rainy) of a year are represented in table 5.9. Maximum value of radon concentration was found to be 87.97±1.79 Bq/m^3 (in the third basement of malls). The minimum value was found to be 5.09±0.33 Bq/m^3 (at the third floor of the malls). The maximum value of thoron concentration found to be 29.21±2.64 Bq/m^3 (in the third basement of the malls). The minimum value of thoron concentration was found to be 3.06±0.21 Bq/m^3. Variations in radon and thoron concentration are shown in figure 5.9 and 5.10. Graphs reveal that the maximum value of radon and thoron concentration was found in winter season (October-January) in the lowest basement (third basement) of the present study and the minimum value of radon and thoron concentration was found in summer season (April-July) at the third floor of the malls. The radon and thoron activity decreased in monsoon season because of the fact that the soil is saturated with water [23].

Locations	Seasonal Variation of Radon Concentration (Bqm^{-3})				Seasonal Variation of thoron Concentration (Bqm^{-3})			
	Winter	Spring	Summer	Rainy	Winter	Spring	Summer	Rainy
B3	87.97 ±1.79	54.06 ±1.10	38.42 ±1.47	60.76 ±2.32	29.21 ±2.64	22.84 ±1.38	18.31 ±1.22	27.13 ±1.86
B2	78.51 ±1.41	49.13 ±0.88	29.07 ±0.91	47.03 ±1.47	28.78 ±3.80	20.76 ±1.75	15.60 ±0.52	25.09 ±0.83
B1	54.08 ±0.93	33.31 ±0.57	23.40 ±0.94	42.39 ±1.70	29.20 ±1.75	19.56 ±1.12	13.42 ±0.73	16.10 ±1.16
G0	42.89 ±1.01	26.59 ±0.62	16.21 ±0.77	31.92 ±1.52	27.28 ±0.63	19.91 ±0.45	12.23 ±0.61	21.16 ±1.06
F1	24.83 ±1.39	14.80 ±0.83	10.96 ±0.85	24.19 ±1.86	15.64 ±0.62	8.50 ±0.35	7.34 ±0.68	10.66 ±1.16
F2	17.83 ±0.56	10.32 ±0.33	7.29 ±0.67	14.33 ±1.31	10.85 ±0.46	7.49 ±0.31	4.57 ±0.35	7.61 ±0.58
F3	13.68 ±0.46	7.54 ±0.25	5.09 ±0.33	8.84 ±0.62	7.66 ±0.89	6.60 ±0.59	3.06 ±0.21	5.70 ±0.41
AV±SE	45.37 ±4.69	27.79 ±2.96	18.45 ±1.95	32.66 ±2.97	21.40 ±1.67	15.12 ±1.21	10.64 ±0.94	16.33 ±1.41

* SE (standard error)= $\sigma/\sqrt{N}$, where σ is SD (standard deviation) and N is no. of observations

Table 5.9: Seasonal variations in radon and thoron concentration in multi-storied malls of Delhi NCR and Faridabad, Haryana

Variations in the Potential Alpha Energy Concentration (PAEC) due to radon and thoron progeny in the multi-storied malls selected in Delhi NCR and district Faridabad Haryana (India) during all the four seasons: winter, spring, summer and rainy of a year are shown in table 5.10. Table shows that maximum value of PAEC due to radon progeny was found to be 9.51±0.19 mWL (in the third basement of the malls) and minimum value was found to be 0.55±0.04 mWL (at the third floor of the malls). Whereas, maximum value of PAEC due to thoron progeny was found to be

0.79±0.07 mWL (in the third basement of the malls) and minimum value was found to be 0.08±0.01 mWL (at the third floor of the malls). Maximum value of PAEC due to radon and thoron progeny was found in winter season (October-January) and in the third basement of the malls where is no any provision for the ventilation and minimum value was found in summer season (April-July) at the third floor of the malls when A.C. was working.

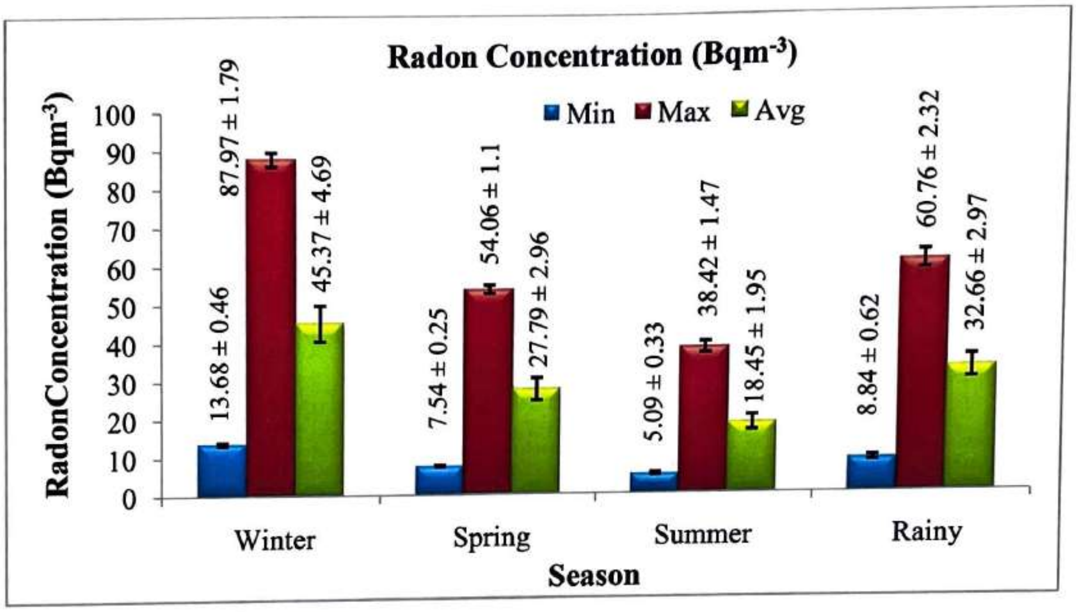

Figure 5.9: Graphical variations of radon concentration in multi-storied malls of Delhi NCR and Faridabad, Haryana during all the seasons of a year

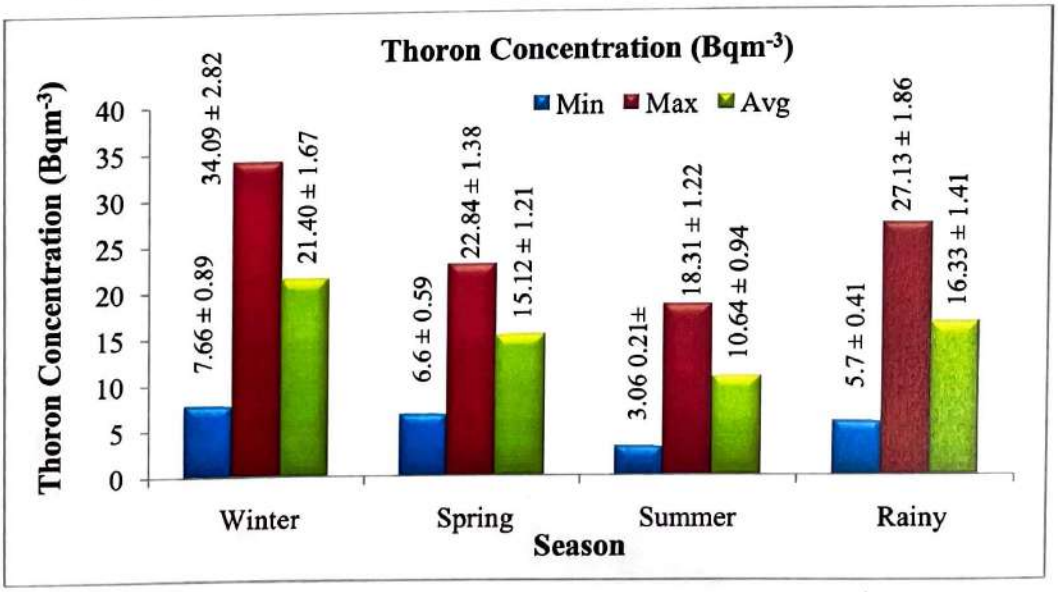

Figure 5.10: Graphical variations of thoron concentration in multi-storied malls of Delhi NCR and Faridabad, Haryana during all the seasons of a year

Location	Seasonal Variation of PAEC due to Radon (mWL)				Seasonal Variation of PAEC due to Thoron (mWL)			
	Winter	Spring	Summer	Rainy	Winter	Spring	Summer	Rainy
B3	9.51 ±0.19	5.85 ±0.12	4.15 ±0.16	6.57 ±0.25	0.79 ±0.07	0.62 ±0.04	0.50 ±0.03	0.73 ±0.05
B2	8.49 ±0.15	5.31 ±0.10	3.14 ±0.10	5.08 ±0.16	0.78 ±0.10	0.56 ±0.05	0.42 ±0.01	0.68 ±0.02
B1	5.85 ±0.10	3.60 ±0.06	2.53 ±0.10	4.58 ±0.18	0.79 ±0.05	0.53 ±0.03	0.36 ±0.02	0.46 ±0.03
G0	4.64 ±0.11	2.87 ±0.07	1.75 ±0.08	3.45 ±0.17	0.74 ±0.02	0.54 ±0.01	0.33 ±0.02	0.57 ±0.03
F1	2.68 ±0.15	1.60 ±0.090	1.19 ±0.09	2.62 ±0.20	0.42 ±0.02	0.23 ±0.01	0.20 ±0.02	0.29 ±0.03
F2	1.93 ±0.06	1.12 ±0.04	0.79 ±0.07	1.55 ±0.14	0.29 ±0.01	0.20 ±0.01	0.12 ±0.01	0.21 ±0.02
F3	1.48 ±0.05	0.82 ±0.03	0.55 ±0.04	0.96 ±0.07	0.21 ±0.02	0.18 ±0.02	0.08 ±0.01	0.15 ±0.01
AV±SE*	4.91 ±0.51	3.00 ±0.32	1.99 ±0.21	3.53 ±0.32	0.58 ±0.05	0.41 ±0.03	0.29 ±0.03	0.44 ±0.04

* SE (standard error)= $\sigma/\sqrt{N}$, where σ is SD (standard deviation) and N is no. of observations

Table 5.10: Seasonal Variations of PAEC due to radon and thoron progeny in multi-storied malls of Delhi NCR and Faridabad, Haryana

Seasonal variation in the exposure due to radon and thoron progeny in WLM calculated from the equation 4.5 discussed in chapter 4 under section 4.1.5 in the multi-storied malls selected in Delhi NCR and district Faridabad Haryana (India) are shown in table 5.11. From table it is clear that the maximum value of exposure due to radon daughters was found to be 97.01×10^{-3} WLM (in the third basement of malls) whereas, minimum value was found to be 5.61×10^{-3} WLM (at the third floor of the malls). The maximum exposure due to thoron progeny was found to be 8.05×10^{-3} WLM and minimum value of exposure due to thoron daughters was found to be 0.83×10^{-3} WLM during summer season (April-July). Results shows that maximum value of exposure due to radon and thoron progeny was found in winter season (October-January) in the third basement of malls whereas the minimum value of PAEC due to radon and thoron progeny was found during summer season (April-July) at the third floor of the malls.

Location	Seasonal variation of exposure due to radon Progeny (WLMx10^{-3})				Seasonal variation of exposure due to thoron progeny (WLMx10^{-3})			
	Winter	Spring	Summer	Rainy	Winter	Spring	Summer	Rainy
B3	97.01	59.62	42.37	67.00	8.05	6.30	5.05	7.48
B2	86.57	54.18	32.06	51.86	7.93	5.72	4.30	6.92
B1	59.65	36.73	25.81	46.75	8.05	5.39	3.70	4.69
G0	47.30	29.32	17.87	35.19	7.52	5.49	3.37	5.83
F1	27.38	16.32	12.09	26.67	4.31	2.34	2.02	2.94
F2	19.67	11.38	8.04	15.80	2.99	2.06	1.26	2.10
F3	15.08	8.32	5.61	9.75	2.11	1.82	0.83	1.57
AV±SE*	50.03	30.65	20.34	36.01	5.90	4.17	2.93	4.50

* SE (standard error)= $\sigma/\sqrt{N}$, where σ is SD (standard deviation) and N is no. of observations

Table 5.11: Seasonal variations of exposure due to radon and thoron Progeny in multi-storied malls of Delhi NCR and Faridabad, Haryana

Annual exposure due to radon and thoron progeny is calculated as a cumulative value of exposures at every floor of the malls due to all the seasons of a year are represented in table 5.12. From table it is clear that annual exposure due to radon progeny varies from 38.76×10^{-3} WLM (at third floor of the malls) to 266.00×10^{-3} WLM (in the third basement of the mall) with an average value of 137.03×10^{-3} WLM whereas, annual exposure due to thoron progeny varies from 6.33×10^{-3} WLM (at third floor of the malls) to 26.88×10^{-3} WLM (in the third basement of the malls) with an average value of 17.45×10^{-3} WLM. Maximum value of annual exposure due to radon and thoron progeny was found in winter season (October-January) in third basement of the malls and minimum value was found in summer season (April-July) at the third floor of the malls. Annual exposure due to radon and thoron (Rn+Th) progeny varies from 45.09×10^{-3} WLM to 292.88×10^{-3} WLM with an average value of 154.48×10^{-3} WLM.

