INVESTIGATION OF RADON/THORON LEVELS AND NATURAL RADIOACTIVITY IN ENVIRONMENT

A Thesis Submitted to the Babasaheb Bhimrao Ambedkar University, Lucknow
Fulfillment of Requirement for the Award of Degree of

Doctor of Philosophy
in Applied Physics

BY

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BABASAHEB BHIMRAO AMBEDKAR UNIVERSITY
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ESTABLISHED 1996

Department of Applied Physics

Babasaheb Bhimrao Ambedkar University,
(A CentralUniversity)
Lucknow, Uttar Pradesh – 226025

2016

DEDICATED TO MY MOTHER

(Late Smt. Shanti Devi)

DECLARATION

I declare that the Ph.D. Thesis entitled "**Investigation of Radon/Thoron Levels and Natural Radioactivity in Environment"** has been prepared by me. The work has not been submitted elsewhere for the award of any other degree or diploma. Further, I declare that the material embodied in the present work is based on original research work, free from any form of falsification, fabrication and plagiarism, the indebtedness to others have been duly acknowledged at relevant places. I shall be solely responsible for any such dispute arising out of my doctoral work.

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ACKNOWLEDGEMENTS

First of all, I would like to thank God for all he has given me.

I would like to express my deep sense of gratitude to my Ph.D Supervisor, Dr. R. G. Sonkawade, former Dean School of Physical Sciences, Babasaheb Bhimrao Ambedkar University (Central University) Lucknow and Co-Supervisor, Dr. Devesh Kumar (Associate Professor) Babasaheb Bhimrao Ambedkar University, (Central University) Lucknow and Dr. Ajay Kumar Mahur Head, Basic and Applied Sciences, Vivekananda College of Technical and Management Aligarh, for the continuous support of my Ph.D study for their motivation, enthusiasm and immense knowledge. Their guidance and valuable suggestions help me in all the time of research and writing of this thesis.

I express my deepest gratitude to Prof Vipin Saxena Dean School of Physical Sciences and Dr B.C. Yadav coordinator applied physics, Babasaheb Bhimrao Ambedkar University (Central University) Lucknow for his support during my Ph. D work.

I also wish to express my sincere thanks to Prof. Avinash Sharma and Prof Vinod Kumar, University School of Basic & Applied Sciences, GGSIP University, Delhi for his guidance shown during my Ph.D work. His valuable suggestions and incisive criticism not only strengthened my skills but also helped me to be more confident

I am thankful to Prof. R.C.Ramola, H.N.B. University (Central University) Garhwal, Uttrakhand, for providing experimental facilities for natural radioactivity measurements.

I am also thankful to Dr. Mukesh Kumar, Associate Professor S.V.College, Aligarh, Uttar Pradesh for providing facilities for chemical etching and spark counting system.

I am thankful to Dr S. Asad Ali, AMU Aligarh, for providing facility Optical binocular optical research microscope and many suggestions during my Ph.D. study.

Specially Thanks to my friends Mr. Lalit Mohan Singh, Junior research fellow at GGSIPU, Delhi and Mr. Satyendra Kumar, Mr. Rajeev Kumar for their Support and help.

I am in dearth of proper words to express my abounding feelings for my wife, Mrs Manju Sharma who has been a source of inspiration to me and my daughters and son, Chanchal Sharma, Anjali Sharma and Tarun Sharma for their understanding and cooperation shown.

I am really at the loss of the words to express my obligation to my father who has supported me. I miss very much my mother who is no more in my life to share my moment of joy. I dedicate this thesis to my mother late Smt. Shanti Devi.

(ANIL SHARMA)

Investigation of Radon/Thoron Levels and Natural Radioactivity in Environment

Abstract

The exposure of human beings to ionizing radiation from natural sources is a continuing and inescapable feature of life on earth. For most individuals, this exposure exceeds that from all man-made sources combined. There are two main contributors to natural radiation exposures: high-energy cosmic ray particles incident on the earth's atmosphere and radioactive nuclides that originated in the earth's crust and are present everywhere in the environment, including the human body itself. Radon is a noble gas in the uranium decay series with a fairly long half life of 3.8 days. Being an inert gas it can easily disperse into the atmosphere as soon as it is released. The solid alpha active decay products of radon (^{218}Po, ^{214}Po) become airborne and attach themselves to the dust particles, aerosols and water droplets in the atmosphere. When inhaled, these solid decay products along with air may get deposited in the trachea-bronchial (T-B) and pulmonary (P) region of lungs resulting in the continuous irradiation by α-particles of the cells which may cause lung cancer. Radon is the problem in all types of homes, including old homes, new homes, drafty homes, insulated homes, homes with basements and homes without basements.

Measurements of indoor radon are of importance because the radiation dose to human population due to inhalation of radon and its daughters contributes more than 50% of the total dose from natural sources and large scale studies have been carried out worldwide. On the other hand there exist only a few studies relating to passive measurements of thoron. It is assumed that the inhalation dose to the human beings from thoron and its progeny is negligible although recent studies in many countries have revealed that this may not be entirely correct.

It is well known that exposure of population to high concentrations of radon and its daughters for a long period leads to pathological effects like the respiratory functional changes and the occurrence of lung cancer. In homes the predominant source of radon in indoor air is the soil beneath structures, but building materials and water used in the homes and in a few cases natural gas may also contribute. The concentrations of radium in soil and in rocks vary several orders of magnitude. This variation in source strength results in the variation of radon concentrations among dwellings. Keeping the radiation hazards of radon for general population in mind, it is quite important to make a systematic study of the indoor radon concentration in Indian dwellings. For this purpose, radon measurements have been carried out in a number of dwellings in the cities of different states of India.

Natural radioactivity is wide spread in the earth's environment coming from Uranium (^{238}U) and Thorium (^{232}Th) series and Potassium (^{40}K), existing in various geological formations like soils, rocks, plants, water and air. Radiological implication of these radionuclides is due to the gamma ray exposure of the body and α-irradiation of lung tissues from inhalation of radon and its daughters. The assessment of gamma radiation dose and radon exhalation rate from natural sources is of particular interest as natural radiation is the largest contributor to external dose of the world population.

In the present study, low level gamma ray spectrometric set up at H N B University Garhwal, Uttrakhand, India using a NaI (Tl) detector was used for measurement of activity concentration of the natural radionuclides (^{226}Ra, ^{232}Th and ^{40}K) in coal, fly ash, soil and cement samples. Radiation dose and health risk have been estimated from the activity concentration of natural radionuclides.

This thesis elaborates the brief description of radon/thoron measurement and natural radioactivity for assessing the total health hazards in the environment.

The present work is organized into following six chapters:

Chapter-I: This chapter describes a brief review of literature and gives an account of the history of radon and thoron and its health hazard effects, the indoor radon sources, factors affecting indoor radon concentration levels and the applications of radon measurements. A brief description of meteorological parameters, radon induced health effects, risk of radon exposure at work places. Introduction of natural radioactivity and health effects due to radioactivity is given. This chapter also contains definitions and discussion of radiation levels and their effects and definitions action level, dose limit, effective dose, Equilibrium Equivalent Concentration of radon (EEC radon), Potential Alpha Energy Concentration (PAEC), Working Level (WL), Working Level Month (WLM), Indoor internal exposure due to radon inhalation, Radium equivalent activity (Raeq), Absorbed gamma dose rate (D) and External (H_{ex}) and Internal (H_{in}) hazard index.

Chapter – II: A brief description of the historical development of Solid State Nuclear Track Detectors (SSNTDs), criteria for track formation in polymeric film (LR-115 type II Solid state nuclear track detector) and revelation of tracks is given in this chapter. This chapter gives an account of various instantaneous and time integrated radon measurement techniques. Tracks etch technique using Solid State Nuclear Track Detectors is one of the most widely used technique for radon measurement. The principle of detection consists of the damage imparted in the detector material by alpha particles from radon and its decay products which can be observed under optical microscope and spark counting system.

In the present study, twin chamber dosimeter cup was used for the measurement of indoor and outdoor radon concentrations. Alpha sensitive plastic track detector (Pelliculable LR-115

Type II Manufactured by Kodak Pathe, France) is used. It is a 12 μm thick film red dyed cellulose nitrate emulsion coated on inert polyester base of 100 μm thickness and has maximum sensitivity for alpha particles, fission fragments and ionizing particles with high enough LET.

Radon exhalation rate is of prime importance for the estimation of radiation risk from various materials. Sealed Can Technique and Smart radon monitor were used for radon exhalation measurements in solid samples.

A low level gamma ray spectrometric set up at H N B University Garhwal, Uttrakhand, India using a NaI (Tl) detector was used for measurement of activity concentration of the natural radionuclides, (^{226}Ra, ^{232}Th and ^{40}K) in coal, fly ash, soil and cement samples.

Chapter-III: In this chapter, the results of measurements of radon and its concentration in a large number of dwellings carried out in following:

(i) In about 60 dwellings of Dwarka, Delhi state of India, to assess the variability of expected exposure of the population to radon and its progeny.

(ii) In some dwellings of Jaipur, Rajasthan, state of India.

(iii) In Aligarh, Uttar Pradesh state of India, near Kasimpur thermal power plant were selected for measurements of indoor radon levels.

Solid State Nuclear Track Detectors (SSNTD's) based twin chamber dosimeters were also used for measuring radon (^{222}Rn) and Thoron (^{220}Rn) gases and their progeny concentration in the dwellings of three cities. The dosimeters employ two LR-115 type-II peliculable, cellulose nitrate detector films inside each of the two chambers fitted with filter and polymeric membrane for the discrimination of radon and thoron gas and a third detector is placed externally for progeny measurements.

Chapter-IV: Measurements of natural radioactivity and radiation doses were carried out on the following material samples having wide applications, collected from different places and parts of the country:

(i) Coal and fly ash samples, collected from different thermal power stations at Kolaghat, and Kasimpur situated in West Bengal and Uttar Pradesh states of India. Measurements have been made to estimate the enhancement of natural radioactivity in fly ash due to coal combustion.

The thermal power plants all over the country produce a large quantity of fly ash which if not utilized or properly disposed off, may become one of the greatest radiation menaces to the nation and its inhabitants.

(ii) Soil samples, collected from Kasimpur thermal power plant situated in Uttar Pradesh state of India.

(iii) Cement samples collected from different benders of Aligarh region of Uttar Pradesh of India.

An attempt has been also made to determine the radium equivalent activity and external hazard index in various commodities. The presence of natural radioactivity level in all the samples have been found to be well below the permissible limits.

Chapter-V: Sealed can technique and Smart radon monitor were used for the measurement of radon exhalation rate from: Coal, fly ash, soil, cement and sand samples collected from different parts of India.

In the present study, we have also made measurements for radon exhalation rate in different building materials like Paints, Plastered, Fired and Unfired Brick etc., commonly used for building construction in this region of the state of Uttar Pradesh of India. Present investigation concludes that the radon effective dose is quit lower than the action level of 1 mSv for all the reported samples.

Chapter-VI: This chapter concludes the outcomes of this research work and presents a discussion of the prevention of health hazards in the study area.

The future scope of the present work has also been presented.