The annual exposure due to radon and thoron progeny was converted into annual effective dose by using dose conversion factors; for radon daughter the dose conversion factor for members of the public is 3.88 mSv per WLM [7], whereas for thoron daughters the conversion factor is 3.4 mSv per WLM [21]. Annual effective dose for the inhabitants varies from 0.17 mSv to 1.12 mSv with an average value of 0.59 mSv.

Location	Annual exposure due to Radon progeny ($WLMx10^{-3}$)	Annual exposure due to thoron progeny ($WLMx10^{-3}$)	Annual Exposure due to (Rn+Th) progeny ($WLMx10^{-3}$)	Annual effective dose (mSv)
B3	266.00	26.88	292.88	1.12
B2	224.67	24.87	249.54	0.96
B1	168.92	21.84	190.76	0.73
G0	129.68	22.21	151.89	0.58
F1	82.46	11.61	94.07	0.36
F2	54.89	8.41	63.3	0.24
F3	38.76	6.33	45.09	0.17
Average	137.03	17.45	154.48	0.59

Table 5.12: Annual exposure due to radon and thoron progeny and annual effective dose in Multi-storied malls of Delhi NCR and Faridabad, Haryana

Variations in inhalation dose during all the four seasons of a year in multi-storied malls selected in Delhi NCR and district Faridabad Haryana (India) are shown in table 5.13. It shows that maximum value of inhalation dose is 3.01 mSv/y (in the third basement of malls) and minimum value is 0.20 mSv/y (at the third floor of the malls). From the above mentioned data it is clear that maximum value of inhalation dose was found in winter (October-January) in third basement of malls and minimum value was found in summers (April-July) at third floor of the malls.

Location	Seasonal variation of inhalation dose (mSv/y)			
	Winter	Spring	Summer	Rainy
B3	3.01	1.96	1.44	2.24
B2	2.75	1.79	1.13	1.83
B1	2.11	1.34	0.93	1.52
G0	1.77	1.17	0.71	1.34
F1	1.02	0.59	0.46	0.89
F2	0.73	0.45	0.30	0.56
F3	0.54	0.35	0.20	0.37
Average	1.70	1.09	0.74	1.25

Table 5.13: Seasonal variations of Inhalation dose in multi-storied malls of Delhi NCR and Faridabad, Haryana

Seasonal variations in the effective dose in multi-storied malls selected in Delhi NCR and district Faridabad Haryana (India) are shown in table 5.14.

Location	Seasonal Effective Dose (mSv)				Annual effective dose (mSv)
	Winter	Spring	Summer	Rainy	
B3	0.40	0.25	0.18	0.28	1.12
B2	0.36	0.23	0.14	0.22	0.96
B1	0.25	0.16	0.11	0.19	0.73
G0	0.21	0.13	0.08	0.15	0.58
F1	0.12	0.07	0.05	0.11	0.36
F2	0.09	0.05	0.04	0.07	0.24
F3	0.06	0.04	0.02	0.04	0.17
Average	0.21	0.13	0.09	0.15	0.59

Table 5.14: Variations of seasonal effective dose and annual effective dose in multi-storied malls of Delhi NCR and Faridabad, Haryana

From table it is clear that the maximum dose was found to be 0.40 mSv during winter (October-January) in third basement of malls and minimum dose received was found to be 0.02 mSv during summer (April-July) at the third floor of the malls. Annual effective dose received by the inhabitants of multi-storied malls varies from 1.12 mSv (in the lowest basement (third) of present study) to 0.17 mSv at the third floor of the malls as shown in figure 5.11 with an average value of 0.59 mSv.

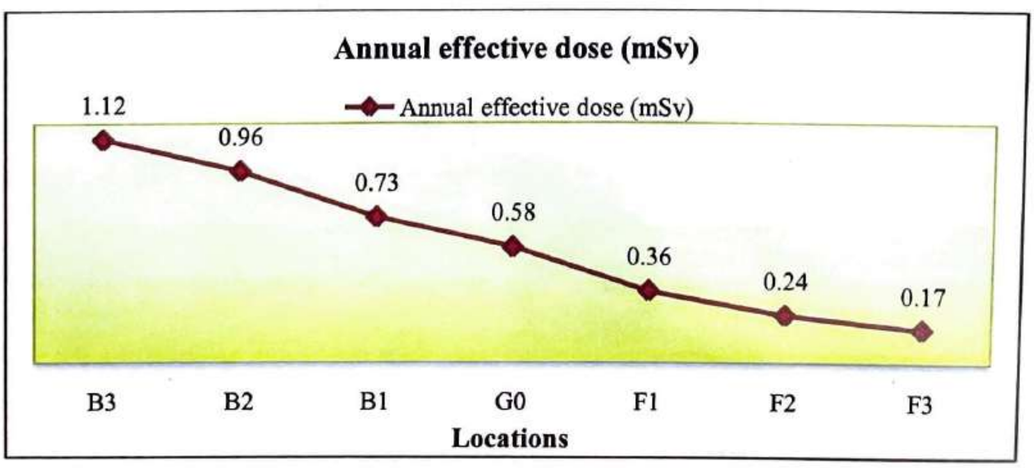

Figure 5.11: Graphical variations of annual effective dose in multi-storied malls of Delhi NCR and Haryana

5.1.6 Conclusion

- Results show two types of variations; one is according to the different seasons of a year and other is according to the floor of the malls.
- In case of seasonal variations the maximum values of radon and thoron activity were observed during winters and minimum values were observed during summers. According to the floor level the maximum concentration of radon and thoron were found at the lowest basements (third basement) of the malls selected in the present study because there is no any ventilation.
- As the height of the malls (buildings) increases, the radiological exposure to the workers and visitors to the malls decreases.
- The highest concentration of radon and thoron was found to be 87.97±1.79 Bqm^{-3} and 29.21±2.64 Bqm^{-3} in the third basement of the malls where the multiple surfaces are in contact to ground during winters whereas lowest values of radon and thoron concentration was found to be 5.09±0.33 Bqm^{-3} and 3.06±0.21 Bqm^{-3} at the third floor of the malls during summers.
- Annual effective dose is found to be higher in the lower basements as comparative to other floors of the malls because of poor ventilation and its vicinity with the ground.
- Results indicate that maximum value of annual effective dose is slightly higher than the recommended safety limit of 1.0 mSv/y for general public but below the safety limits of 20 mSv for the workplaces as recommended by the ICRP 1993.

5.2 CASE STUDY-II

In this case study the results are incorporated for thermal power plants premises of Delhi NCR and Haryana during all the seasons of a year from January 2015 to January 2016.

5.2.1 Introduction

Coal based thermal power plants are extensively used to fulfill the growing demand of electricity in India [24-25]. In this process, the environmental condition of thermal power plant premises and its surroundings is going to worsen. Coal has trace amount of naturally occurring radioactive isotopes such as: uranium, thorium, potassium, radon and its daughter products [26-27]. Radon is a renowned radioactive element which is hazardous to the public health. On burning the coal, these radioactive elements released to the surrounding in the form of gases & solid waste (ash) and pollute the environment [28]. Around 10% of ash generated by thermal power plants is released in the surrounding environment from the chimney; rest of 85-90% ash is collected as a bottom ash in the boiler which is more toxic than the parent coal itself [29]. In all the process, from handling of coal, their combustion to the duty towards the management of ash produced: the workers are at risk of getting health issues [30]. In spite of this, workers are continuously exposed to the contaminated environment of power plant which is a matter of concern from the health point of view [31-32]. Various estimations in the thermal power plants are reported in the literature by a number of researchers [33, 31, 34-38]. So, the radiological estimations are essential in the environment of coal based thermal power plant premises. In the present study radon, thoron and their progeny concentrations were estimated in the coal based thermal power plants situated in Haryana, India.

5.2.2 About The Study Area

In this study of workplaces the measurements were carried out in the thermal power plants of Delhi NCR and Haryana. Haryana lies at the latitude of 29° 3' 56.78" N and longitude 76° 2' 25.78" E. Its elevation is 219 meters height. Haryana is one of the northern states of India; to some extent it is situated at Punjab region and surrounding the state of New Delhi.

1. The present study of Thermal power plant situated in Haryana, India was carried out from January 2015 to January 2016. The results were calculated during all the four seasons of a year: spring (January-April), summer (April-July), rainy (July-October), winter (October to January).
2. Total 10 locations were selected in each plant from the entrance gate to the coal area and locations are represented as PPL-1 (power plant location-1) to PPL-10 (power plant location-10).
3. The selected locations represented as PPL-1 to PPL-10 were chosen in the order of coal area, fly ash area, water treatment plant, chlorination plant, boiler area, near entrance gate, turbine area, power generating room, control room and workshop respectively. Uniformity was maintained for the selection and the

representation of the location so that the cumulative data can be represented authentically.

4. At every location twin cup dosimeter loaded with LR-115 type II detectors were exposed for the seasonal radiological assessment and in total 70 twin cup dosimeters were installed for each plant during the study of each season and the process was repeated for all the four seasons of a year.

5.2.3 Experimental Technique

In the present study radon and thoron concentration, PAEC due to radon and thoron progeny, inhalation dose, annual exposure due to radon and thoron progeny and annual effective dose were calculated with track etch technique using Solid State Nuclear Track Detectors. In this technique Twin cup dosimeters loaded with LR-115 type II Solid State Nuclear Track Detectors in the pieces of 2.5 × 2.5 cm were exposed at the selected locations during all the four seasons of a year. The detail of this technique has been discussed in chapter 3 under section 3.8.

5.2.4 Formulas Used

The radon and thoron concentration was calculated using equations 4.1 and 4.2 and Potential Alpha Energy Concentration due to radon and thoron progeny was calculated using equation 4.3 of fourth chapter under the subsection 4.1.4. The inhalation dose due to radon and thoron in mSv/y was estimated using the equation 4.4 under the section 4.1.5 of fourth chapter.

5.2.5 Results and Discussion

In the present case study radon and thoron concentration, PAEC due to radon and thoron progeny, Inhalation dose, exposure due to radon and thoron progeny and annual effective dose were calculated during all the four seasons, from the samples collected from the thermal power plants situated in Haryana (India) using equations as mentioned in 5.2.4. The exposure due to radon and thoron progeny was calculated from equation 4.5 as discussed in chapter 4 under section 4.1.5 for duration of 90 days (exposure time of each season). The exposure due to radon and thoron progeny was converted into effective dose by using dose conversion factors; for radon daughter the dose conversion factor for members of the public is 3.88 mSv per WLM [7], whereas for thoron daughters the conversion factor is 3.4 mSv per WLM [21]. The calculated results for all the parameters are elaborated in the tabular form and explained separately for all the seasons of a calendar year.

(i) Results for spring season (January 2015-April 2015)

During the spring season, the results calculated for radon and thoron concentration and Potential Alpha Energy Concentration (PAEC) due to radon and thoron progeny are elaborated in table 5.15. Table shows that radon concentration varies from 95.73±1.11 Bqm^{-3} to 338.23±1.52 Bqm^{-3} with an average value of 196.27±16.00 Bqm^{-3}. The thoron concentration varies from 52.81±1.20 Bqm^{-3} to 176.68±2.51 Bqm^{-3} with an average value of 113.69±8.51 Bqm^{-3} during spring season (January-April).

Location	Radon concentration C_R (Bq m^{-3})	Thoron concentration C_T (Bq m^{-3})	PAEC (Rn) (mWL)	PAEC (Th) (mWL)
PPL-1	338.23±1.52	176.68±2.51	36.57±0.16	4.78±0.07
PPL-2	312.33±1.50	167.68±1.40	33.77±0.16	4.53±0.04
PPL-3	223.72±1.27	142.65±0.89	24.19±0.14	3.86±0.02
PPL-4	291.03±1.67	175.97±1.47	31.46±0.18	4.76±0.04
PPL-5	187.10±1.64	107.13±1.58	20.23±0.18	2.90±0.04
PPL-6	98.54±1.66	52.81±1.20	10.65±0.18	1.43±0.03
PPL-7	165.38±1.29	90.77±1.49	17.88±0.14	2.45±0.04
PPL-8	120.60±0.70	77.43±1.09	13.04±0.08	2.09±0.03
PPL-9	95.73±1.11	58.31±1.43	10.35±0.12	1.58±0.04
PPL-10	130.00±1.78	87.45±1.50	14.05±0.19	2.36±0.04
Av±SE*	196.27±16.00	113.69±8.51	21.22±1.73	3.07±0.23

* SE (standard error)= $\sigma/\sqrt{N}$, where σ is SD (standard deviation) and N is no. of observations

Table 5.15: Radon and thoron concentration and PAEC due to radon and thoron progeny in the premises of thermal power plants during spring season

The Potential Alpha Energy Concentration (PAEC) due to radon progeny as shown in table 5.15 varies from 10.35±0.12 mWL to 36.57±0.16 mWL with an average value of 21.22±1.73 mWL and PAEC due to thoron progeny varies from 1.43±0.03 mWL to 4.78±0.07 mWL with an average value of 3.07±0.23 mWL during spring season (January-April). The variations in radon and thoron concentration are shown in figure 5.12 and 5.13. Graphs shows that the minimum values of radon and thoron concentration were found at the ninth location (control room) and at the sixth location (near entrance gate) selected in the thermal power plants respectively whereas maximum values of radon and thoron concentration were found at the first location (coal area) selected in the thermal power plants.

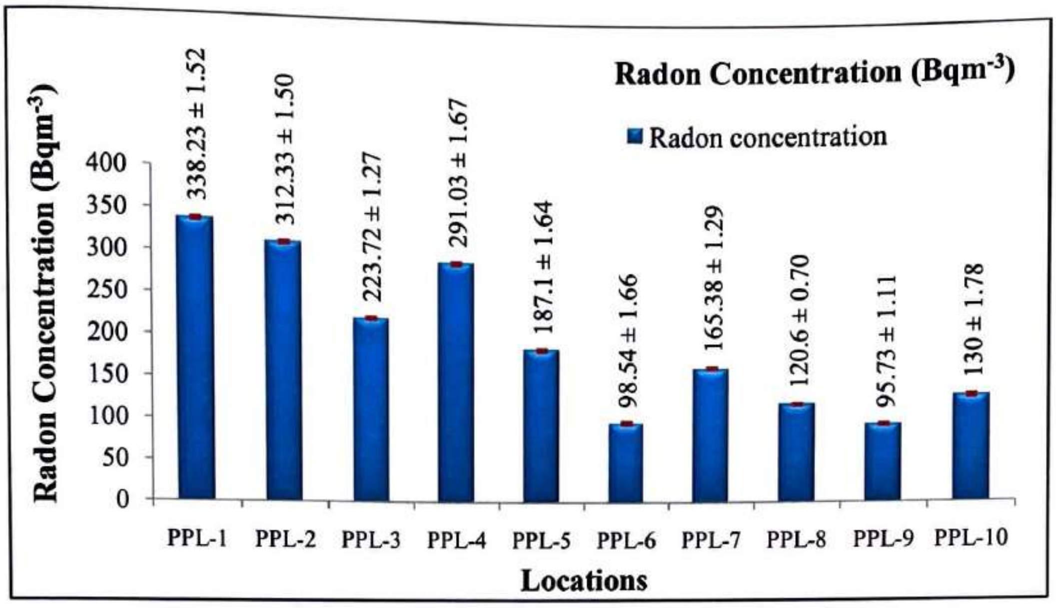

Figure 5.12: Graphical variations of radon concentration in the premises of thermal power plants during spring season

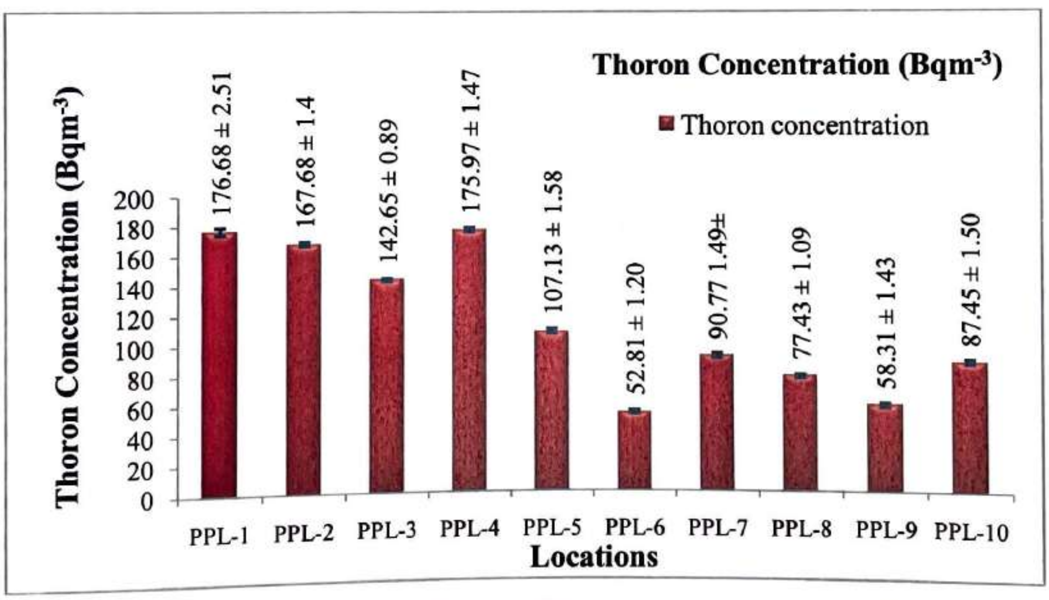

Figure 5.13: Graphical variations of thoron concentration in the premises of thermal power plants during spring season

Results for the exposure due to radon and thoron progeny for the spring season are shown in table 5.16. The exposure due to radon progeny varies from 103.49×10^{-3} WLM to 365.66×10^{-3} WLM with an average value of 212.18×10^{-3} WLM and due to thoron progeny varies from 14.27×10^{-3} WLM to 47.75×10^{-3} WLM with an average value of 30.73×10^{-3} WLM during spring season (January-April).

Location	Exposure due to radon progeny (WLMx10^{-3})	Exposure due to thoron progeny (WLMx10^{-3})	Exposure due to (Rn+Th) progeny (WLMx10^{-3})	Inhalation dose D (mSv/y)	Effective dose (mSv)
PPL-1	365.66	47.75	413.41	13.02	1.58
PPL-2	337.65	45.32	382.97	12.13	1.46
PPL-3	241.86	38.56	280.42	9.21	1.07
PPL-4	314.63	47.56	362.19	11.76	1.38
PPL-5	202.27	28.96	231.23	7.42	0.88
PPL-6	106.53	14.27	120.80	3.82	0.46
PPL-7	178.79	24.53	203.32	6.47	0.78
PPL-8	130.38	20.93	151.31	4.98	0.58
PPL-9	103.49	15.76	119.25	3.88	0.46
PPL-10	140.54	23.64	164.18	5.46	0.63
Average	212.18	30.73	242.91	7.81	0.93

Table 5.16: Exposure due to radon and thoron progeny, inhalation dose and effective dose in the premises of thermal power plants during spring season

Results for effective dose and inhalation are shown in table 5.16. Table shows that the inhalation dose varies from 3.82 mSv/y to 13.02 mSv/y with an average value of 7.81 mSv/y. Effective doses calculated in mSv varies from 0.46 mSv to 1.58 mSv with an average value of 0.93 mSv. Minimum value of effective dose due to radon and thoron progeny was found at the Control room and near the entrance gate of the thermal power plants whereas the maximum values were found at the coal area.

(ii) Results for Summer season (April 2015- July 2015)

During the summer season, the results calculated for radon and thoron concentration and Potential Alpha Energy Concentration (PAEC) due to radon and thoron progeny are elaborated in table 5.17. From table it is clear that radon concentration varies from 87.03±1.44 Bqm^{-3} to 307.48±1.63 Bqm^{-3} with an average value of 178.33±14.52 Bqm^{-3} whereas, the thoron concentration varies from 48.85±1.69 Bqm^{-3} to 164.97±0.96 Bqm^{-3} with an average value of 105.51±7.88 Bqm^{-3} during summer season (April-July).

Location	Radon concentration C_R (Bq m^{-3})	Thoron concentration C_T (Bq m^{-3})	PAEC (Rn) (mWL)	PAEC (Th) (mWL)
PPL-1	307.48±1.63	164.97±0.96	33.24±0.18	4.46±0.03
PPL-2	283.93±1.44	162.79±1.30	30.70±0.16	4.40±0.04
PPL-3	203.38±1.08	129.91±1.27	21.99±0.12	3.51±0.03
PPL-4	263.66±1.09	155.59±1.55	28.50±0.12	4.21±0.04
PPL-5	170.09±1.74	100.97±1.25	18.39±0.19	2.73±0.03
PPL-6	89.58±1.18	48.85±1.69	9.68±0.13	1.32±0.05
PPL-7	150.35±1.38	85.56±1.21	16.25±0.15	2.31±0.03
PPL-8	109.63±1.14	71.63±0.59	11.85±0.12	1.94±0.02
PPL-9	87.03±1.44	53.94±1.26	9.41±0.16	1.46±0.03
PPL-10	118.19±0.783	80.90±1.058	12.78±0.09	2.19±0.03
Av±SE*	178.33±14.52	105.51±7.88	19.28±1.57	2.85±0.21

* SE (standard error)= $\sigma/\sqrt{N}$, where σ is SD (standard deviation) and N is no. of observations

Table 5.17: Radon and thoron concentration and PAEC due to radon and thoron progeny in the premises of thermal power plants during summer season

The Potential Alpha Energy Concentration (PAEC) due to radon progeny as shown in table 5.17 varies from 9.41±0.16 mWL to 33.24±0.18 mWL with an average value of 19.28±1.57 mWL and PAEC due to thoron progeny varies from 1.32±0.05 mWL to 4.46±0.03 mWL with an average value of 2.85±0.21 mWL during summer season (April-July). The variations in radon and thoron concentration are shown in figure 5.14 and 5.15. Graphs shows that the minimum values of radon and thoron concentration were found at the ninth location (control room) and at the sixth location (near entrance gate) selected in the thermal power plants respectively whereas maximum values of radon and thoron concentration were found at the first location (coal area) selected in the thermal power plants.

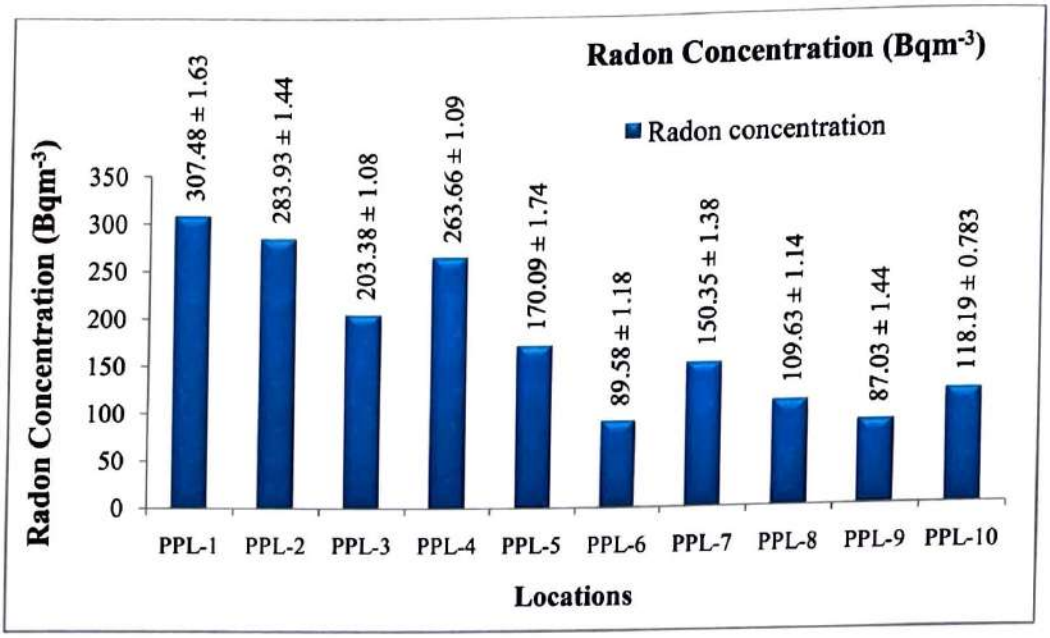

Figure 5.14: Graphical variations of radon concentration in the premises of thermal power plants during summer season

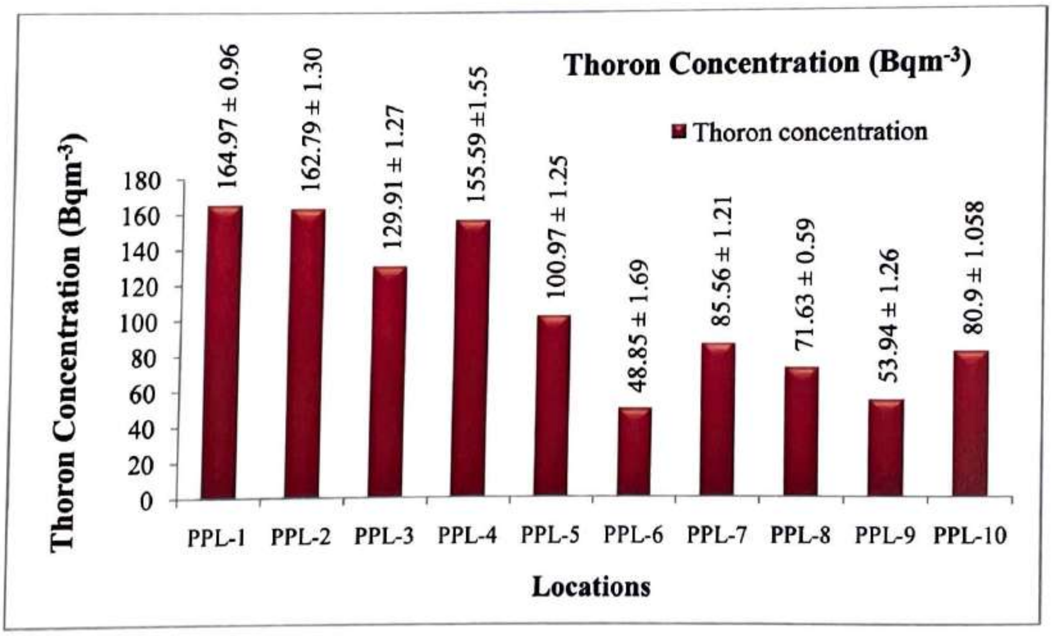

Figure 5.15: Graphical variations of thoron concentration in the premises of thermal power plants during summer season

Results for the exposure due to radon and thoron progeny for the spring season are shown in table 5.18. The exposure due to radon progeny varies from 94.09×10^{-3} WLM to 332.41×10^{-3} WLM with an average value of 192.79×10^{-3} WLM and exposure due to thoron progeny varies from 13.20×10^{-3} WLM to 44.59×10^{-3} WLM with an average value of 28.52×10^{-3} WLM during summer season (April-July).