Contents

CHAPTER-1

INTRODUCTION

1.1 GENERAL

Studies on natural environment radiation and natural radioactivity are of a very importance in radiation physics, health physics and other allied branch of natural science. The estimation of radon and its decay products concentration in indoor and outdoor atmosphere has been done by research scientists all over the world. Ionizing radiation originates from both natural as well as manmade source of radiation. The natural sources are cosmic rays and the natural radioactivity present in the rocks, soil and fly ash. Whereas the manmade sources of radiation are nuclear explosion, nuclear installations, radiation sources and radionuclides used in industry, agriculture and medicine, air travel and various types of electronic devices. Radon is the progeny of uranium decay series formed from heavier radioactive decay of radium, almost found everywhere on the earth in trace amounts, being distributed in ground water, soil and in the lower atmosphere. Radon is the heaviest known inert gas, nine times heaver than air. The major contributions of dose in normal background region from natural radiation to exist due to inhalation of radon, thoron and its progeny (Prostendorfer, 1994; UNSCEAR 2000). For the occurrence of high indoor radon concentration, one must understand the source material, rate of removal and transport mechanics. It is found that the Radon, largely in homes, from both naturally occurring and manmade sources of radiation, constitutes about 50% of the dose equivalent received by the general population. The radon concentration in the environment varies according to meteorological conditions and the place, time and height above the ground. It is observed that high level of radon inhaled causes lung cancer. The occurrence of lung cancer and the respiratory functional changes have been found due to continuous exposure of population to high radon concentration and its daughters (BEIR, 1999). Measurement of radon has become a global phenomenon due to its health hazard effect on population (Radiation workers and general public). The external dose from radon and its progeny carried through the air received by individuals is a small amount of the external natural radiation dose.

1.2 Radiation

Radiation is energy that comes from a source and travels through space and may be able to penetrate various materials in its path. Radiations are of two types i.e. Ionizing and Non Ionizing radiation. Ionization radiation consists of electromagnetic wave or subatomic particles that are energetic enough to detach electron from atoms, ionizing them. The phenomenon of ionization depends on the wave or energy of the impinging individual particles, not on their numbers. Examples are energetic alpha particle, beta particle and neutrons. Radiation that has enough energy to move atoms in a molecule around or cause them to vibrate, but not enough to remove electrons is known as non-ionizing radiations. Examples are visible light, sound wave and microwave.

1.2.1 TYPES OF RADIATON

Generally we talked about the radiation, there are four types of radiation each having different characteristics. The following ionizing radiations are described below.

ALPHA RADIATION

Alpha radiation consists of heavy, very short-range particles emitted by atoms of elements i.e. radium. It is thousands time heavier than electron. Some characteristics of alpha particle are:

Alpha particle may travel few inches in air.

Most alpha particles can be stopped by human skin

Alpha particle cannot penetrate clothing.

Alpha radiation can detect by a thin-window Geiger-Mueller (GM) probe.

Humans are affected by Alpha-emitting materials if these are inhaled, swallowed through open wounds.

Examples: Alpha radiation emitted from Uranium-238, Radium-226, and Radon-222 etc.

BETA RADIATION

Beta radiation consists of electrons having short-range. Characteristics of beta radiation are:

Beta particles are more penetrating than alpha particles.

Beta-emitting contaminants if deposited internally may be harmful.

Beta emitters can be detected by survey instrument and also a thin-window GM Probe.

Some beta emitters having very low-energy and poorly penetrating radiations may be difficult to detect.

Examples of beta emitters: strontium-90, carbon-14, and sulfur-35.

GAMMA AND X-RAYS RADIATION

Gamma radiation and x rays are electromagnetic radiation like visible light, radio waves, and ultraviolet light. Gamma rays and x rays are highly penetrating radiation because they are able to travel many feet in air.

Gamma radiation is detected by survey meters with a sodium iodide detector probe.

Examples: iodine-131, cesium-137, cobalt-60, radium-226 etc.

NEUTRON RADIATION:

Neutrons are uncharged particles and do not produce ionization directly. But, their interaction with the atom of matter can give rise to alpha, beta, gamma or X-rays, which then produce ionization. Neutrons are penetrating and can be stopped by thick mass of concrete, water or paraffin.

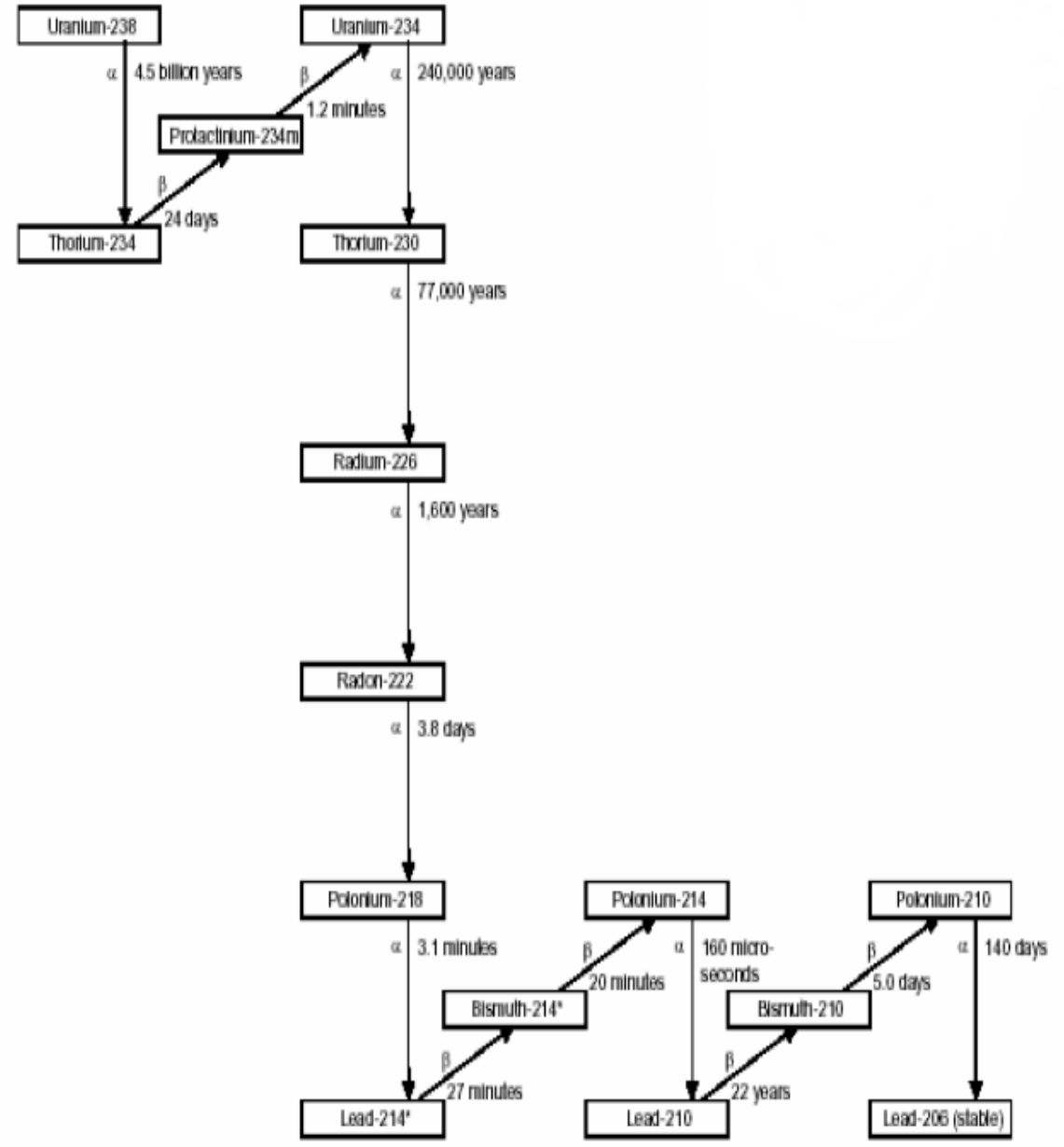
1.3 NATURAL RADIOACTIVITY (Uranium, Thorium, Potassium)

Radioactive decay is spontaneous phenomenon of emission of particle or electromagnetic radiation from an atomic nucleus. Thermodynamic instability of nucleus is responsible for the spontaneous decay so as to obtain more stable nucleus. Nuclear decay is accompanied by emission of alpha, beta, gamma, neutron, proton and even heavier elements (isotopes). It was first observed in 1896 by a French scientist A Henri Becquerel and emitted radiation called Becquerel rays. Three main decay series are observed in nature, commonly called the thorium, uranium and actinium series and ending in three different stable isotopes of lead

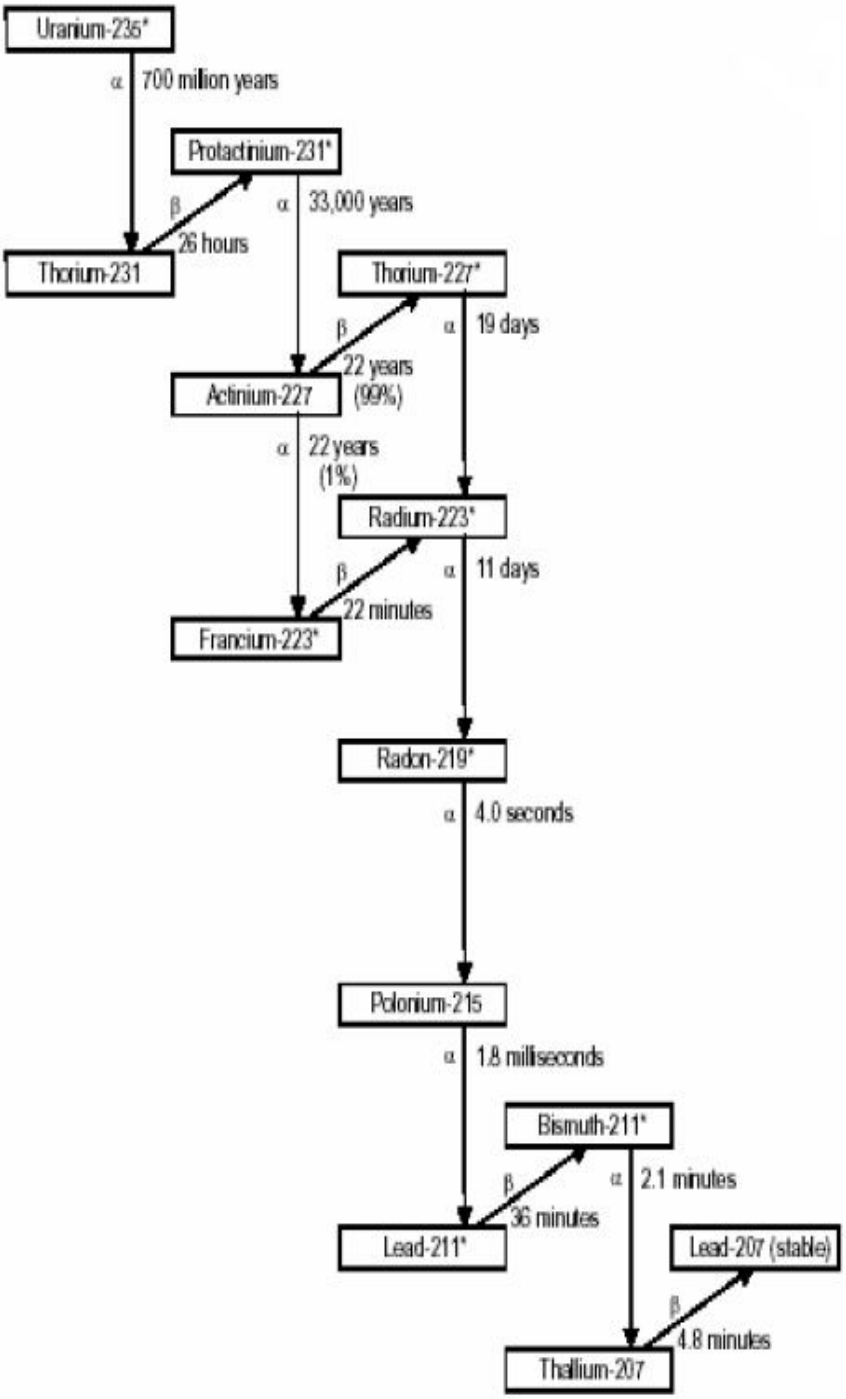
Terrestrial radiation exposure, mainly in the form of gamma radiation, is due to primordial radionuclides in the earth crust. Because of their extremely long half-lives, they have existed since the existence of Earth. Especially ^{40}K and the nuclides of the uranium-radium and thorium series are relevant with respect to radiation exposure of the population. Uranium and thorium disintegrate, via several decay products, to stable lead. The concentrations of the natural radionuclides, ^{238}U, ^{232}Th, their daughter products and ^{40}K, present in the soils and rocks, which in turn depend upon the local geology of each region in the world (Radhakrishna et al., 1993; Quindos et al., 1994) which are causes of variation of doses. Certain regions of the world have particularly high absorbed dose rates due to ambient radiation produced by high activity concentrations of natural radioactive substances in the soil (thorium containing monazite sand in Brazil and India, granite rock with high thorium and uranium contains in France).