Location	Exposure due to radon progeny (WLMx10^{-3})	Exposure due to thoron progeny (WLMx10^{-3})	Exposure due to (Rn+Th) progeny (WLMx10^{-3})	Inhalation dose D (mSv/y)	Effective dose (mSv)
PPL-1	332.41	44.59	377.00	11.94	1.44
PPL-2	306.96	43.99	350.95	11.26	1.34
PPL-3	219.87	35.11	254.98	8.38	0.97
PPL-4	285.04	42.05	327.09	10.56	1.25
PPL-5	183.88	27.29	211.17	6.83	0.81
PPL-6	96.84	13.20	110.00	3.50	0.42
PPL-7	162.54	23.12	185.67	5.95	0.71
PPL-8	118.52	19.36	137.88	4.55	0.53
PPL-9	94.09	14.58	108.67	3.55	0.41
PPL-10	127.77	21.87	149.64	4.99	0.57
Average	192.79	28.52	221.31	7.15	0.84

Table 5.18: Exposure due to radon and thoron progeny, inhalation dose and effective dose in the premises of thermal power plants during summer season

The inhalation dose as shown in table 5.18 varies from 3.50 mSv/y to 11.94 mSv/y with an average value of 7.15mSv/y. Effective dose calculated in mSv varies from 0.41 mSv to 1.44 mSv with an average value of 0.84 mSv. Minimum value of effective dose due to radon and thoron progeny was found at the Control room and near the entrance gate of the thermal power plants whereas the maximum values were found at the coal area.

(iii) Results for rainy season (July 2015-October 2015)

During the rainy season, the results calculated for radon and thoron concentration and Potential Alpha Energy Concentration (PAEC) due to radon and thoron progeny are elaborated in table 5.19. From table it is clear that radon concentration varies from 101.15±0.85 Bqm^{-3} to 357.21±1.61 Bqm^{-3} with an average value of 206.26±16.83 Bqm^{-3} whereas, the thoron concentration varies from 57.42±1.32 Bqm^{-3} to 191.41±0.81 Bqm^{-3} with an average value of 119.38±8.91 Bqm^{-3} during rainy season ((July-October).

Location	Radon concentration C_R (Bq m^{-3})	Thoron concentration C_T (Bq m^{-3})	PAEC (Rn) (mWL)	PAEC (Th) (mWL)
PPL-1	357.21±1.61	191.41±0.81	38.62±0.17	5.17±0.02
PPL-2	338.10±1.26	182.10±1.03	36.55±0.14	4.92±0.03
PPL-3	235.70±2.06	146.12±1.22	25.48±0.22	3.95±0.03
PPL-4	287.80±1.26	174.00±1.52	31.11±0.14	4.70±0.04
PPL-5	205.57±1.50	114.90±1.01	22.22±0.16	3.11±0.03
PPL-6	101.15±0.85	57.42±1.32	10.93±0.09	1.55±0.04
PPL-7	174.14±1.43	95.39±1.47	18.83±0.15	2.58±0.04
PPL-8	119.07±1.68	82.24±1.42	12.87±0.18	2.22±0.04
PPL-9	105.61±1.69	60.29±1.12	11.42±0.18	1.63±0.03
PPL-10	138.26±1.29	89.96±1.18	14.95±0.14	2.43±0.03
Av±SE*	206.26±16.83	119.38±8.91	22.30±1.82	3.23±0.24

* SE (standard error)= $\sigma/\sqrt{N}$, where σ is SD (standard deviation) and N is no. of observations

Table 5.19: Radon and thoron concentration and PAEC due to radon and thoron progeny in the premises of thermal power plants during rainy season

The variations in radon and thoron concentration are shown in the figure 5.16 and 5.17.

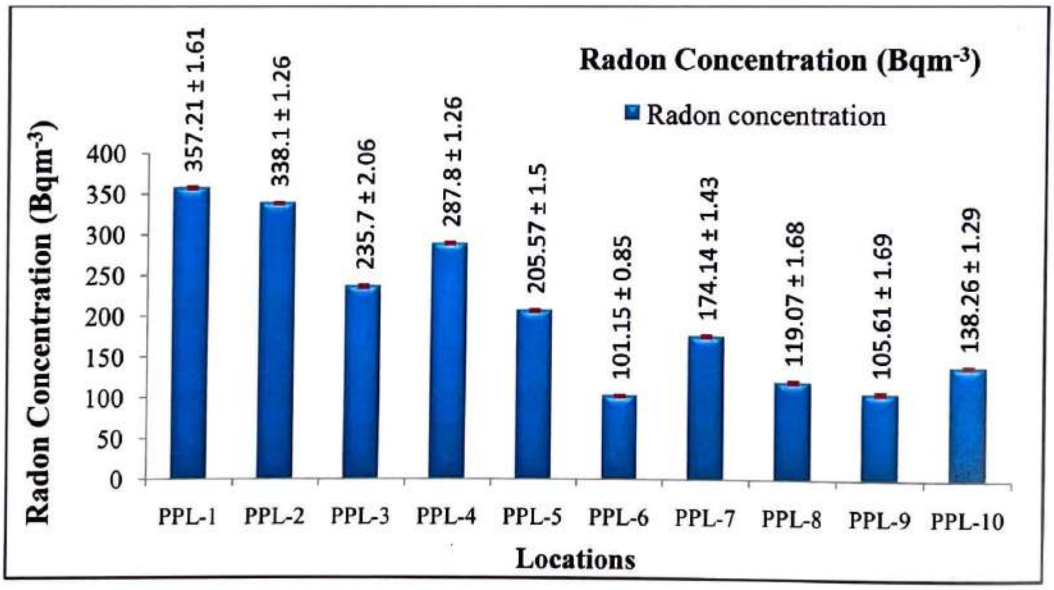

Figure 5.16: Graphical variations of radon concentration in the premises of thermal power plants during rainy season

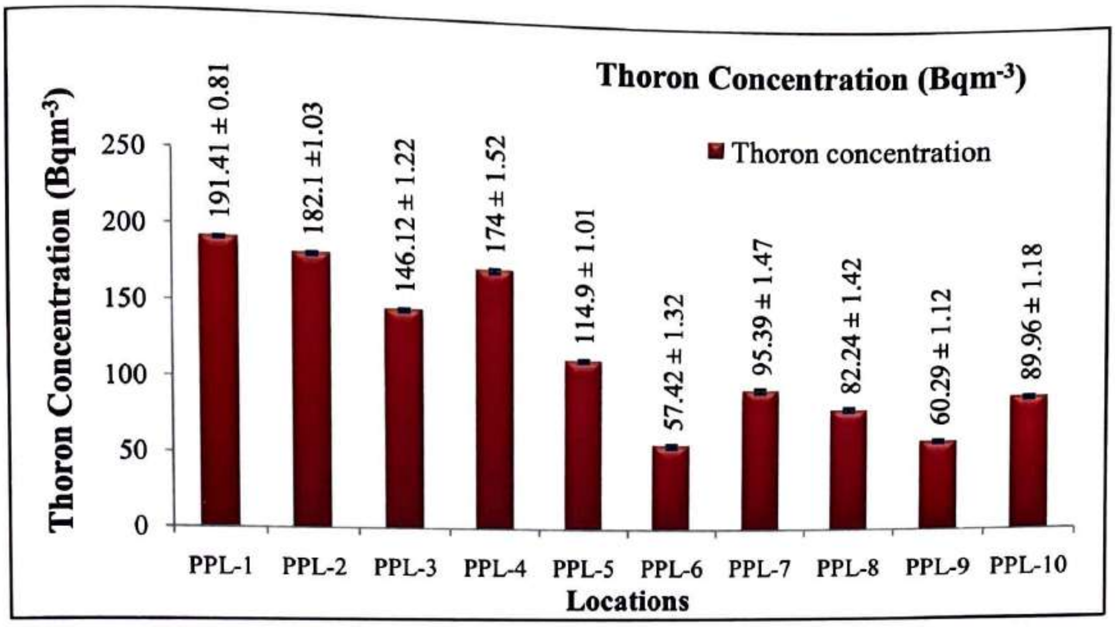

Figure 5.17: Graphical variations of thoron concentration in the premises of thermal power plants during rainy season

Graphs shows that the minimum values of radon and thoron concentration were found at the sixth location (near entrance gate) in the thermal power plants whereas maximum values of radon and thoron concentration were found at the first location (coal area) in the thermal power plants.

The potential alpha energy concentration (PAEC) due to radon and thoron progeny is shown in table 5.19. Table shows that PAEC due to radon progeny varies from 10.93±0.09 mWL to 38.62±0.17 mWL with an average value of 22.30±1.82 mWL and PAEC due to thoron progeny varies from 1.55±0.04 mWL to 5.17±0.02 mWL with an average value of 3.23±0.24 mWL during rainy season (July-October).

Results for the exposure due to radon and thoron progeny for the rainy season are shown in table 5.20. The exposure due to radon progeny varies from 109.35×10^{-3} WLM to 386.17×10^{-3} WLM with an average value of 222.98×10^{-3} WLM and due to thoron progeny varies from 15.52×10^{-3} WLM to 51.73×10^{-3} WLM with an average value of 32.27×10^{-3} WLM during rainy season (July-October).

Location	Exposure due to radon progeny (WLMx10^{-3})	Exposure due to thoron progeny (WLMx10^{-3})	Exposure due to (Rn+Th) progeny (WLMx10^{-3})	Inhalation dose D (mSv/y)	Effective dose (mSv)
PPL-1	386.17	51.73	437.90	13.86	1.67
PPL-2	365.52	49.22	414.74	13.14	1.59
PPL-3	254.81	39.49	294.30	9.61	1.12
PPL-4	311.13	47.03	358.16	11.63	1.37
PPL-5	222.24	31.05	253.29	8.09	0.97
PPL-6	109.35	15.52	124.87	4.00	0.48
PPL-7	188.26	25.78	214.04	6.81	0.82
PPL-8	128.73	22.23	150.96	5.05	0.58
PPL-9	114.17	16.29	130.46	4.18	0.50
PPL-10	149.47	24.31	173.78	5.73	0.66
Average	222.98	32.27	255.25	8.21	0.98

Table 5.20: Exposure due to radon and thoron, inhalation dose and effective dose in the premises of thermal power plants during rainy season

Results of effective dose and inhalation dose are also shown in table 5.20. Results shows that the inhalation dose varies from 4.00 mSv/y to 13.86 mSv/y with an average value of 8.21 mSv/y. Effective dose calculated in mSv varies from 0.48 mSv to 1.67 mSv with an average value of 0.98 mSv. Minimum value of effective dose due to radon and thoron progeny was found to 1.67 mSv with an average value of 0.98 mSv. Minimum value of effective dose due to radon and thoron progeny was found near the entrance gate of the thermal power plants whereas the maximum values were found at the coal area of thermal power plants.

(iv) Results for winter season (October 2015-January 2016)

During the winter season, the results calculated for radon and thoron concentration and Potential Alpha Energy Concentration (PAEC) due to radon and thoron are elaborated in table 5.21. From table it is clear that radon concentration varies from 105.23±0.66 Bqm^{-3} to 379.61±0.47 Bqm^{-3} with an average value of 220.93±18.14 Bqm^{-3} whereas, the thoron concentration varies from 61.22±0.64 Bqm^{-3} to 198.76±1.39 Bqm^{-3} with an average value of 127.28±9.43 Bqm^{-3} during winter season (October-January).

Location	Radon concentration C_R (Bqm^{-3})	Thoron concentration C_T (Bqm^{-3})	PAEC (Rn) (mWL)	PAEC (Th) (mWL)
PPL-1	379.61±0.47	198.76±1.39	41.04±0.05	5.37±0.04
PPL-2	363.08±1.61	193.11±3.78	39.25±0.17	5.22±0.10
PPL-3	248.63±1.77	162.18±1.41	26.88±0.19	4.38±0.04
PPL-4	313.51±1.28	184.13±1.59	33.89±0.14	4.98±0.04
PPL-5	221.76±1.15	127.81±1.63	23.97±0.12	3.45±0.04
PPL-6	105.23±0.66	61.22±0.64	11.38±0.07	1.65±0.02
PPL-7	192.38±1.72	98.34±1.01	20.80±0.19	2.66±0.03
PPL-8	127.63±1.44	86.30±1.17	13.80±0.16	2.33±0.03
PPL-9	109.29±0.84	63.53±1.51	11.81±0.09	1.72±0.04
PPL-10	148.14±1.55	97.47±1.31	16.02±0.17	2.63±0.04
Av±SE*	220.93±18.14	127.28±9.43	23.88±1.96	3.44±0.25

*SE is (standard error) $=\sigma/\sqrt{N}$, where σ is SD (standard deviation) and N is no. of observations

Table 5.21: Radon and thoron concentration and PAEC due to radon and thoron progeny in the premises of thermal power plants during winter season

Table 5.21 shows that Potential Alpha Energy Concentration (PAEC) due to radon progeny varies from 11.38±0.07 mWL to 41.04±0.05 mWL with an average value of 23.88±1.96 mWL and PAEC due to thoron progeny varies from 1.65±0.02 mWL to 5.37±0.04 mWL with an average value of 3.44±0.25 mWL during winter season (October-January). The variations in radon and thoron concentration are shown in figure 5.18 and 5.19. Graphs shows that the minimum values of radon and thoron concentration were found at the sixth location (near entrance gate) selected in the thermal power plants whereas maximum values of radon and thoron concentration were found at the first location (coal area) in the thermal power plants.

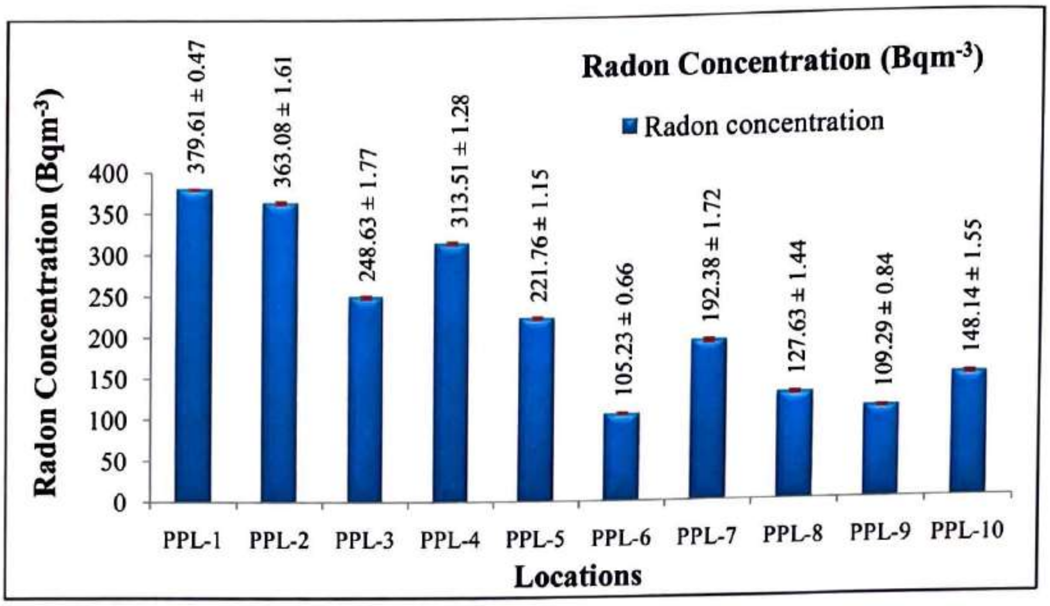

Figure 5.18: Graphical variations of radon concentration in power plants premises during winter season

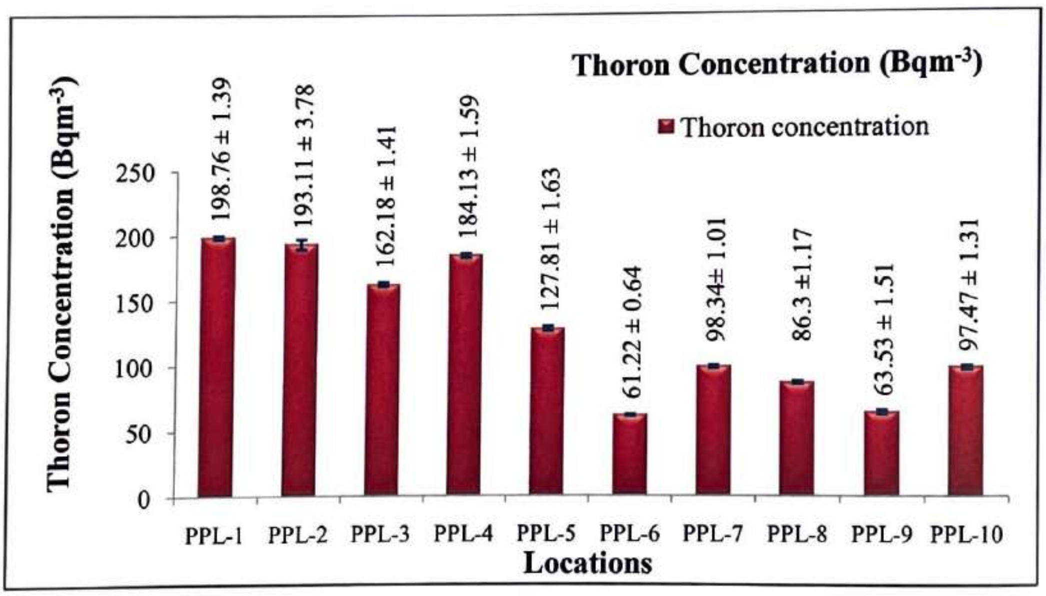

Figure 5.19: Graphical variations of thoron concentration in power plants premises during winter season

Results for the exposure due to radon and thoron progeny for the winter season are shown in table 5.22. The exposure due to radon progeny varies from 113.77×10^{-3} WLM to 410.39×10^{-3} WLM with an average value of 238.84×10^{-3} WLM and due to thoron progeny varies from 16.55×10^{-3} WLM to 53.72×10^{-3} WLM with an average value of 34.40×10^{-3} WLM during winter Season (October-January).

Location	Exposure due to radon progeny (WLMx10^{-3})	Exposure due to thoron progeny (WLMx10^{-3})	Exposure due to (Rn+Th) progeny (WLMx10^{-3})	Inhalation dose D (mSv/y)	Effective dose (mSv)
PPL-1	410.39	53.72	464.11	14.62	1.78
PPL-2	392.52	52.19	444.71	14.06	1.70
PPL-3	268.79	43.83	312.62	10.32	1.19
PPL-4	338.93	49.76	388.69	12.54	1.48
PPL-5	239.74	34.54	274.28	8.81	1.05
PPL-6	113.77	16.55	130.32	4.20	0.50
PPL-7	207.98	26.58	234.56	7.36	0.90
PPL-8	137.98	23.32	161.31	5.37	0.61
PPL-9	118.15	17.17	135.32	4.356	0.52
PPL-10	160.15	26.34	186.49	6.17	0.71
Average	238.84	34.40	273.24	8.78	1.04

Table 5.22: Exposure due to radon and thoron, inhalation dose and effective dose in the premises of thermal power plants during winter Season

Results for effective dose and inhalation dose are shown in table 5.22. Table shows that the inhalation dose varies from 4.20 mSv/y to 14.62 mSv/y with an average value of 8.78 mSv/y. Effective dose calculated in mSv varies from 0.50 mSv to 1.78 mSv with an average value of 1.04 mSv. Minimum value of effective dose due to radon and thoron progeny was found near the entrance gate of the thermal power plants whereas the maximum values were found at the coal area of thermal power plants.

Variation in radon and thoron concentration with respect to the weather is a well-known fact and seasonal variations in radon and thoron concentration in the thermal power plants premises situated in Haryana during all the four seasons (winter, spring, summer and rainy) of a year are represented in table 5.23. Maximum value of radon concentration was found to be 379±0.47 Bqm^{-3} whereas, minimum value was found to be 87.03±1.44 Bqm^{-3}. The maximum value of thoron concentration for the workers of thermal power plants was found to be 198.76±1.39 Bqm^{-3} whereas, minimum value of thoron concentration was found to be 48.85±1.69 Bqm^{-3}. Variations in radon and thoron concentration are shown in figure 5.20 and 5.21. Graphs reveal that the maximum value of radon and thoron concentration was found in winter season

(October-January) in the coal area of thermal power plants and the minimum value of radon and thoron concentration was found in summer season (April-July) at the control room and entrance gate. The variations in the values at the entrance gate and control room are approximately same. The radon and thoron activity was found to be comparatively low in the monsoon season rather than the winter but higher than the spring season and lowest were found in the summer.

Location	Seasonal variations in radon concentration (C_R) (Bqm^{-3})				Seasonal variations in thoron concentration (C_T) (Bqm^{-3})			
	Winter	Spring	Summer	Rainy	Winter	Spring	Summer	Rainy
PPL-1	379.61 ±0.47	338.23 ±1.52	307.48 ±1.63	357.21 ±1.61	198.76 ±1.39	176.68 ±2.51	164.97 ±0.96	191.41 ±0.81
PPL-2	363.08 ±1.61	312.33 ±1.50	283.9 3±1.44	338.10 ±1.26	193.11 ±3.78	167.68 ±1.40	162.7 9±1.30	182.10 ±1.03
PPL-3	248.63 ±1.77	223.72 ±1.27	203.38 ±1.08	235.70 ±2.06	162.18 ±1.41	142.65 ±0.89	129.91 ±1.27	146.12 ±1.22
PPL-4	313.51 ±1.28	291.03 ±1.67	263.66 ±1.09	287.80 ±1.26	184.13 ±1.59	175.97 ±1.47	155.59 ±1.55	174.00 ±1.52
PPL-5	221.76 ±1.15	187.10 ±1.64	170.09 ±1.74	205.57 ±1.50	127.81 ±1.63	107.13 ±1.58	100.97 ±1.25	114.90 ±1.01
PPL-6	105.23 ±0.66	98.54 ±1.66	89.58 ±1.18	101.15 ±0.85	61.22 ±0.64	52.81 ±1.20	48.85 ±1.69	57.42 ±1.32
PPL-7	192.38 ±1.72	165.38 ±1.29	150.35 ±1.38	174.14 ±1.43	98.34 ±1.01	90.77 ±1.49	85.56 ±1.21	95.39 ±1.47
PPL-8	127.63 ±1.44	120.60 ±0.70	109.63 ±1.14	119.07 ±1.68	86.30 ±1.17	77.43 ±1.09	71.63 ±0.59	82.24 ±1.42
PPL-9	109.29 ±0.84	95.73 ±1.11	87.03 ±1.44	105.61 ±1.69	63.53 ±1.51	58.31 ±1.43	53.94 ±1.26	60.29 ±1.12
PPL-10	148.14 ±1.55	130.00 ±1.78	118.19 ±0.783	138.26 ±1.29	97.47 ±1.31	87.45 ±1.50	80.90 ±1.058	89.96 ±1.18
AV±SE*	220.93 ±18.14	196.27 ±16.00	178.33 ±14.52	206.26 ±16.83	127.28 ±9.43	113.69 ±8.51	105.51 ±7.88	119.38 ±8.91

* SE (standard error)= $\sigma/\sqrt{N}$, where σ is SD (standard deviation) and N is no. of observations

Table 5.23: Seasonal variations of radon and thoron concentration in the premises of thermal power plants of Delhi NCR and Haryana

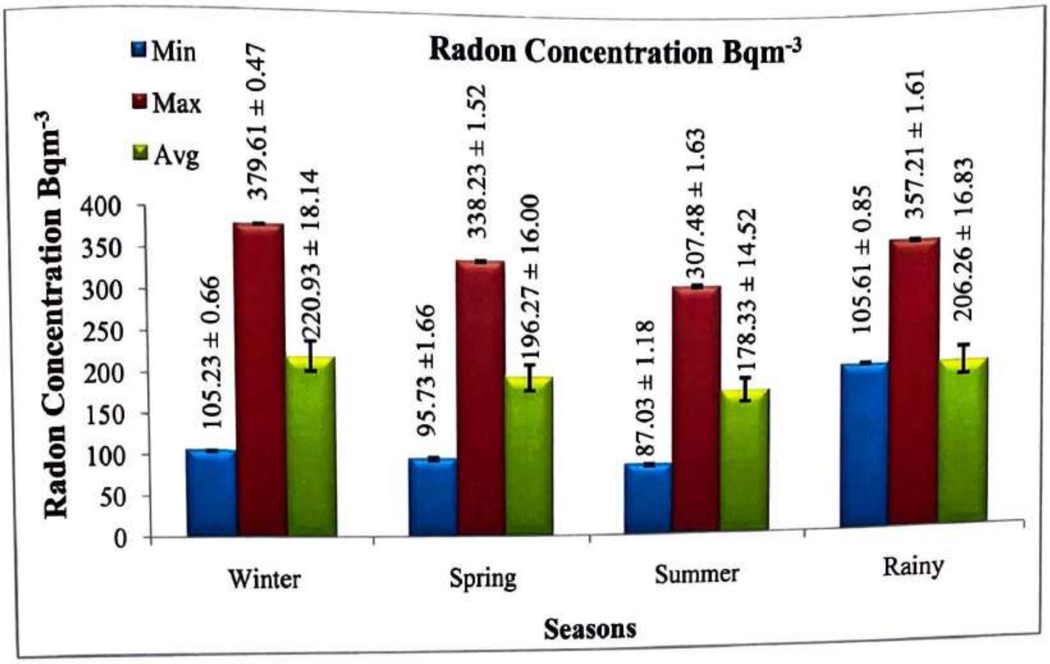

Figure 5.20: Graphical variations of radon concentration in the premises of thermal power plants of Delhi NCR and Haryana during all the seasons of a year