1.3.1 Natural Decay Series

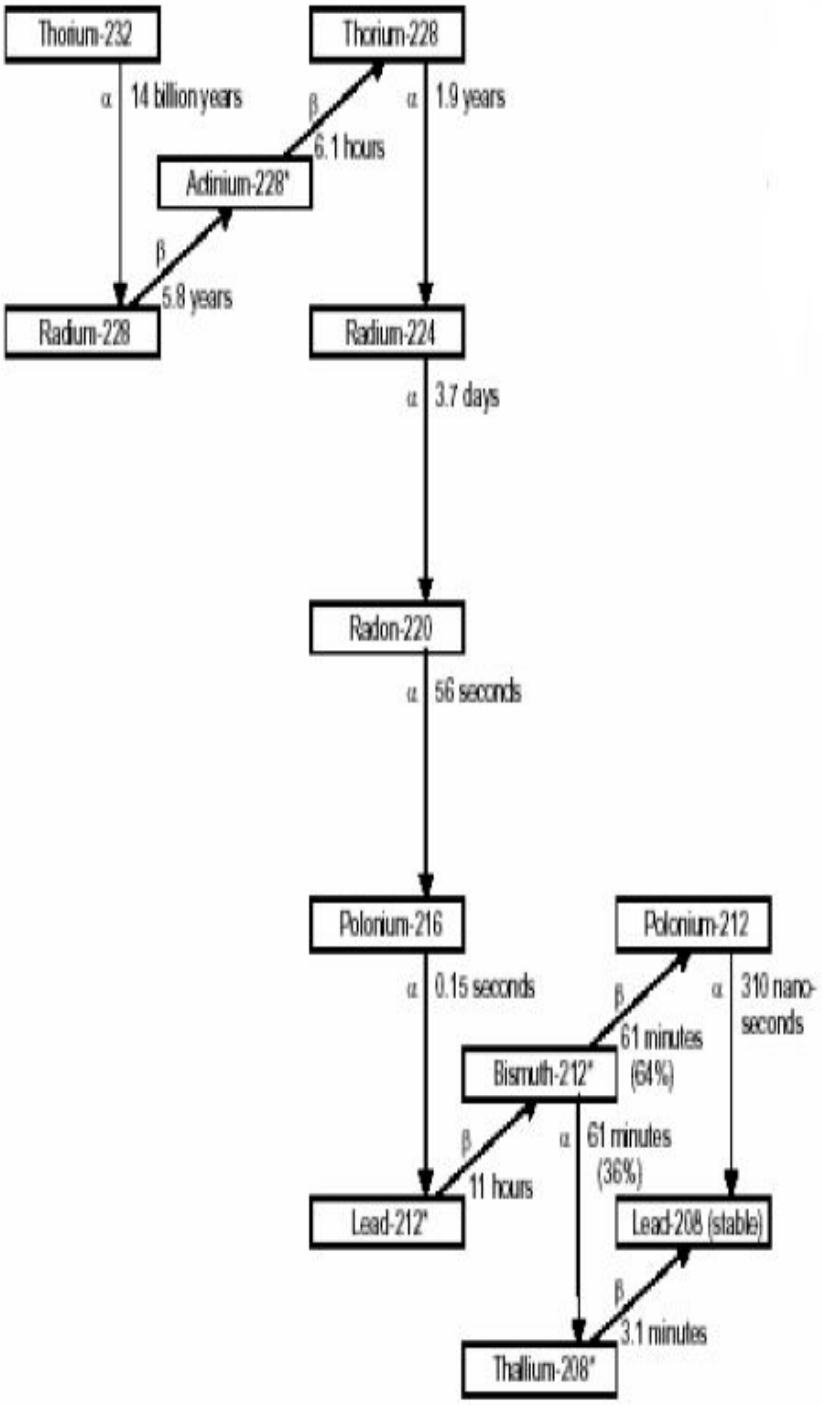
Uranium-238



Uranium-235

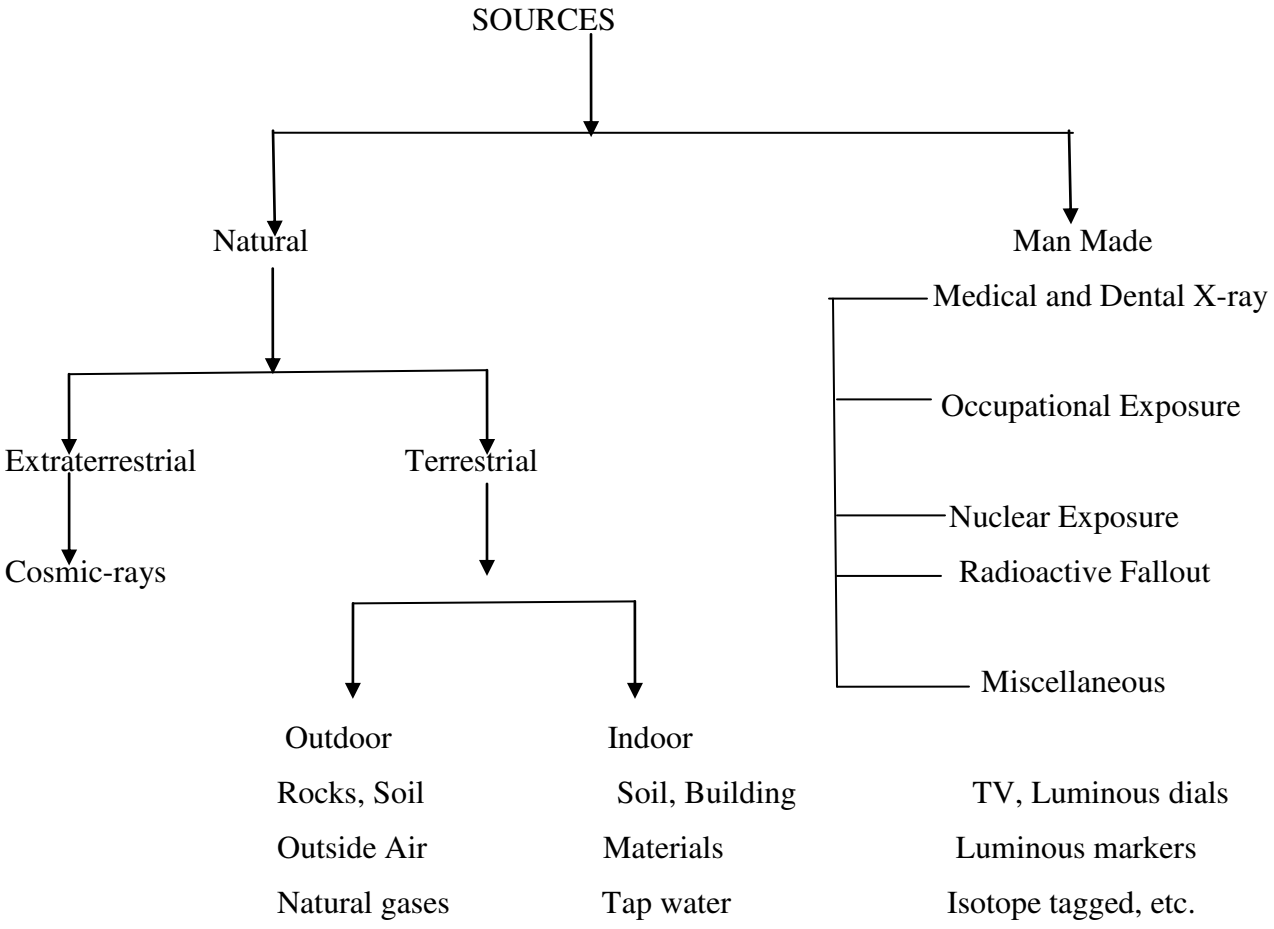

Uranium-235*
α 700 million years
Protactinium-231*
β 26 hours
α 33,000 years
Thorium-231
Thorium-227*
β 22 years (99%)
α 19 days
Actinium-227
α 22 years (1%)
Radium-223*
β 22 minutes
α 11 days
Francium-223*
Radon-219*
α 4.0 seconds
Polonium-215
α 1.8 milliseconds
Bismuth-211*
β 36 minutes
α 2.1 minutes
Lead-211*
Lead-207 (stable)
β 4.8 minutes
Thallium-207

Thorium-232


Thorium-232
Thorium-228
α 14 billion years
β 6.1 hours
α 1.9 years
Actinium-228*
β 5.8 years
Radium-228
Radium-224
α 3.7 days
Radon-220
α 56 seconds
Polonium-216
Polonium-212
α 0.15 seconds
β 61 minutes (64%)
α 310 nano-seconds
Bismuth-212*
β 11 hours
α 61 minutes (36%)
Lead-212*
Lead-208 (stable)
β 3.1 minutes
Thallium-208*

1.4 SOURCES OF RADIATION EXPOSURE

Human beings are always exposed by artificial and natural radiation radiations. These sources of radiation are shown in figure.



1.5 RADON

Radon is a chemical element with symbol Rn having atomic number 86 and mass number of 222. Initially the name of radon was “Niton” from the Latin word “nitens”. It is a radioactive, colorless, odorless, tasteless inert gas, occurring naturally as an indirect decay product of uranium or thorium. Thoron is an isotope which possesses an atomic number (Z) of 86 and a mass number of 220 (^{220}Rn).

Both Radon and Thoron in their normal condition are in gaseous state. Half-lives of Radon are 3.8 days while of Thoron is 55.6 seconds.

It was discovered by English physicist Ernest Rutherford in 1899. The discovery is also credited to Curies (Kolthoff and Philip, 1966) and German physicist Friedrich Ernst Dorn in 1898, 1900 respectively. The International Committee on Chemical Elements assumes the name "Radon" in 1923.

1.5.1 PHYSICAL AND CHEMICAL PROPERTIES OF RADON

- Phase : Gas
- Melting Point of radon : 202K
- Boiling Point of radon : 211K
- Heat of Fusion is 3.247 kJ/mol
- Heat of Vaporization is: 18.1 kJ/mol
- Specific Heat Capacity: 20.786 J/mol·1/K
- Atomic number: 86
- Atomic mass: (222) $g.mol^{-1}$
- Density: $9.96*10^{-3}$ $g.cm^3$ at 20°C
- Energy of first ionization:1037 $kJ.mol^{-1}$

1.6 THORON AND ITS PROGENY

Thoron concentration in a room falls off exponentially with distance from its sources because of its short life (55.6 sec.). Due to this, for comparability of thoron measurements it may be necessary for measurement protocol to include a precise statement on measuring thoron concentration at a particular distance from the source. This recommendation has particular relevance to human exposure assessment. Generally people breath air close to walls during sleep. During this stage lung dose due to thoron gas itself may even be greater than that from the inhalation from the thoron progeny. These may

be presented in room air at much lower concentration and will be much more uniformly distributed in the room air than the thoron gas itself. Since the correlation between thoron gas and its progeny ^{212}Pb cannot always be ensured, correct estimate of the dose may even require measurement of both the gas itself and its progeny. For thoron measurement in water, as in case of the radon in water measurements, it is recommended that procedures should be adapted to reduce thoron losses during sampling.