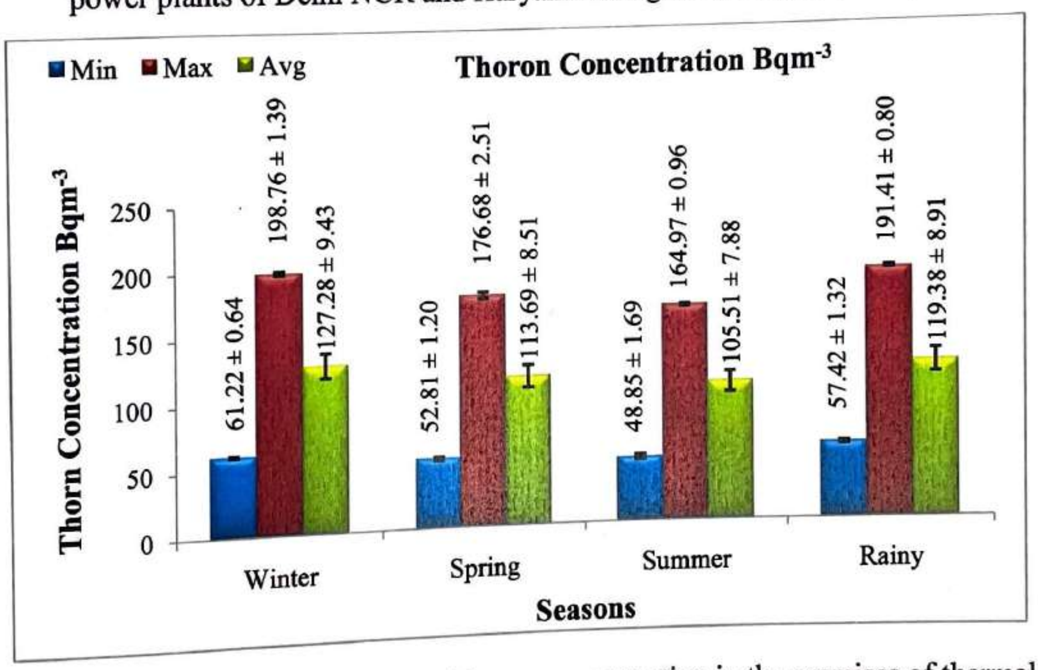

Figure 5.21: Graphical variations of thoron concentration in the premises of thermal power plants of Delhi NCR and Haryana during all the seasons of a year

Deviations in the Potential Alpha Energy Concentration (PAEC) due to radon and thoron progeny in the thermal power plants premises situated in Haryana (India) during all the four seasons: winter, spring, summer and rainy of a year are shown in table 5.24.

Location	Seasonal variations of PAEC (Rn) mWL				Seasonal variations of PAEC (Th) mWL			
	Winter	Spring	Summer	Rainy	Winter	Spring	Summer	Rainy
PPL-1	41.04 ±0.05	36.57 ±0.16	33.24 ±0.18	38.62 ±0.17	5.37 ±0.04	4.78 ±0.07	4.46 ±0.03	5.17 ±0.02
PPL-2	39.25 ±0.17	33.77 ±0.16	30.70 ±0.16	36.55 ±0.14	5.22 ±0.10	4.53 ±0.04	4.40 ±0.04	4.92 ±0.03
PPL-3	26.88 ±0.19	24.19 ±0.14	21.99 ±0.12	25.48 ±0.22	4.38 ±0.04	3.86 ±0.02	3.51 ±0.03	3.95 ±0.03
PPL-4	33.89 ±0.14	31.46 ±0.18	28.50 ±0.12	31.11 ±0.14	4.98 ±0.04	4.76 ±0.04	4.21 ±0.04	4.70 ±0.04
PPL-5	23.97 ±0.12	20.23 ±0.18	18.39 ±0.19	22.22 ±0.16	3.45 ±0.04	2.90 ±0.04	2.73 ±0.03	3.11 ±0.03
PPL-6	11.38 ±0.07	10.65 ±0.18	9.68 ±0.13	10.93 ±0.09	1.65 ±0.02	1.43 ±0.03	1.32 ±0.05	1.55 ±0.04
PPL-7	20.80 ±0.19	17.88 ±0.14	16.25 ±0.15	18.83 ±0.15	2.66 ±0.03	2.45 ±0.04	2.31 ±0.03	2.58 ±0.04
PPL-8	13.80 ±0.16	13.04 ±0.08	11.85 ±0.12	12.87 ±0.18	2.33 ±0.03	2.09 ±0.03	1.94 ±0.02	2.22 ±0.04
PPL-9	11.81 ±0.09	10.35 ±0.12	9.41 ±0.16	11.42 ±0.18	1.72 ±0.04	1.58 ±0.04	1.46 ±0.03	1.63 ±0.03
PPL-10	16.02 ±0.17	14.05 ±0.19	12.78 ±0.09	14.95 ±0.14	2.63 ±0.04	2.36 ±0.04	2.19 ±0.03	2.43 ±0.03
AV±SE *	23.88 ±1.96	21.22 ±1.73	19.28 ±1.57	22.30 ±1.82	3.44 ±0.25	3.07 ±0.23	2.85 ±0.21	3.23 ±0.24

* SE (standard error)= $\sigma/\sqrt{N}$, where σ is SD (standard deviation) and N is no. of observations

Table 5.24: Seasonal variations of Potential alpha energy concentration due to radon and thoron progeny in the premises of thermal power plants of Delhi NCR and Haryana

Table shows that maximum value of PAEC due to radon progeny was found to be 41.04±0.05 mWL (in the coal area) and minimum value was found to be 9.41±0.16 mWL (in the control room) Whereas, maximum value of PAEC due to thoron progeny was found to be 5.37±0.04 mWL (in the coal area) and minimum value was found to be 1.32±0.05 mWL (at the entrance gate). Maximum value of PAEC due to radon and thoron progeny was found in winter (October-January) season and in the coal area of thermal power plants for both radon and thoron and minimum values were found in summer season (April-July) in the control room and at the entrance gate of thermal power plants respectively.

Seasonal variations in the exposure due to radon and thoron progeny in WLM are shown in table 5.25.

Location	Seasonal variation of exposure due to radon progeny (WLM x10^{-3})				Seasonal variation of exposure due to thoron progeny (WLM x10^{-3})			
	Winter	Spring	Summer	Rainy	Winter	Spring	Summer	Rainy
PPL-1	410.39	365.66	332.41	386.17	53.72	47.75	44.59	51.73
PPL-2	392.52	337.65	306.96	365.52	52.19	45.32	43.99	49.22
PPL-3	268.79	241.86	219.87	254.81	43.83	38.56	35.11	39.49
PPL-4	338.93	314.63	285.04	311.13	49.76	47.56	42.05	47.03
PPL-5	239.74	202.27	183.88	222.24	34.54	28.96	27.29	31.05
PPL-6	113.77	106.53	96.84	109.35	16.55	14.27	13.20	15.52
PPL-7	207.98	178.79	162.54	188.26	26.58	24.53	23.12	25.78
PPL-8	137.98	130.38	118.52	128.73	23.32	20.93	19.36	22.23
PPL-9	118.15	103.49	94.09	114.17	17.17	15.76	14.58	16.29
PPL-10	160.15	140.54	127.77	149.47	26.34	23.64	21.87	24.31
Average	238.84	212.18	192.79	222.98	34.40	30.73	28.52	32.27

Table 5.25: Seasonal variations of exposure due to radon and thoron progeny in the premises of thermal power plants of Delhi NCR and Haryana

From table 5.25 it is clear that the maximum value of exposure due to radon daughters was found to be 410.39×10^{-3} WLM whereas, minimum value was found to be 94.09×10^{-3} WLM. The maximum exposure due to thoron daughters was found to be 53.72 WLM and minimum value of exposure due to thoron daughters was found to be 13.20 WLM during summer (April-July). Results shows that maximum value of exposure due to radon and thoron progeny was found in winter season (October-January) in the coal area of thermal power plants whereas the minimum value of PAEC due to radon and thoron progeny was found during summer season (April-July) control room and near the entrance gate of the thermal power plants.

Annual exposure due to radon and thoron progeny is calculated as a cumulative value of exposures at every location due to all the seasons of a year and represented in table 5.26. From table 5.26 it is clear that annual exposure due to radon progeny varies from 426.49×10^{-3} WLM to 1494.63×10^{-3} WLM with an average value of 866.79×10^{-3} WLM whereas, annual exposure due to thoron progeny varies from 59.54×10^{-3} WLM to 197.79×10^{-3} WLM with an average value of 125.91×10^{-3} WLM. Maximum value of annual exposure due to radon and thoron progeny was found in winter season (October-January) in the coal area of thermal power plants and minimum value was found in summer season (April-July) near the entrance gate. Annual exposure due to radon and thoron (Rn+Th) progeny varies from 486.03×10^{-3} WLM to 1692.42×10^{-3} WLM with an average value of 992.71×10^{-3} WLM. Annual effective dose for the inhabitants varies from 1.86 mSv to 6.47 mSv with an average value of 3.79 mSv.

Location	Annual exposure due to Radon progeny (WLMx10^{-3})	Annual exposure due to thoron progeny (WLMx10^{-3})	Annual exposure due to (Rn+Th) progeny (WLMx10^{-3})	Annual effective dose (mSv)
PPL-1	1494.63	197.79	1692.42	6.47
PPL-2	1402.65	190.73	1593.38	6.09
PPL-3	985.33	156.99	1142.32	4.35
PPL-4	1249.73	186.40	1436.13	5.48
PPL-5	848.13	121.83	969.96	3.71
PPL-6	426.49	59.54	486.03	1.86
PPL-7	737.57	100.02	837.59	3.21
PPL-8	515.61	85.84	601.45	2.30
PPL-9	429.89	63.80	493.69	1.89
PPL-10	577.93	96.15	674.08	2.57
Average	866.79	125.91	992.71	3.79

Table 5.26: Annual exposure due to radon and thoron progeny and annual effective dose in the premises of thermal power plants of Delhi NCR and Haryana

Seasonal variations in the effective dose received in the thermal power plants premises are shown in table 5.27. From table it is clear that the maximum dose received by the workers was found to be 1.78 mSv during winter (October-January) in the coal area whereas, minimum dose received was found to be 0.41 mSv during summer (April-July) in the control room of the thermal power plants. Annual effective dose received by the workers of thermal power plants situated in Haryana (India) varies from 1.86 mSv (near the entrance gate) to 6.47 mSv in the coal area with an average value of 3.79 mSv. Graphical variations of annual effective dose are shown in figure 5.22.

Location	Effective dose on seasonal basis (mSv)				Annual effective dose (mSv)
	Winter	Spring	Summer	Rainy	
PPL-1	1.78	1.58	1.44	1.67	6.47
PPL-2	1.70	1.46	1.34	1.59	6.09
PPL-3	1.19	1.07	0.97	1.12	4.35
PPL-4	1.48	1.38	1.25	1.37	5.48
PPL-5	1.05	0.88	0.81	0.97	3.71
PPL-6	0.50	0.46	0.42	0.48	1.86
PPL-7	0.90	0.78	0.71	0.82	3.21
PPL-8	0.61	0.58	0.53	0.58	2.30
PPL-9	0.52	0.46	0.41	0.50	1.89
PPL-10	0.71	0.63	0.57	0.66	2.57
Average	1.04	0.93	0.84	0.98	3.79

Table 5.27: Seasonal variations of effective dose and annual effective dose in the premises of thermal power plants of Delhi NCR and Haryana

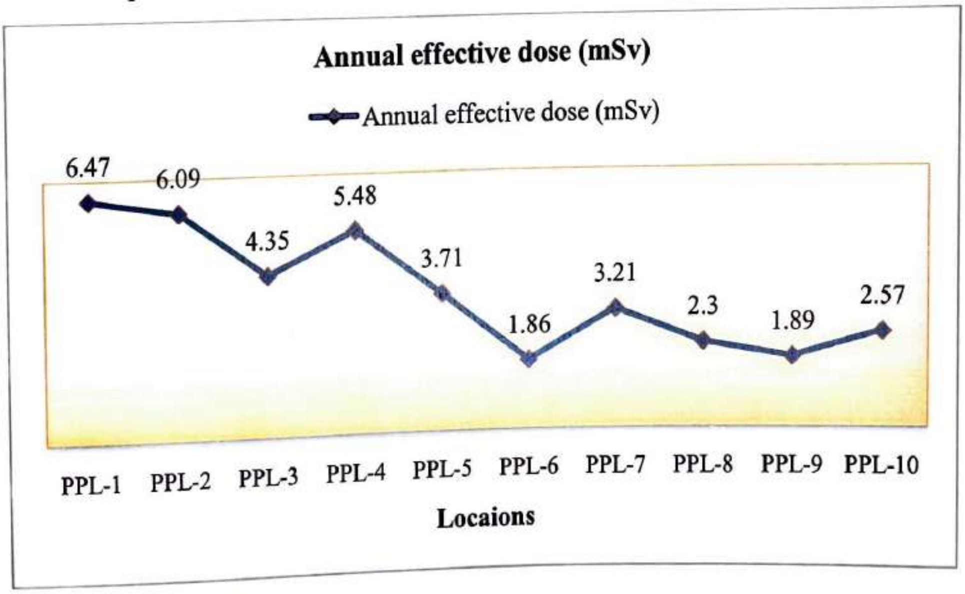

Figure 5.22: Graphical variations of annual effective dose in the premises of thermal power plants of Delhi NCR and Haryana

Variations in inhalation dose during all the four seasons of a year are shown in table 5.28. It shows clear that minimum value of inhalation dose was found to be 3.50 mSv/y (near the entrance gate) during summers and maximum value of inhalation dose was found to be 14.62 mSv/y (in the coal area) during winters. From the data mentioned in the table it is clear that maximum value of inhalation dose was found in winter (October-January) in coal area of thermal power plants and minimum value was found in summers (April-July) near entrance gate of the thermal power plants.

Location	Seasonal variation of inhalation dose (mSv)			
	Winter	Spring	Summer	Rainy
PPL-1	14.62	13.02	11.94	13.86
PPL-2	14.06	12.13	11.26	13.14
PPL-3	10.32	9.21	8.38	9.61
PPL-4	12.54	11.76	10.56	11.63
PPL-5	8.81	7.42	6.83	8.09
PPL-6	4.20	3.82	3.50	4.00
PPL-7	7.36	6.47	5.95	6.81
PPL-8	5.37	4.98	4.55	5.05
PPL-9	4.36	3.88	3.55	4.18
PPL-10	6.17	5.46	4.99	5.73
Average	8.78	7.81	7.15	8.21

Table 5.28: Seasonal variations of inhalation dose in the thermal power plants premises of Delhi NCR and Haryana

5.2.6 Conclusion

- Results indicate that the higher concentration of radon was found to be 379.61±0.47 Bqm^{-3} in coal area during winters and minimum value of radon concentration was found to be 87.03±1.44 Bqm^{-3} near entrance gate during summers.
- Maximum concentration was observed at coal area for both the radon and thoron but the minimum value was found at control room and near the entrance gate with slight variations to each other.
- During spring and summers minimum values of radon concentration were observed in control room whereas during winters and rainy season the minimum values were observed near the entrance gate.
- The estimated results for radon and thoron concentration and annual effective dose are within the safe limits of 500-1000 Bqm^{-3} and 20 mSv for workplaces as recommended by ICRP 1993.

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CHAPTER VI

CONCLUSION AND SCOPE FOR FUTURE WORK

This chapter comprises the outcomes of complete research work carried out in dwellings and workplaces of District Faridabad, Southern Haryana, India. The entire investigation was divided into four parts:

Assessments of Radioactivity (Radon-thoron levels) in dwellings:

1. Measurements of Radon-thoron levels in the dwellings in the vicinity of fly ash dumping site situated in Faridabad, Haryana, India and its seasonal variation during all the four seasons of a year.
2. Measurements of Radon-thoron levels in the dwellings of high rise buildings of greater Faridabad, Southern Haryana, India and its spatial and seasonal variation during all the four seasons of a year.

Assessments of Radioactivity (Radon-thoron levels) in workplaces:

1. Measurements of Radon-thoron levels in the environment of multi-storied malls selected in Delhi NCR and Faridabad, Haryana, India and its seasonal variation during all the four seasons of a year.
2. Measurements of Radon-thoron levels in the working environment of coal based thermal power plants in Haryana, India and its seasonal variation during all the four seasons of a year.

6.1. CONCLUSION FROM THE MEASUREMENTS

6.1.1. Measurements of Radon-Thoron Levels nearby Fly Ash Dumping Site

In first case study assessments were done in the dwellings nearby the fly ash dumping site situated in Faridabad, Haryana, India during all the four seasons of a year: winter (October-January), spring (January-April), summer (April-July) and rainy (July-October). In this case study total ten locations were selected near by the fly ash dumping site and out of ten; nine locations were selected in the indoor environment of dwellings near the fly ash dumping site at a successively increasing distance of approximately 500 meter from the prior location and one location was selected inside the cave of a temple near the fly ash dumping site found during the survey of the field.

The location of cave was considered to observe the combined effect of its vicinity to the fly ash dumping site, effect of ventilation (where is no any provision) and building material. Results can be concluded on the two different types of observations: Location (Nearest and farthest) from the dumping site and different seasons of an academic year

a) Variations with the locations

- From the results, effect of fly ash dumping site was observed because the radon-thoron levels were found to be higher in those dwellings which are at the nearest location to the dumping site as compared to the other distant dwellings.
- Highest concentration of radon(139.79±2.93 Bqm^{-3}) and thoron (78.37±2.16 Bqm^{-3}) was found inside the cave of a temple which may be because of its vicinity to the dumping site, none of any provision for the ventilation and building material used for the construction of cave.
- Apart of the cave, the highest concentration of radon (82.41±1.69 Bqm^{-3}) and thoron (43.91±1.83 Bqm^{-3}) was found in the dwellings, at the nearest location to the fly ash dumping site. It is because, these ashes which are rich of NORM and a source or radon and thoron, can easily deploy to the surrounding environment in the form of aerosol. It may enhance the indoor inhalation dose for the population living in the vicinity to the fly ash dumping site.
- During the observations firstly it was assumed that it may be a local area problem or because of some particular life style of the inhabitants but the thought was changed when we observe that, the radon-thoron levels were decreasing as we move at the locations away from the site. The minimum concentrations of radon and thoron were observed at the farthest location from the dumping site.
- Maximum annual dose was received by the inhabitants that are at closest location from the fly ash dumping site and it was found to be 1.42 mSv which is slightly higher than the safety limit of 1 mSv as recommended by ICRP 1993.
- An inverse relation was found between distance and radon-thoron levels, means that as the distance between the dwellings and fly ash dumping site increases, the radon-thoron levels decreases.

b) Variations with the seasons

- Results observed from the seasonal variations concluded that, maximum radon-thoron levels were observed during winter and rainy season as compared to the spring and summers. It is because the dwellers remain the doors and windows closed very frequently during winters to maintain their thermal comfort especially over the night when temperature falls considerably. For these types of varying ventilation conditions (day-night) a passive time integrated technique can be more reliable which is used in this study.
- The maximum dose (0.38 mSv) received by the dwellers, was observed during winters whereas the minimum dose (0.03 mSv) was received during summers. The population living in the vicinity of fly ash dumping site is at higher risk of radon-thoron levels during winters as compared to the other seasons of a year.

From the complete observations during a year it was concluded that, the dwellers that are closest to the dumping site are at a greater risk of radon-thoron levels during the winters as compared to the other seasons and the other dwellers that are distant apart from the dumping site. Annual effective dose received by the inhabitants is slightly higher than the (1 mSv) recommended limit of ICRP 1993 so that some remedial action should be taken for the dwellers living in the vicinity of fly ash dumping site.

6.1.2. Measurements of Radon-Thoron Levels in High Rise (Vertical) Buildings

In the second case study the measurements were carried out in the dwellings of high rise (vertical) buildings of Greater Faridabad, Haryana. In the present study five towers or high rise buildings were selected and in each tower total ten floors were investigated from ground (G-0) to the ninth (G-9) floor of the buildings. To maintain the uniformity and for the authenticity of data, Non-AC area of the houses were taken for the observations. The measurements were done during all the four seasons of a year. Detailed results are reported in chapter 4. Concluded results drawn from the detailed measurements are discussed on the basis of two types of observations: first on the basis of floor level of the buildings and second on the basis of different seasons of a year.

a) Results on the basis of floor level

- Results concluded from the observations of present study shows that, radon-thoron levels changes considerably with the height of the building.
- A contrary relation was obtained between the height of the building and radon-thoron levels, means that as the height of the building increases radon-thoron level decreases.
- Maximum concentration of radon (78.38±0.71 Bqm^{-3}) and thoron (37.08±1.74 Bqm^{-3}) was found at the ground floor of the buildings and decreases as moves towards upper floors and found minimum at the upper most floor of the present study.
- Soil is a prime source of indoor radon and because of this maximum radon-thoron levels were found at the ground floor because of the vicinity to the soil under beneath. Compact structure and comparatively poor ventilation and improper exchange of air at the lower floors of closely packed newly constructed high rise buildings is another important cause of high radon-thoron levels at the ground floor of the buildings.
- Minimum concentration of radon (8.68±0.57 Bqm^{-3}) and thoron (5.21±0.53Bqm^{-3}) was found at the uppermost floor (ninth floor of the present study) of the buildings. This is because the dwellers of upper floors experienced high wind speed and proper ventilation because of proper exchange of air. In addition to this, the effect of radon because of soil gas is also negligible at the upper floors.
- The maximum annual effective dose (1.04 mSv) was received by the inhabitants at the ground floor and minimum (0.26 mSv) annual effective dose was found to be at the uppermost floors of the present study. The dose delivered in the present study is nearly same as recommended (1 mSv) by ICRP 1993 and within the safe limits.

b) Results on the basis of seasons

- Maximum radon-thoron levels were found during winters because the dwellers remain the doors and windows closed to conserve the indoor temperature to maintain their thermal comfort especially at the upper floors where dwellers experienced high wind speed and temperature falls rapidly.

- Reduced ventilation is another important cause of high indoor radon-thoron levels. Because of closed doors and windows, radon and thoron emanated from the building materials and water used in house hold activities set in the indoor environment and increase the radon-thoron levels considerably during winters as compared to the other seasons of the year.
- Minimum concentration of radon and thoron was found during summers when the dwellers remain the doors open for the proper exchange of air. The exchange of air improves the ventilation and reduces the indoor radon-thoron levels.

From results it was concluded that the dwellers at the ground floor are comparatively at high risk of radon especially during winters. The variations in the observations may be because of different life styles of the inhabitants, habits of the individual that effect the ventilation, temperature of the outdoor environment (season),building materials, water used for the household activities and their vicinity to the ground. The results are within the safe limit of 100 Bqm^{-3} as recommended by WHO but above than the world average level of indoor radon (40 Bqm^{-3}) as given by UNSCEAR 2000.

6.1.3. Comparison of Both the Case Studies of Dwellings

- On comparison of both the case studies we observe that the radon, thoron and their progeny concentrations were higher in the dwellings nearest to the fly ash dumping site as compared to the dwellings at the ground floor of the buildings.
- In the case studies of dwellings near the fly ash dumping site, the average indoor radon concentration (54.36±5.05 Bqm^{-3}) is above than the world average radon concentration of 40 Bqm^{-3} as given by UNSCEAR 2000 but, the average indoor radon (36.27±3.01 Bqm^{-3}) concentration is lower than the world average radon concentration of 40 Bqm^{-3}.

6.2. CONCLUSION FROM THE RADON-THORON LEVELS IN WORKPLACES

6.2.1. Measurements of Radon-Thoron Levels in Multi-Storied Malls

In this case study assessments were done for the workers of multi-storied malls selected in Delhi NCR and Faridabad, Haryana, India during all the four seasons of a year. In this case study fifteen malls were selected from the third basement to the third floor of the malls including the ground floor. The purpose of this study was the assessment of dose delivered to the workers, working below (basements) or above the ground floor of the malls. Results can be concluded on the basis of seasons and the level of the floor.

a) Results on the basis of floor level

- Results drawn from the observations show that the maximum radon-thoron levels were observed in the lowest basements (third basement in the present study) as compared to the other floors of the malls.
- The maximum concentration of radon and thoron in the third basements of the malls was found to be 87.97±1.79 Bqm^{-3} and 29.21±2.64 Bqm^{-3}respectively. This is because the multiple surfaces of the basements are in contact with the soil as compared to the ground surface where only one surface can be in contact with the soil under beneath.
- The minimum concentration of radon (5.09±0.33 Bqm^{-3}) and thoron (3.06±0.21Bqm^{-3}) was found at the third floor of the malls this is because the ventilation at the upper floors is better than the lower floors and their distance from the soil under beneath. The main source of radon concentration on the third floor of the malls is building material used for the construction.
- Results conclude that the workers of basements (below ground floors) receive the higher concentration of radon and thoron than the workers of above ground floors.
- As the height of the malls increases, radon and thoron concentration decreases, means the ground floor workers receive lower dose due to radon and thoron progeny as compared to the third basement of the malls.

b) Results on the basis of seasons

- Maximum concentration of radon and thoron was observed during winter season.
- Minimum concentration of radon and thoron was found during summer season. This may be because of the effect of A.C. during summers which exhaust the air pollutants.
- The maximum annual effective dose due to radon and thoron progeny was found to be 1.12 mSv.

From the study it is concluded that the workers of the basements are working at high radon levels during winters in comparison to the other floors of the malls and other seasons of the year. The results (1.12 mSv) are below the safe limit of workers (20 mSv) as recommended by the ICRP 1993 but, slightly higher than the safety limit of 1 mSv for general public.