1.7 SOURCES OF INDOOR RADON

Indoor radon has its primary sources from walls, and ceilings which are constructed of building materials, rock, soil etc. Materials housed in the room, radon rich water or gas and inlet air etc. are the secondary sources of indoor radon. The main contributors to the indoor radon levels are as follows:

1.7.1 SOIL

In the indoor atmosphere soil is the primary source of radon which is found in trace quantities. Radon gas, which is chemically inert, transports through soil and into dwellings through cracks and other openings in the building materials directly. There are two a mechanism by which radon enters from soil: the first mechanism is the movement of radon by molecular diffusion through the air pore system in soil and the second significant mechanism of entry is the forced flow which is created by forces that drive air infiltration into buildings viz. the thermal stack effect and wind loading on the building shell. Fractures and hole in building foundations are enough to allow convective migration and gas transport.

1.7.2 WATER

Radon can be transferred to the indoor air through the use of water during typical house hold activities like showering, laundering etc. The amount of radon in water at the point of use depends primarily on two factors i.e. the local geologic character and type of water supply. The radon in water is controlled by emission of radon into water and by chemical concentration of radium in the host soil or rock. The structure of the rock matrix may play an important role in radon release in to water. The release of

radon in to the surrounding water dominates due to diffusion along micro crystalline imperfections (Hess et al., 1985). Highest levels were observed in drilled wells; especially in granite area and lower concentration were found in water from dug wells and surface water sources.

It is likely that, in normal circumstances, radon escaping from ground water in the soil does not give rise to higher concentration in buildings. The reason is partly that the water content in the soil horizon immediately above the water table is so great that diffusion through the soil is prevented. Only if the radon concentration in the ground water is much higher than that in the soil gas and if the ground water is in motion or flows out at the surface, it is likely that sufficient radon will be released to affect its concentration in the building.

1.7.3 NATURAL GAS

Radon is also mixed in natural gas due to the presence of radium in the surrounding soil of gas well. Radon moves with natural gas to the point of domestic use. The concentration of radon at wells has been measured from undetectable limits up to about 5.4×10^4 Bq m^{-3}. The concentration of radon at site of use depends upon the concentration of radon at the wellhead, production rate of natural gas, natural gas processing, pipeline dilution, pipeline transmission time and storage time (Fleisher et. al., 1975). The radon concentration in natural gas range from 0.1 to 0.2 pCi l^{-1} at the burning point which is less than the radon concentration emanated from other sources and it is not a significant contributor to indoor radon (Abu-Jarad et.al., 1980). The radon is also found in liquid petroleum gas and the value of radon concentration in LPG varies from 70.3 Bq m^{-3} to 4.8×10^4 Bq m^{-3} (Hess et.al.)

1.7.4 BUILDING MATERIALS

Building materials may be one of the important sources of indoor radon when the value of radium contents of materials is above to the normal value and emanation rates are too high. Building materials are easily characterized as indoor radon source than the soil and rocks. Estimate of radon emanation

rates or ratios for soil and rock performed both in concentration with interests in uranium exploration and for the use of radon as an atmospheric tracer, have been reviewed in detail by Tanner (1987). Ingersoll (1983) has measured the radon emanation rates in a number of building materials. The result of the study indicates that strongest radon emanator is concrete and weakest, the wood. Measurement of the emanation in concrete components revealed that sand is the strongest emanatory and cement, the weakest. Within a given type of building material the radon emanation rate varied substantially from one sample to another sample. Even though uranium content of materials might be approximately the same, the radon emanation rates might differ widely, e.g. granite and rocks used for heat storage have a higher uranium concentration than concrete and yet they exhale radon at lower rates. It was concluded that the physical properties of the various classes of materials account for the wide dispersion of escape to production ratios and thus radon exhalation rate measurements for various materials are very important

1.7.5 HOMES AND BUILDINGS

Subsoil emanation has been reported to be a significant source of indoor radon (O' Riordan, 1980). The significance is much higher if there are cracks in the base structure or floor which can act as empty points of subsoil air into the indoor space. Often direct ingress from soil dominates over other sources of indoor radon. Figure given as below illustrates the various possible entry rates of radon from soil to the indoor atmosphere. The flux of radon from soil through the basement structure cannot be accounted solely by diffusion. Another mechanism of a pressure driven flow of soil air can be potential cause for the efficient passage of radon from underground. This is based on the small pressure difference between the lower part of the house interior and the outdoors (Nazaroff and Nero., 1988). However, building materials rarely cause radon problems by themselves. Radon gets in through:

1. Cracks in solid floors.

2. Construction joints.

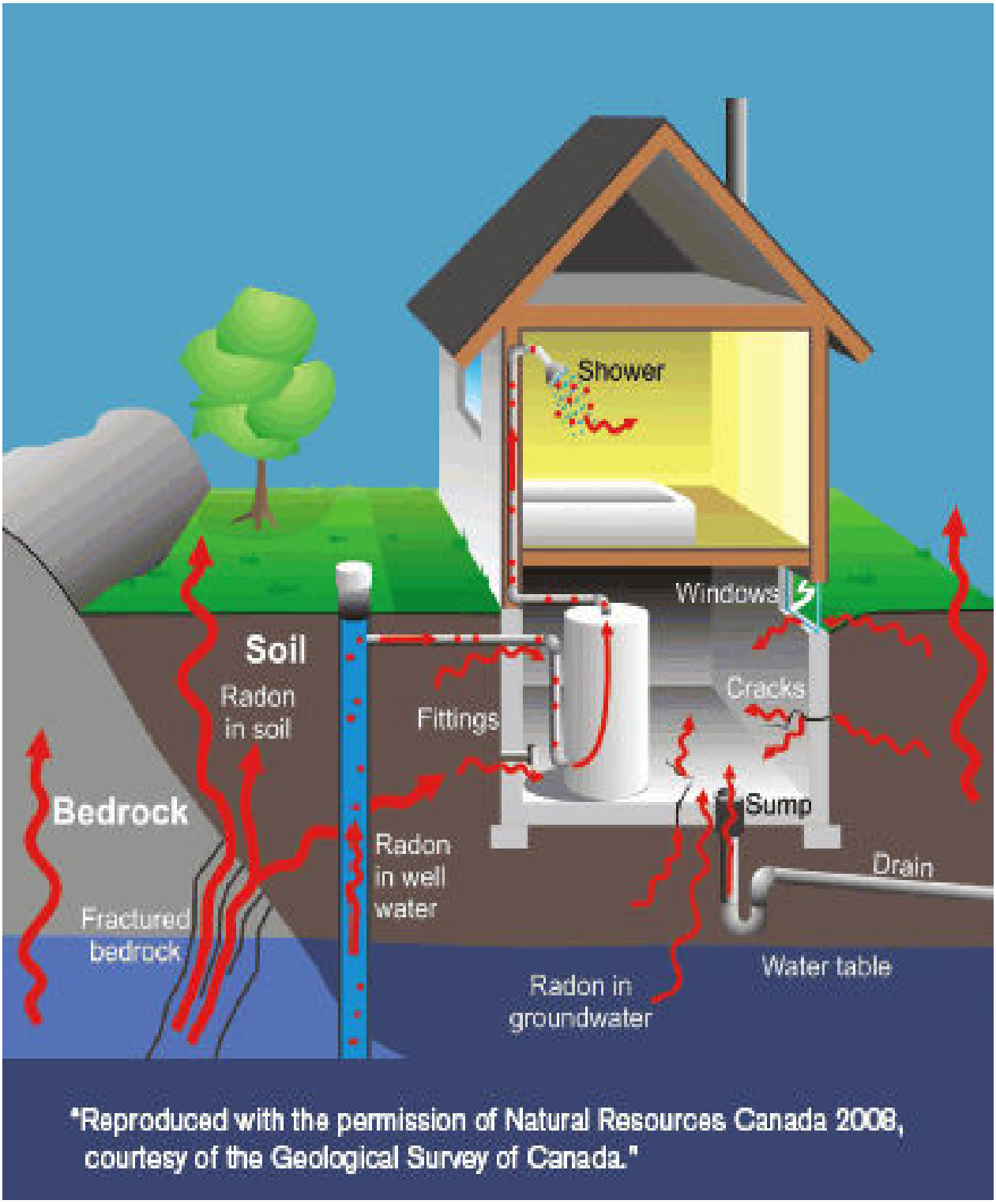
3. Cavity inside walls.

4. Water supply.

5. Cracks in walls.

6. Gaps in suspended floors.

7. Gaps around service pipes.


Shower
Windows
Soil
Radon
in soil
Fittings
Cracks
Bedrock
Sump
Radon
in well
water
Drain
Fractured
bedrock
Water table
Radon in
groundwater
"Reproduced with the permission of Natural Resources Canada 2008,
courtesy of the Geological Survey of Canada."

1.8 HEALTH EFFECTS DUE TO RADON

Inhalation of radon gas leads to its uniform distribution in whole body. Due to low solubility of radon in body tissues the resulting effective dose equivalent from inhalation is normally small as compared to the dose from inhaled radon daughters.

Nearly one fifth of total cancer deaths in industrialized countries occur due to lung cancer which common form of lethal cancer. The proportion is still higher in many countries (Doll and Peto, 1981).

Bronchogenic (lung cancer) was found in the bronchial airway which is situated in the central part of the lung. Few cases have been found in small airways deep in the alveoli and in the lungs (Kreyberg, 1967). The cancer found in the large airways is termed as epidermoid tumours and as carcinomas in small airways. The occurrence of different types of tumours varies with age at which the cancer occurs. Exposure to radon progeny, cigarette smoking and inhalation of other pollutants or combination of these are the prominent causes for the occurrence of lung cancer.

1.8.1 LUNG CANCER

Inhaled aerosols during breathing are attached with radon progeny and may be trapped by the sticky mucus present in the bronchial airways as the range of alpha particles emitted by the radon progeny lies within the sensitive basal cells located under the inside surface of the bronchial airways. For a given concentration of radon progeny in the air various factors determine the number of alpha radiations actually irradiating the basal thin layer of bronchial tree.

The speed with which the mucus clears the aerosols away from the lung by physiological processes and depth of basal cells below the mucus layer having some of the factors i.e. age of the person, aerosols size and breathing pattern. The unattached fraction of radon progeny which are smaller than aerosols are more likely to be deposited in the lung contributing significantly to the radiation dose to the lung.

The respiratory tract where alpha particles were deposited can be divided into following three regions

i: Nasopharyngeal (N-P)

Ii: Tracheobronchial (T-B)

Iii: Alveolar Interstitial (A-I)

Nasopharyngeal region is responsible for the humidification of the inhaled air and filtering of aerosols and the dust. Although radon progeny may be deposited along this upper respiratory tract, but no evidence of increases in nasal cancer risk has been found with mining population due to increased radon progeny (Nazaroff and Nero, 1988). The main risk is always for the bronchogenic cancer. The T-B region is provided with mucus secreting glands so that deposited particles can be translocated rapidly by mucociliary action to throat for swallowing. T-B region must be considered while assessing the fraction of deposited radon progeny which can more efficiently irradiate the bronchial epithelium. The A-I region is characterised by the absence of a thin barrier tissue. Through deposited radon progeny from A-I region are cleared through ciliated airways and lymphatic drainage ducts, only absorption into the blood serves as a mechanism of translocation of the particle from lung to the other organs A fraction of the attached as well as unattached radon progeny is deposited in the three regions. Direct measurement show that about half of the unattached progeny inhaled are deposited in the T-B region of the lungs (George and Breslin, 1969).