6.2.2. Measurements of Radon-Thoron Levels in Coal-Based Thermal Power Plants

In the present case study the assessments were done in the premises of coal-based thermal power plants of Haryana, India during all the four seasons of a year. From health and hygiene point of view of the workers, these assessments were necessary. In this case study total ten locations were selected in the order of coal area, fly ash area, water treatment plant, chlorination plant, boiler area, near the entrance gate, turbine area, power generating room, control room, and workshop respectively. Outcomes of the study can be concluded in two different categories: locations selected and seasons of the year.

a) Results on the basis of location selected

- Maximum concentration of radon (379.61±0.71 Bqm^{-3}) and thoron (198.76±1.39 Bqm^{-3}) was found at the coal area of the plants. This is because the coal has trace amount of naturally occurring radioactive isotopes such as: uranium, thorium, potassium, radon and its daughter products. On burning the coal, these radioactive elements released to the surrounding in the form of gases and solid waste (ash) and pollute the environment.
- Minimum concentration of radon (87.03±1.44 Bqm^{-3}) was observed in the control room whereas minimum value of thoron (48.85±1.69 Bqm^{-3}) was found at the gate area of the power plants. This is because the gate area and control room are distant apart from the coal and fly ash area.

b) Results on the basis of seasons

- Maximum concentration of radon (379.61±0.47 Bqm^{-3}) and thoron (198.76±1.39 Bqm^{-3}) was observed during winters at the coal area of the thermal power plants.

- The minimum concentration of radon (87.03±1.44 Bqm^{-3}) and thoron (48.85±1.69 Bqm^{-3}) was observed during summers in the control room and at the entrance gate respectively.

From results it was concluded that the workers of coal area and fly ash area are at high risk of radon and thoron during winters as compared to the other workers of the plant. The employees of gate area and control room are at lower limit of risks of radon during each season.

6.2.3. Comparison of Both the Case Studies of Workplaces

- On comparison of both the case studies we observe that the radon, thoron and their progeny concentrations were higher in the premises of thermal power plants as compared to the multi storied malls.
- In the case study of thermal power plants, the average radon concentration was found to be (220.93±18.14 Bqm^{-3}) and in case of multi storied malls the average radon concentration was found to be (45.37±4.69 Bqm^{-3}).
- The average dose (3.79 mSv) delivered to the workers of coal based thermal power plants is high as compared to the dose (0.59 mSv) delivered to the workers of multi storied malls. So, the workers of thermal power plants are at higher risk of radiation exposure as compared to the workers of multi storied malls. The results are under the limit of 20 mSv recommended by ICRP 1993 for the workers of malls and thermal power plants.

6.3. SCOPE FOR FUTURE WORK

In this research work, efforts have been made to measure the radon and thoron concentration, Potential Alpha Energy Concentration (PAEC) due to radon, thoron and their progeny, inhalation dose and annual effective dose in various dwellings and workplaces of Southern Haryana, India. As per literature survey, a number of reports have been published for radon-thoron concentration in different parts of the Haryana, but data remains scanty in, Southern Haryana, India. So, the existing data can be pooled with data provided in this research work and it helps in preparing the proper radon map of Haryana. Though, we have been able to reach certain conclusions regarding the radon-thoron levels in Southern Haryana, a major scope exist for future investigations in the following lines:

- Apart from the present study, radon exhalation rate and radium content can be calculated in various building materials used for the construction purpose and the observed data can be reported to the concerned regulatory bodies. It helps in the choice of proper building materials used for the construction.
- In the nearby region of Faridabad, the measurements can be made in the thermal springs and the dwellings around the thermal springs.
- Radon levels can be calculated in water samples collected from the underground and above ground sources and a comparative study can be prepared.
- Measurements can be made in the dwellings around the thermal power plants. The observations from these studies can represent the impact of thermal power plants in the localized society.
- Prior to an earthquake, pre-seismic stress or deformation of rocks release some gases from the deeper parts of the earth to the surface, and radon is one of them. So, prior prediction of earthquake can be made with the assessment of radon concentration.

LIST OF PUBLICATIONS

1. INTERNATIONAL AND NATIONAL JOURNALS

Sr. No	Title with page number and date of publication	Journal	Whether peer reviewed	Impact factor	Whether you paid any money or not for publication	Remarks
1	Radon-thoron and their progeny dosimetry in multi-storeyed malls in Delhi NCR (India) using plastic track detectors, Vol. 4, No. 7, 2017, pp. 255-265.	International Journal of Low Radiation	Yes	0.21	No	
2	Natural radioactivity in Indian vegetation samples, Vol. 13, No. 2, 2015, pp. 143-150.	International Journal of Radiation Research	Yes	1.69	No	
3	Radon-Thoron and Their Progeny Measurements in High Rise Buildings in District Faridabad, Haryana, Vol. 5, No. 2, 2014, pp. 60-63.	ISST Journal of Applied Physics	Yes		No	
4	Indoor assessment of radon, thoron and their progeny levels in the dwellings near the fly ash dumping sites situated in Faridabad (Haryana) India, Vol. 4, 2015, pp. 80-81.	International journal of scientific research	Yes		No	

5	Study of Radon Exhalation and Emanation Rates from Fly Ash Samples, Vol. 5 No. 2, 2014, pp. 96-100.	ISST Journal of Applied Physics	Yes		No	
6	Radiological Impact of Exposure to Radon-Thoron and Their Progeny Present In the Environment of Fly Ash Dumping Site in Faridabad (Haryana), Vol. 5, No. 2, 2014, pp. 106-108.	ISST Journal of Applied Physics	Yes		No	
7	Study of radon and thoron concentration in the dwellings of Faridabad, Southern Haryana, India, Vol. 7, No. 1, 2016, PP. 13-15.	ISST Journal of Applied Physics	Yes		No	

2. INTERNATIONAL AND NATIONAL CONFERENCES

1. Nitin Gupta and Maneesha Garg, "Radon, Thoron and their progeny measurements in the environment", National Conference on Science in Media 2012, Organized by YMCA University of Science and Technology, Faridabad, Haryana (India), 3 -4 December, 2012.
2. Nitin Gupta, Krishan Kant and Maneesha Garg, "Indoor Estimation of Radon, Thoron and Their Progeny in High Rise Dwellings in Faridabad, Haryana", International Conference on Emerging Trends in Basic and Applied Sciences at Maharaja Agrasen University, Baddi, HP, 1-2 May, 2015, pp. 46
3. Nitin Gupta, Krishan Kant and Maneesha Garg, "Radiological Assessment of indoor radon, thoron and their progeny levels in the dwellings near the fly ash dumping sites situated in Faridabad (Haryana) India", 19th National conference on Solid State Nuclear Track Detectors and their Applications (SSNTDs -19), NIT Jalandher, Punjab, 19-21 Nov 2015
4. Nitin Gupta, Krishan Kant and Maneesha Garg, "Bi-annual Estimation of radon and thoron levels in high rise dwellings situated in Faridabad (Southern Haryana) India", 19th National conference on Solid State Nuclear Track Detectors and their Applications (SSNTDs -19), NIT Jalandher, Punjab, 19-21 Nov 2015,
5. Nitin Gupta, Krishan Kant and Maneesha Garg, "Assessment of Radon, Thoron and Their Progeny Concentration in Multi Storeyed Malls in District Faridabad, Haryana (India)", National Conference on Recent Advancements in Science & Technology (RAST - 2016), at Arya P.G. College, Panipat, 27- 28 February, 2016, pp. 47.
6. Nitin Gupta, Krishan Kant and Maneesha Garg, "Radiological impact of radon, thoron and their progeny concentration using Twin Cup Dosimeters in dwellings of high rise Buildings situated in Faridabad, Haryana, India" National Conference on Role of Science and Technology towards Make in India (RSTTMI-2016), YMCA University of science and technology, Faridabad, 5-7 march 2016, Pp. 3.
7. Nitin Gupta, Krishan Kant and Maneesha Garg, "Study of radon and thoron concentration in the dwellings of Faridabad city Southern Haryana", National Conference on Emerging Trends and Technologies in Sciences (NCETTS-2016), Aggarwal PG College, Ballabhgarh, Faridabad, March 25-26, 2016, pp. 20.

8. Nitin Gupta, Krishan Kant and Maneesha Garg, "Study of Radon, Thoron and Their Progeny Concentration in Flats of District Faridabad, Haryana, India", National Conference on Emerging Trends and Technologies in Sciences (NCETTS2016), Aggarwal PG College, Ballabhgarh, Faridabad, March 25-26, 2016, pp. 49.

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PUBLICATIONS:

International and National Journals

1. Nitin Gupta, Krishan Kant, Maneesha Garg, "Radon-thoron and their progeny dosimetry in multi-storeyed malls in Delhi NCR (India) using plastic track detectors", International Journal of Low Radiation, Vol. 4, No. 7, 2017, pp. 255-265.
2. K. Kant, R. Gupta, R. Kumari N. Gupta, M. Garg, Maneesha Garg, "Natural radioactivity in Indian vegetation samples", International Journal of Radiation Research, Vol. 13, No. 2, 2015, pp. 143-150
3. Nitin Gupta, Krishan Kant, Maneesha Garg, "Radon-Thoron and Their Progeny Measurements in High Rise Buildings in District Faridabad, Haryana", ISST Journal of Applied Physics Vol. 5, No. 2, 2014, pp. 60-63.
4. Nitin Gupta, Krishan Kant, Maneesha Garg, "Indoor assessment of radon, thoron and their progeny levels in the dwellings near the fly ash dumping sites situated in Faridabad (Haryana) India", International journal of Scientific Research Vol. 4, 2015, pp. 80-81.
5. Raj Kumari, Ravinder Jain, Krishan Kant, Nitin Gupta, Maneesha Garg, Manikant Yadav, "Study of Radon Exhalation and Emanation Rates from Fly Ash Samples, ISST Journal of Applied Physics", Vol. 5 No. 2, 2014, pp. 96-100.
6. Nitin Gupta, Krishan Kant, Maneesha Garg, "Radiological Impact of Exposure to Radon-Thoron and Their Progeny Present In the Environment of Fly Ash Dumping Site in Faridabad (Haryana)", ISST Journal of Applied Physics, Vol. 5, No. 2, 2014, pp. 106-108.

7. Nitin Gupta, Krishan Kant, Maneesha Garg, "Study of radon and thoron concentration in the dwellings of Faridabad, Southern Haryana, India", ISST Journal of Applied Physics, Vol. 7, No. 1, 2016, PP. 13-15

International and National Conferences

1. Nitin Gupta and Maneesha Garg, "Radon, Thoron and their progeny measurements in the environment", National Conference on Science in Media 2012, Organized by YMCA University of Science and Technology, Faridabad, Haryana (India), 3 -4 December, 2012.
2. Nitin Gupta, Krishan Kant and Maneesha Garg, "Indoor Estimation of Radon, Thoron and Their Progeny in High Rise Dwellings in Faridabad, Haryana", International Conference on Emerging Trends in Basic and Applied Sciences at Maharaja Agrasen University, Baddi, HP, 1-2 May, 2015, pp. 46
3. Nitin Gupta, Krishan Kant and Maneesha Garg, "Radiological Assessment of indoor radon, thoron and their progeny levels in the dwellings near the fly ash dumping sites situated in Faridabad (Haryana) India", 19th National conference on Solid State Nuclear Track Detectors and their Applications (SSNTDs -19), NIT Jalandher, Punjab, 19-21 Nov 2015
4. Nitin Gupta, Krishan Kant and Maneesha Garg, "Bi-annual Estimation of radon and thoron levels in high rise dwellings situated in Faridabad (Southern Haryana) India", 19th National conference on Solid State Nuclear Track Detectors and their Applications (SSNTDs -19), NIT Jalandher, Punjab, 19-21 Nov 2015,
5. Nitin Gupta, Krishan Kant and Maneesha Garg, "Assessment of Radon, Thoron and Their Progeny Concentration in Multi Storeyed Malls in District Faridabad, Haryana (India)", National Conference on Recent Advancements in Science & Technology (RAST - 2016), at Arya P.G. College, Panipat, 27- 28 February, 2016, pp. 47.
6. Nitin Gupta, Krishan Kant and Maneesha Garg, "Radiological impact of radon, thoron and their progeny concentration using Twin Cup Dosimeters in dwellings of high rise Buildings situated in Faridabad, Haryana, India" National Conference on Role of Science and Technology towards Make in India (RSTTMI-2016), YMCA University of science and technology, Faridabad, 5-7 march 2016, Pp. 3.
7. Nitin Gupta, Krishan Kant and Maneesha Garg, "Study of radon and thoron concentration in the dwellings of Faridabad city Southern Haryana", National Conference on Emerging Trends and Technologies in Sciences (NCETTS-2016), Aggarwal PG College, Ballabhgarh, Faridabad, March 25-26, 2016, pp. 20.
8. Nitin Gupta, Krishan Kant and Maneesha Garg, "Study of Radon, Thoron and Their Progeny Concentration in Flats of District Faridabad, Haryana, India", National Conference on Emerging Trends and Technologies in Sciences (NCETTS2016), Aggarwal PG College, Ballabhgarh, Faridabad, March 25-26, 2016, pp. 49.

ACHIEVEMENTS:

- Best Paper Award in National Conference on Science in Media, Dec 2012, Faridabad.
- Best Poster Award in 18th National Symposium on Solid State Nuclear Track Detectors and Their Applications (SSNTDs-18), Oct 2013, Faridabad, pp 163.

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- Life Membership of Nuclear Track Society of India (Reg.No.S/62495), Radiochemistry Division, BARC, Trombay, Mumbai.

PRACTICAL TRAINING:

- Attended 15th International Workshop on " **The Physics of Semiconductor Devices (IWPSD-2009)"** *at Jamia Milia Isalmia, New Delhi*, Dec 2009
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