1.9 DIFFUSION OF RADON

Indoor radon entry has been modelled most commonly as adjective transport by pressure-driven air flow from the soil through foundation cracks and openings. Radon generation in the concrete floor and radon diffusion from the soil through the concrete floor has generally been ignored. The attention has now been directed toward the importance of diffusion as a significant mechanism for radon entry. Rogers and Nielson (1990) identified diffusion through concrete floors and the contiguous soil as a

significant mechanism for radon entry for many soils under typical long-term average foundation air-pressure gradients. In ground water, radon moves by diffusion and primarily by the mechanical flow of water. Radon solubility in water is relatively low and with its short radioactive half-life of 3.82 days, much of it will decay before it can be released from groundwater. At normal environmental conditions the radon diffusion through hydrocarbon phase is much more than water phases (Nazaroff, 1988). Radon diffusion and transport through different media is a complex process and is affected by several factors (Tanner, 1980; Singh et al., 1999).

1.10 TRANSPORT OF RADON

Radon, as a gas, flows freely in the environment. Radon is produced by minerals and certain rocks it is introduced into the soils and air around those sources. There are different way to determine the radon concentration in air, and the pores of the soil, also determine by the extent to which the radon atoms formed actually emanate from the mineral grains and whether radon can leave the pore space either by diffusion or together with a flow of air or water. Transportation of radon through the soil takes place by diffusion or with air ambient gases e.g. CO_2 and CH_4 or water moving in the soil horizons. As radon is having limited life it disintegrates after a certain diffusion distance. 90% of radon emanated from radon source, e.g. a deep lying soil horizon, and transported by diffusion, will normal moisture content and 5 cm in water, about 2 cm in sandy soil, with normal moisture content and 5 cm in air (UNSCEAR, 1982). The transport distance for thoron is insignificant because of its half life i.e. 55.6 seconds.

1.11 RADON EXHALATION RATE

Building materials are one of the main sources of radon activity inside dwellings. A large variation in radon activity is observed in dwellings as the uranium concentrations in natural materials used as building materials vary from place to place. Thus it is desirable to measure the radon exhalation from building materials used in different regions. Emission of radon per unit area per unit time is known as

"radon exhalation rate". Radon exhalation rates are two types: surface exhalation rate and mass exhalation rate. "Can technique" was used for the measurement of radon exhalation from solids has been widely used also in combination with several active measuring techniques (Stranden, 1983). In the present study estimations have been made for the radon exhalation rate from commonly used building materials.

Surface exhalation rate and mass exhalation rate are calculated using the relation (Fleischer and Morgo-campero, 1978; Sharma et al., 2015; and Abu-Jarad et al., 1980):

$$E_X = \frac{CV\lambda}{A\left[T + \frac{1}{\lambda}\left\{e^{-\lambda T} - 1\right\}\right]}$$

$$E_M = \frac{CV\lambda}{M\left[T + \frac{1}{\lambda}\left\{e^{-\lambda T} - 1\right\}\right]}$$

Where,

E_x = radon surface exhalation rate in (Bq m^{-2} h^{-1})

E_M = radon mass exhalation rate in (Bq kg^{-1} h^{-1})

C = radon exposure as measured by LR -115 solid state nuclear track detector (Bq m^{-3} h)

V = the effective volume of can in (m^3)

Λ = the decay constant for radon in (h^{-1})

T = the exposure time in (h)

A = the area of the can in (m^2) and M is mass of the sample.

1.12 RADIATION PROTECTION

Radiation protection, also known as radiological protection, is the science which protecting the environment and people due to the harmful effects of ionizing radiation, which includes both particle radiation and high energy electromagnetic radiation.

It has long been recognized that large doses of ionizing radiation can damage human tissues. Over the years, as more was learned, scientists become increasingly concerned about the potentially damaging effects of exposure to large doses of radiation. The need to regulate exposure to radiation prompted the formation of a number of expert bodies to consider what is needed to be done. In 1928, an independent non-governmental body of experts in the field, the International X-ray and radium protection Committee was established. It later was renamed the International Commission on Radiological Protection (ICRP). It propose to establish basic principles for, and issue recommendations on, radiation protection, these principles and recommendations from the basis of national regulations governing the exposure of radiation workers and members of the public. They also have been incorporated by the International Atomic Energy Agency (IAEA) into its Basic Safety Standards for Radiation Protection published jointly with the World Health Organization (WHO), International Labour Organization (ILO), and the OECD Nuclear Energy Agency (NEA). These standards are used worldwide to ensure safety and radiation protection of radiation workers and the general public.

An international body was formed in 1955 by the General Assembly of the United Nations as the UN Scientific Committee on the Effect of Atomic Radiation (UNSCEAR). UNSCEAR is directed to assemble study and disseminate information on the observed levels of ionizing radiation and radioactivity (natural and man-made) in the environment, and on the effects of such radiation on man and the environment.

Basic approaches to radiation protection are consistent all over the world. The ICRP recommends that any exposure above the natural background radiation should be kept as low as reasonably achievable, but below the individual dose limits. The individual dose limits for radiation workers averaged over 5 years is 100 mSv, and for members of the general public, is 1 mSv y^{-1}. These dose limits have been established based on a prudent approach by assuming that there is no threshold dose below which there would be no effect. It means that any additional dose will cause a proportional increase in the chance of health effect. This relationship has not yet been established in the low dose range where the dose limits have been set.

There are many high natural background radiation areas around the world where the annual radiation dose received by members of the general public is several times higher than the ICRP dose limit for radiation workers. The numbers of people exposed are too small to expect to detect any increases in health effects epidemiologically. Still the fact that there is no evidence so far of any increase dose not mean the risk is being totally disregarded.

The ICRP and the IAEA recommend the individual dose must be kept as low as reasonably achievable, and consideration must be given to the presence of other sources, which may cause simultaneous radiation exposure to the same group of the public. Also, allowance for future sources or practices must be kept in mind so that the total dose received by an individual member of the public dose not exceeds the dose limit.

In general, the average annual dose received by radiation workers is found to be considerably lower than the individual dose limits. Good radiation protection practice can thus result in low radiation exposure to workers.

First, there is the assumption that any increased level of radiation above natural background will carry some risk of harm to health.

Second, it aims to protect future generations from activities conducted today.

1.13 MONITORING AND CONTROLLING EXPOSURE

Radiation has always been present in the environment and in our bodies. The human body cannot sense ionizing radiation, but a range of instruments exist which are capable of detecting even very low levels of radiation from natural and man-made sources. There are following standard ways to restrain exposure to radiation.

Time: Dose from the radiation source can be reducing by Minimizing the exposure time

Distance: Deepness of radiation decreases with distance, by an inverse square law.

Shielding: Radiation formed of energetic particles such as gamma rays and neutrons can be stoped by lead bricks, concrete, or water . Few radioactive materials are stored underwater or in rooms constructed of thick concrete or lined with lead. Beta particles are stop by shielding of special plastic and air will stop alpha particles. The forcefulness of a material in shielding radiation is determined by its halve value thicknesses, the thickness of material that reduces the radiation by half. This significance is a function of the material, energy and type of ionizing radiation.

1.14 RADIATION RISKS AND ADVANTAGE

Radiation is not only harmful to human beings but it is just like a good friend too. We all face risks in life every day. It is impossible to eliminate them all, but it is possible to reduce them. Not only exposure to radiation is harmful but also there are beneficial effects too. Radiation is a key tool in the treatment of certain kinds of cancer. Strenuous attempts are made in the nuclear industry to reduce such risks to as low as possible but the use of radiation and nuclear techniques in medicine, industry, agriculture and other scientific and technological fields has brought tremendous benefits to society.

1.15 EFFECT OF RADIOACTIVITY ON HEALTH

Different radionuclides emit ionizing radiations; differ in their ability to penetrate matter depending upon the type of radiation emitted and its energy. Alpha particles are able to penetrate the outer layer of skin and whenever it is emitted outside the body, they do not pose hazard. Beta particles are able to penetrate outer layer of skin, when in contact and they give rise to dose to the skin. Gamma radiation is potentially more penetrate than alpha and beta and can deposit energy to internal organs. Thus internal and external exposures of body by radionuclides and relative importance of these exposures pathways depend upon the types of radiation and the radionuclides involved. As a result from the exposure to ionizing radiation two types of health effect have been introducing i.e. deterministic and stochastic effects. Deterministic effects are those that occur at dose levels far higher than those encountered from the exposure to radioactive materials under normal environmental conditions. Erythematic or reddening of the skin is a form of deterministic effect that may result from skin exposure of 5Gy or more instantaneous absorbed dose. The primary stochastic effect associated with radiation exposure is cancer induction. Generally it is assumed that any resulting health detriment i.e. cellular damage, cancer etc. is brought about by exposure to a radioactive substance and is primarily a function of the amount of energy of ionizing radiation absorbed per unit mass of tissue through which it passes.

It is difficult to demonstrate an increased cancer incidence at lower levels of dose and dose rate from radiation exposure because of the high natural incidence of cancer, which is a major confounding factor in the epidemiological studies. Uranium nuclides emit alpha rays of high ionization power and therefore, it may be hazardous if inhaled or ingested in large amount or dose. Uranium a primordial radionuclide occurs in dispersed state in the Earth crust. (Dyck, 1979; Dunn, 1981). Uranium present in the Earth is transfer to water, plants, food supplements and then to human beings.

Uranium accumulated in humans may have dual effect due to its chemical and radioactive properties. High intake of uranium and its decay products may lead to harmful effect in human beings. It is found from the studies that the food contributes about 15% of ingested uranium while drinking water contributes about 85% (Cothern and Lappenbush, 1983). An exposure of about 0.1 mg/kg of body weight of soluble natural uranium results in transient chemical damage to the kidneys (Lussenhop et al., 1958).

1.16 HEALTH RISK

Suddenly decay of radioactive materials are produce ionizing radiation, it has educate energy to break some chemical bonds and to take away electrons from atoms. Ionizing radiation can be damage living tissue in the human body in a unique manner. The amount and continues exposure due to radiation affect the severity or health effect. Following are two main categories of health effects:

i: stochastic

ii: non-stochastic.

Stochastic effects (i.e. Cancers and mutations viz. teratogenic or genetic) are associated with long-term, low level exposure to radiation and Non-stochastic effects appear due to exposure to high levels of radiation for short term may become more severe is known as ‘acute’ exposure. Radiation sickness and burns are come under the acute health effects. Radiation sickness is termed as “Radiation poisoning”. It can cause happening too soon or even death. Death can happen within two months if the dose is fatal. Following symptoms i.e. nausea, weakness, hair loss, skin burn and diminished organ function are of radiation poisoning. Radioactive Uranium and its major decay product radon are also the main causes of health effects in humans. Normal functioning of the kidney, brain, liver, heart and numerous other systems can be affected by uranium exposure, because uranium is a toxic metal (Craft

et al., 2004). The kidneys are the critical organ for uranium chemo toxicity. According to BEIR VI, 1999 the high dose of radon is second major cause of lung cancer after smoking.

1.17 ABBREVIATIONS

IAEA (International Atomic Energy Agency)

IARP (Indian Association for Radiation Protection)

ICRP (International Commission on Radiological Protection)

BEIR (Biological Effects on Ionizing Radiation)

UNSCEAR (United Nation Scientific Committee on the Effects of Atomic Radiation)

1.18 SOME IMPORTANT TERMS AND UNITS

Estimation of inhalation dose from exposure to Radon and progeny concentration involves many parameters that are explained below in various terminologies.

ABSORBED GAMMA DOSE (D)

Absorbed gamma dose rate in air at 1m above the ground surface for the uniform distribution of radio nuclides (^{238}U, ^{232}Th and ^{40}K) are calculated on the basis of guidelines given by UNSCEAR, (2008). The dose conversion factors for converting the activity concentration of ^{238}U, ^{232}Th and ^{40}K into doses (nGy h^{-1} Bq^{-1} kg^{-1}) are 0.462, 0.604 and 0.0417 respectively.

$$D = (0.462C_U + 0.604\ C_{Th} + 0.0417\ C_K)\ nGy\ h^{-1}$$

ACTION LEVEL

The activity concentration or level of dose rate above which remedial actions or protective actions should be carried out in chronic exposure or emergency exposure situations.

DOSE LIMIT

The value of effective dose or the equivalent dose to individuals from controlled practices that shall not be exceeded.

EFFECTIVE DOSE

Estimate of annual effective dose, account must be taken of the following

i: conversion coefficient from absorbed dose in air to effective dose

ii: The indoor occupancy factor.

The average numerical values of those parameters vary with the age of the population and climate at the location consider. 0.7 Sv Gy^{-1} is reported in UNSCEAR 1993 Report for the conversion coefficient from absorbed dose in air to effective dose received by adult and 0.8 for the indoor occupancy factor is used by the committee i.e. the fraction of time spent indoors and outdoors is 0.8 and 0.2 respectively. These values are retained in the present analysis. The components of the annual effective dose are determined as follows:

Indoors: 84 nGy h^{-1} ×8,760 h × 0.8 × 0.7 Sv Gy^{-1} = 0.41 mSv

Outdoors: 59 nGy h^{-1} × 8,760 h × 0.2 × 0.7 Sv Gy^{-1} = 0.07 mSv

The unit of effective dose is J kg^{-1}, termed the sievert (Sv). Equivalent Dose and Effective Dose are used for assessment of the risk of biological effects produced by ionizing radiation

EQUILIBRIUM EQUIVALENT CONCENTRATIONS (EEC)

The equilibrium equivalent concentration (EEC) of Radon is equal to that quantity of Radon concentration which is in secular equilibrium with its progeny nuclides giving equivalent PAEC for the progeny nuclides present in the atmosphere. If the Radon concentration is C_{Rn} and equivalent factor is F (0.4), then equilibrium equivalent concentration can be expressed as

$$EEC = F * C_{Rn}$$

INDOOR INTERNAL EXPOSURE DUE TO RADON INHALATION

The risk of lung cancer from domestic exposure of ^{222}Rn and its daughter can be estimated directly from the indoor inhalation exposure (Radon) effective dose. The contribution of indoor Radon concentration from the samples can be calculated from the expression (Nazaroff and Nero.1988):

$$C_{Rn} = \frac{E_X \times S}{V \times \lambda_v}$$

Where, C_{Rn}, $E_{X,}$ S, V and λ_v are Radon concentration (Bq m^{-3}), Radon exhalation rate (Bq m^{-2} h^{-1}), Radon exhalation area (m^2), Room volume (m^3) and air exchange rate (h^{-1}) respectively.

POTENTIAL ALPHA ENERGY (PAE)

The potential alpha energy of an atom in the decay chain of Radon/Thoron is the total alpha energy emitted during decay of this atom through the decay chain to ^{210}Pb in the case of Radon progeny or ^{208}Pb in the case of thoron decay products. Its unit is MeV.

RADIUM EQUIVALENT ACTIVITY

Exposure due to radiation is explained in terms of radium equivalent activity (Bq kg^{-1}) to compare the standard activity of materials having different concentration of radionuclides. Following expression give the Radium equivalent activity:

$$Ra_{eq} = C_U + 1.43\ C_{Th} + 0.07\ C_K$$

Where,

$C_{U,}$ = Activity concentration of Uranium (Bq kg^{-1})

C_{Th} = Activity concentration of Thorium (Bq kg^{-1})

C_K = Activity concentration of Potassium (Bq kg^{-1})

WORKING LEVEL (WL)

The working level is defined as the in any combination of short-lived radon decay products in one liter of air produced 130,000 MeV of potential alpha energy. A more exact computation of the potential alpha energy for 1WL concentration is obtain from 100 $pCiL^{-1}$ or 3.7 BqL^{-1} of ^{222}Rn gas or 0.275 BqL^{-1} of ^{222}Rn gas in equilibrium with its daughter products .

1 WL = 1.3×10^5 MeV L^{-1} = 2.08×10^5 Jm^{-3} in SI unit

WORKING LEVEL MONTH (WLM)

The total exposure of radiation depends on the intensity and duration of the exposure. One working level month has 170 hours approximate. Thus inhalation of air with a concentration of 1WL of radon or thoron progeny for 170 working hours results in the exposure of 1 working level month (1WLM).

1 WLM = 3.54 $mJhm^{-3}$ in SI unit

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CHAPTER-2

MEASUREMENT TECHNIQUES AND MATERIALS

2.1 GENERAL

Radon and Thoron measurements are of prime important now days for assessment of various health hazards. The radon and thoron decay by emitting alpha particle, giving rise to daughter who also is radioactive and again decay and in this way forms a series until the stable product is formed. The detection and measurement of Radon can be performed directly on radon or its daughters. Radon and several of its daughters decay by emitting α-particles, ^{214}Pb, ^{214}Bi, ^{210}Pb and ^{210}Bi are also β emitters and gamma radiation accompany their β-emissions. Numerous methods and a variety of instruments are available for the detection of radiation in the environment.

Brief descriptions of various techniques used in the present study are discussed in this chapter.

2.2. METHOD OF SOLID STATE NUCLEAR TRACK DETECTORS (SSNTDs)

Solid state nuclear tracks detectors (SSNTDs) (Fleischer et al., 1975, Iyer R H, 1972) have been used for a long time for radon measurements. They are insulating solids both naturally and man-made. Following types of detector are like inorganic crystals, glasses and plastics. Different types of plastic track detectors viz. Allyl diglycol (CR-39), cellulose nitrate (LR-115, CN-85) and Bisphenol-Apolycarbonate (lexan, Markofolo) are available that record alpha particles energies in a particular range. The etched track method was developed for heavy particles in Nuclear Physics experiments from cosmic rays (Fleischer, 1965) and was then applied to radon monitoring. (Alter and Fleischer, 1981). These detectors are insensitive to gamma rays, fast electrons and protons also. Tracks of the order of 10-20 μm in these detectors can only be produced if the specific energy loss (-dE/dx) is above the minimum value for that detector material. These detectors are also not affected by low temperatures, humidity, moderate heating and light. They present unique characteristics or long term integrating measurements of radon gas for large-scale surveys. (Tommasino, 1990). Nuclear tracks in solids can be revealed by a variety of techniques, the simplest and most widely used of which is that of preferential chemical attack and then

are counted by using optical microscope and spark counting system. The number of tracks per unit area is proportional to radon concentration.

2.3 TRACK FORMATION CRITERIA

Charge, mass and energy of the incident particle are the parameters to judge the validity of various models of track formation. Track formation can also be related to the total energy loss rate, primary ionization and restricted energy loss of the ionizing particle. In terms of these quantities one can set-up a criterion which suggested that the track are formed only when the chosen parameter exceeds a critical value, irrespective of the bombarding particle. The relevance for the formation of a criterion lies in the identification of particle. Fleischer et al., 1967 proposed the dependence of the total amount of energy deposited per unit path length on the track formation. It was proposed that etchable tracks are formed only when dE/dx exceeds a critical (threshold) value (dE/dx)c. This quantity was considered to be the characteristic of the solid. They calculated the values of (dE/dx) and plotted as a function heavy ion in three detectors viz. Muscovite Mica, Lexan Polycarbonate and Cellulose Nitrate. The data were consistent with the hypothesis that for each solid there exists a critical rate of energy loss (dE/dx)c such that particle losing energy more rapidly than this value produced continuous tracks. These ionizing particles which deposit appreciably less energy per unit length can produce no tracks.

Enlarging the latent trails of radiation damage with suitable chemical agent is known as chemical etching technique. In the certain materials shape of the etched track depend not only on the charge, mass and velocity of the incoming particle and on the nature, concentration and temperature of the etchant. The track shape also depends on the ratio of the rate of chemical attack for the bulk material V_B, to the chemical attack along the track V_T. This process of track revelation involves the concept of critical angle given as

$$\theta_C = \mathrm{Sin}^{-1}(V_B/V_T) \qquad (2.1)$$

If the angle of incidence of the charged particles with respect to the surface of the detector is less than the critical angle, the tracks of the incident particles cannot be revealed (Fleischer et al., 1975). As the etchant moves in the material along the damage trails at a faster rate, i.e. $V_T > V_B$, it produces a conical etch pit as shown in Figure 2.3. The etching efficiency of the detection depends upon the critical angle and is given by

$$\eta = 1 - \text{Sin}\ \theta_C \qquad (2.2)$$

The etch rate depends up on the nature of the damage produced by the charged particle, the composition of the material and etching time.

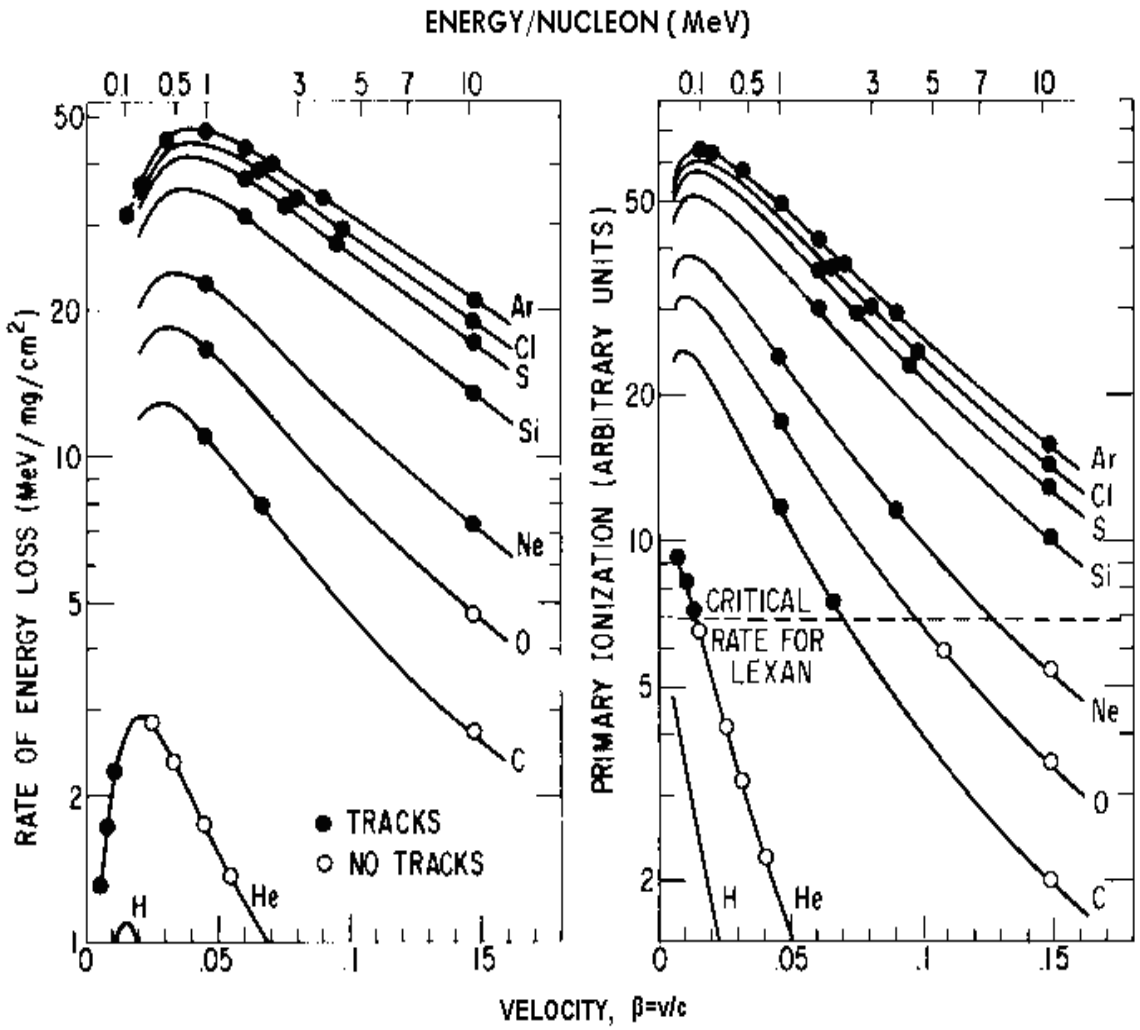

Figure 2.1: Curves of primary ionization rate as a function of relative velocity (β) and energy per nucleon for a number of ions. The experimental points for accelerator ions in lexon polycarbonate are given as open circles for zero registration and as filled circles for 100% registration. Thresholds for other detectors are also indicated.

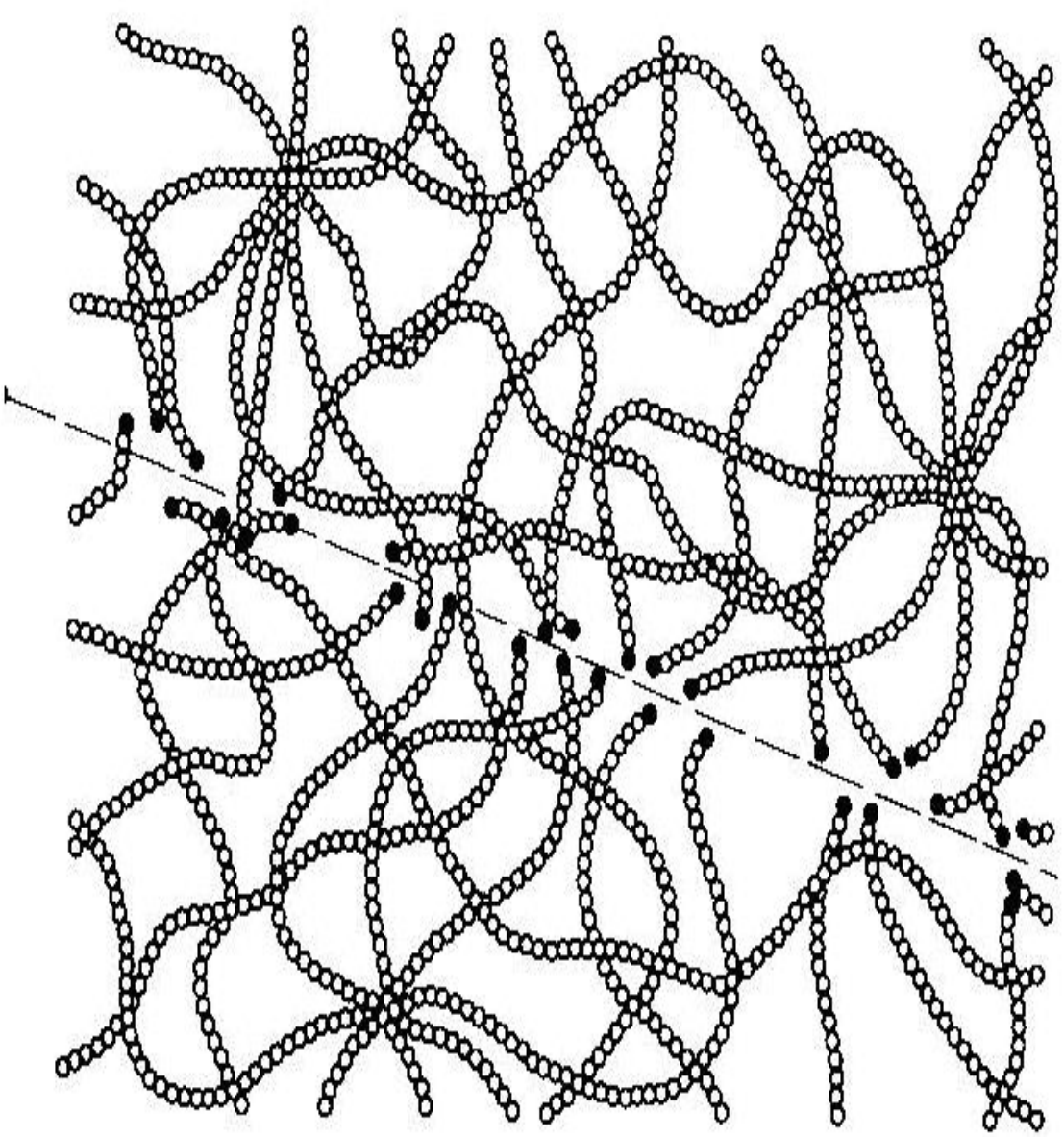

Figure 2.2: Chain cleavage and track formation in organic polymers.

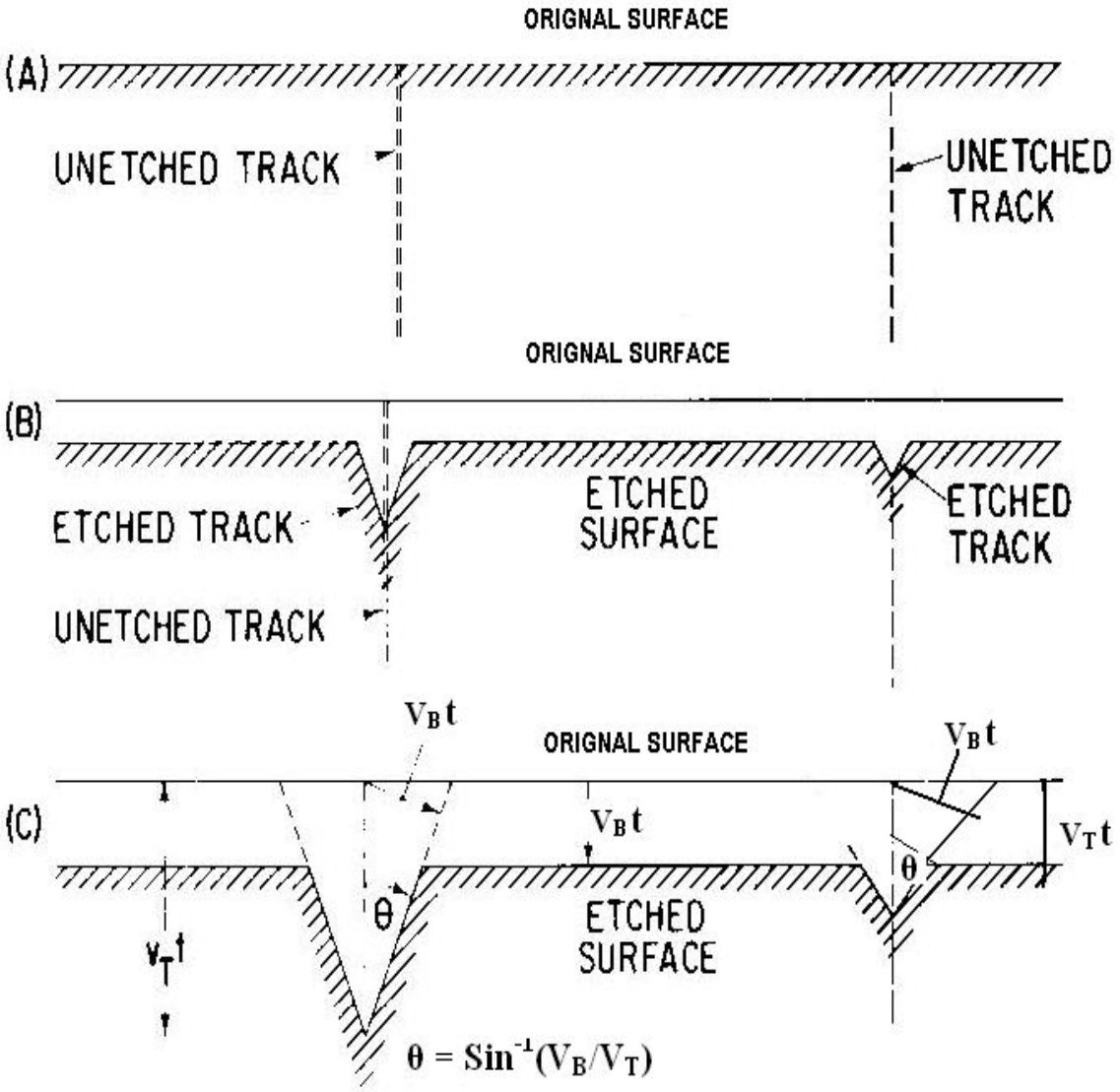

Figure 2.3: Track-etching geometry. Preferential etching along tracks at a rate V_T plus general etching at a bulk rate V_B produce conical holes with a cone angle that can be shown to be $\mathrm{Sin}^{-1}(V_B/V_T)$. The angle is larger and the pit is shallower for the less intense track on the right.

(A) Shows the unetched sample (B) and (C) shows the progressive effects of etching

2.4 CELLULOSE NITRATE TRACK DETECTOR (LR-115 Type II Detector)

Commercially available, LR-115 type-II films manufactured by DOSIRAD, France, are used in this study for detection and measurement of alpha radiation. LR-115 consists of an active layer or cellulose nitrate chemical composition $C_6H_8O_9N_2$ of thickness 11.5 to 12.0 μm which is coated on 100 μm clear polyester base (PET). LR-115 type II SSNTDs mainly detect alpha particles having energy range from 1.7 to 4.8 MeV (Jonsson, 1981; Abu-Jarad et al., 1980). Accordingly, the plate out of radon daughters on the surface of LR-115 will not be registered because their alpha energies (6.0 and 7.68 MeV from ^{218}Po and ^{214}Po, respectively) being more than its upper threshold value.

2.5 MEASUREMENT OF RADON AND THORON USING TWIN CHAMBER DOSIMETER CUPS

Twin cup radon dosimeter is used in present study for the measurement of indoor and outdoor radon concentrations. The alpha track detector, LR-115 type II pelliculable has been used. It is a 12 μm thick film red dyed cellulose nitrate emulsion coated on inert polyester base of 100 μm thickness and has maximum sensitivity for alpha particles, fission fragments and ionizing particles with high enough LET. It is widely used for particle detection and dosimetering weak concentrations of ionizing particles, use of high order resolution neutron radiographic, alpha radiography and cosmic ray investigations, etc. Detector can be used to record the tracks of protons with an energy <100 KeV and alpha particles with energy ~0.06 to 6 MeV. It is insensitive to high energy of electrons, protons and X or γ- rays. The sensitivity is claimed to be one of the best amongst any other plastic detectors. For fast neutrons, it has low detection efficiency (10^{-5} track/neutron) (Khan, 1975). The passage of ionizing radiation through insulating solids creates narrow trails of intense damage on atomic scale. These trails are called 'Tracks' which can be made visible under an ordinary optical microscope through treatment with a suitable chemical etchant that preferentially attacks the damaged material and removes the surrounding

undamaged portion at a slow speed. In this way, the etched tracks are enlarged that represents the sites of original damaged regions. The etching mechanism of track of LR-115 has been studied at varying temperatures range from 30^0C to 60^0C for different etching times and the calculated value of activation energy is 0.1845 eV (Paul and Bose, 1980). The recommended etch conditions given by the manufacturer are 2.5N NaOH, 60^oC, 65 to 95 minutes without agitation. Other suitable etch condition is 2.5N NaOH, 60^oC, 60 to 70 minutes with stirring (Costa-Riberio and Labao, 1975). The dosimeter (length of 4.1 cm and a radius of 3.1 cm) is used in the present study has been developed at Bhabha Atomic Research Centre (BARC), Mumbai. The detector of size 2.5 cm × 2.5 cm. is fitted in membrane compartment which measures radon only which diffuses through 25 μm thick membrane (Semi-permeable) having diffusion coefficient of the order of 10^{-8} to 10^{-7} cm^{-2} s^{-1} into it from ambient air (Eappen and Mayya, 2004). The chamber allows 90% buildup of radon gas in the compartment whereas concentration of thoron gas is suppressed by more than 99% in it. The mean time about 4.5 hours is required for the radon to reach the steady-state concentration inside the dosimeter. 0.56 mm thick glass fibre filter in the compartment F may allow both radon and thoron gases to diffuse in and hence the tracks formed on second detector film fixed in the chamber may provide the concentration of both radon and thoron. Third detector film piece exposed which is in bare mode registers alpha tracks due to radon and thoron gases and their alpha emitting progenies (^{218}Po, ^{216}Po, ^{214}Po and ^{212}Po). After the exposure of the detector for 100 days, the exposed films were etched in 2.5N NaOH solution at 60^0C for 70 min in a fix temperature water bath. Etching process reduces the bulk thickness of detector from 8.0 μm to 4.0 μm. Detectors were pre-sparked using the spark counter as shown in Figure 2.11 (Cross and Tommasino, 1970) at 900 V for the full development of the partially etched tracks. For the counting of the tracks the voltage corresponding to the plateau region of the counter (450 V) was applied. The concentrations were obtained from the observed track densities using appropriate calibration factors. It depends upon the

membrane and the filter characteristics as well as on the alpha particle energies for the cup mode exposure, the etching process parameters and the spark counting characteristics.

Figure 2.5: Twin chamber double dosimeter cup

2.6 MEASUREMENTS OF INDOOR RADON CONCENTRATION

2. 6.1 TRACKS ETCH TECHNIQUE

Track etch technique is one of the most widely used techniques for radon measurement (Fleischer et al., 1975; Franf and Benton, 1977; Alter and Fleischer, 1981; Durrani and Bull, 1987; Ramola et al., 1987; 1992; Klies et al., 1992; Bhagwat, 1993; Ramchandran, 1998; Virk, 1999; Mahur et al., 2006). Solid state nuclear track detector is used as a monitoring device. The principle of detection consists of the damage imparted in the detector material by alpha particles from radon and its decay products. With each alpha particle producing a distinguishable track, these latent tracks can be enlarged to microscopically visible size by the method of chemical etching in which the damaged region reacts at faster rate with a chemical reagent. Tracks per unit area in the detector are proportional to the average exposure rate and exposure time. Exposure time can range up to a year or more. Plastic track detectors which retain alpha tracks without fading for a very long time at ambient temperature. Though several detector materials have been developed but LR-115 and CR-39 are the two most popular track detectors used for radon dosimetry. The advantage of track etch technique is its simplicity, low cost and no electronics involvement in extensive radon surveys. A strong drawback in the use of solid-state nuclear track detectors is that they only integrate the received flux of particles and don't provide time dependent response. Other demerit of track etch technique is its poor sensitivity for integrated time periods of less than a month. In studies of indoor radon, monitoring time period of about three months is adequate.

In "Track Etch Technique" LR-115 type II detector was used for recordring the Potential Alpha Energy Concentration (PAEC) of alpha particle and their progeny in Working Level. These detectors are sensitive to alpha particles of energy range 0.1 to 4 MeV and are not affected by electrons, X-rays and gamma-rays (Jonsson, 1981). It is sensitive to a specific range of energy, unique for the use as radon dosimeter even in bare mode as it is free from plate out effect (Abu-Jarad et al, 1980). The detectors of size 3.0 × 3.0 cm

were fixed in twin chamber dosimeter cups and hanging the dosimeter cups on the wall for a period of three months for exposing the detectors. After 90 days, the latent tracks were produced due to radiation damage, by alpha particles from radon and its progeny. Tracks were revealed by chemical etching in 2.5N NaOH solution at 65^0C for 75 min in water bath. The counting of alpha tracks was done by spark counting system.

2.6.2 ALPHA METER TECHNIQUE

This technique employs a solid-state alpha particle detector counter assembly. The alpha particle detector is a silicon-diffused junction with an active area of 400 mm^2. When an alpha particle enters the n-p junction, a number of electron hole pairs are created which are proportional to the energy of alpha particle. The current flow is sensed and amplified by hundreds of times to produce a pulse that may be counted. The alpha counts are displayed on the light emitting diode (LED) display (Warren, 1977). The other instrumental method of measuring the radon flux includes the alpha cards with a central collector for recording Radon daughters (Card and Bell, 1979; Dyck et al; 1983). The detector records the alpha particles emanated by Radon isotopes and their alpha emitting daughters. Alpha particle having energy less than 1 MeV is not recorded by this instrument.

2.6.3 IONIZATION CHAMBER TECHNIQUE

This is designed to detect the presence of an ionizing particle (Wrenn et al., 1975) and is a gas filled electrode system. A pair of positive and negative ions are creates by the ionizing particle, when the gas passes through the chamber. These ions are attracted in the opposite direction under the influence of electric field. The ionization chamber is operated in the range of potential varying from 100 to 300 volts, so that the multiplication and recombination of the opposite pair is negligible. Ionization chamber techniques can be used for measuring radon concentration down to 10 Bq m^{-3} (Pacer and Czarnecki, 1980).

2.6.4 THERMO LUMINESCENCE DETECTOR TECHNIQUE

This is a technique in which light is emitted by a substance when it is heated and it can be attributed to the previous exposure to ionizing radiation. When a crystal is exposed to ionizing radiation, electron hole ionization pairs are created and some of them combine with the trapped charges. Thermo luminescence detectors used for Radon measurement are very thin wafers (760 m of calcium sulphate doped with dysprosium in a matrix of Teflon), which are mainly sensitive to alpha radiation (McCurdy et al., 1969; Pacer and Czarnecki, 1980). These detectors are generally exposed for 30 days in the uranium exploration program and then processed for their thermo luminescence peaks.

2.6.5 ABSORPTION TECHNIQUE

This is based on the absorption by gas of a suitable absorbing medium and then measurement of gamma activity of trapped daughters, ^{214}Pb and ^{214}Bi. Generally the activity charcoal is used as absorbing material. Normally a few grams of activated charcoal is placed in a can and is exposed to air for a few days. After the exposure, the can is sealed and gamma activity is studied using NaI detector. The trapped radon decays according to laws of radioactivity. After calibration, the radon concentration can be measured from the decay curves. The limitation of this technique is that, as radon has a half-life of only 3.8 days, the exposure period usefully cannot be longer than a week.

2.7 MEASUREMENT OF RADON EXHALATION RATE

2.7.1 CAN TECHNIQUE

Building materials are one of the main sources of radon activity inside dwellings. A large variation in radon activity is observed in dwellings as the uranium concentrations in natural materials used as building materials vary from place to place. Thus it is desirable to measure the radon exhalation from building materials used in different regions. “Can Technique” having the dimension of 7.5 cm height and 7.0 cm diameter (Fleischer and Morgo-campero., 1978, Mahur et al., 2008) was used for radon

exhalation rate measurements in cement, coal, fly ash, soil samples. The piece of LR-115 type II plastic track detector of size 3.0 cm × 3.0 cm. was fixed on the top inside the can. The Cans were sealed for three months. Thus the lower sensitive part of the detector is exposed freely to the emergent radon from the sample in the Can so that it could record the tracks of alpha particles resulting from the decay of radon in the remaining volume of the Can and from ^{218}Po deposited on the inner walls of the Can. Radon and its daughters reach equilibrium in about four hours and hence the equilibrium activity of emergent radon can be obtained from the geometry of the Can and the time of exposure. After the exposure the detectors were etched in 2.5N NaOH at 60^0C for a period of 70 minutes in constant temperature water bath for revelation of tracks. The resulting α- particle tracks were counted by spark counting system.

Surface exhalation rate and mass exhalation rate are calculated using the relation (Fleischer and Morgo-campero, 1978; Mahur et al., 2008; and Abu-Jarad et al., 1980):

$$E_X = \frac{CV\lambda}{A\left[T + \frac{1}{\lambda}\left\{e^{-\lambda T} - 1\right\}\right]}$$

$$E_M = \frac{CV\lambda}{M\left[T + \frac{1}{\lambda}\left\{e^{-\lambda T} - 1\right\}\right]}$$

Where,

E_x = radon surface exhalation rate in (Bq m^{-2} h^{-1})

E_M = radon mass exhalation rate in (Bq kg^{-1} h^{-1})

C = radon exposure as measured by LR -115 solid state nuclear track detector (Bq m^{-3} h)

V = the effective volume of can in (m^3)

Λ = the decay constant for radon in (h^{-1})

T = the exposure time in (h)

A = the area of the can in (m^2) and M is mass of the sample.

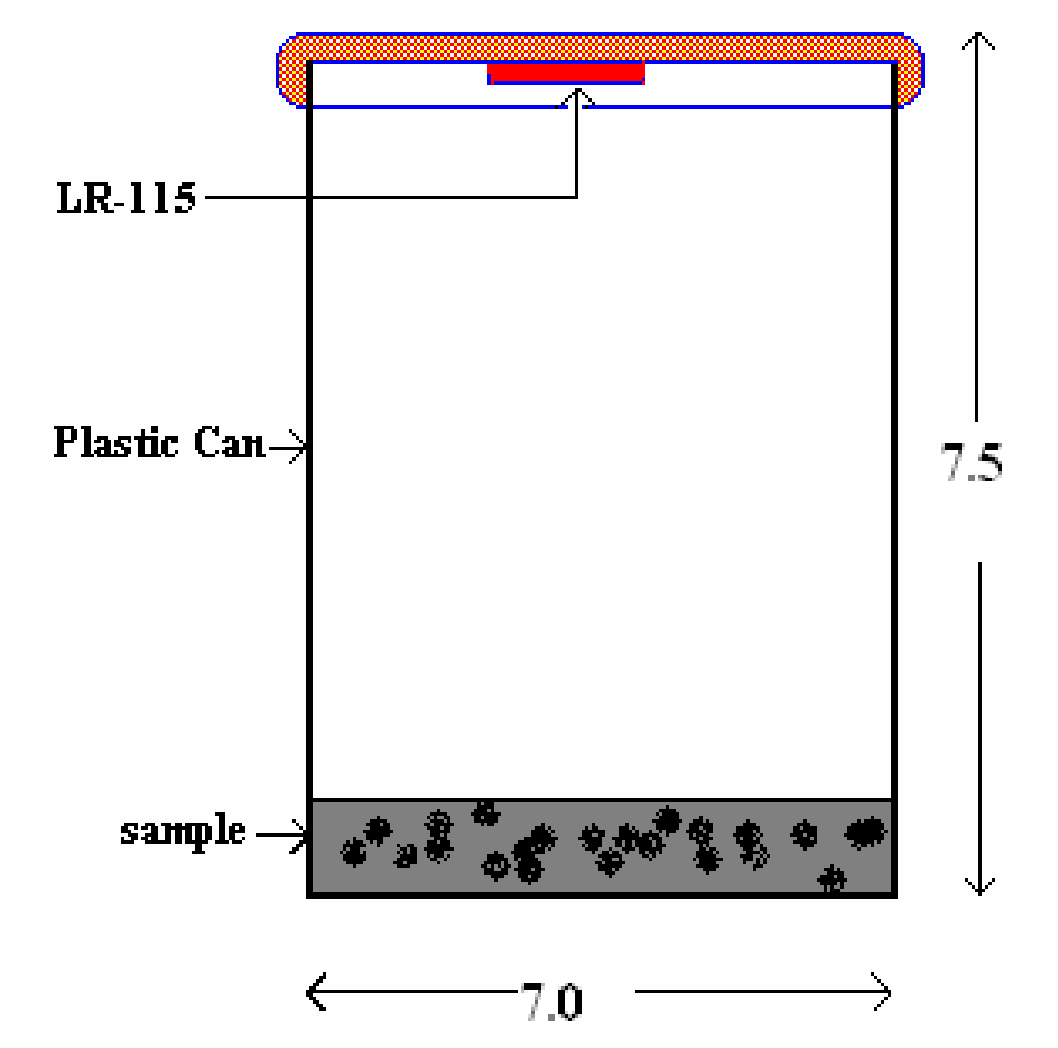

Figure 2.6: “Sealed Can Technique (7.5×7.0 cm)" for measurement of radon exhalation rate

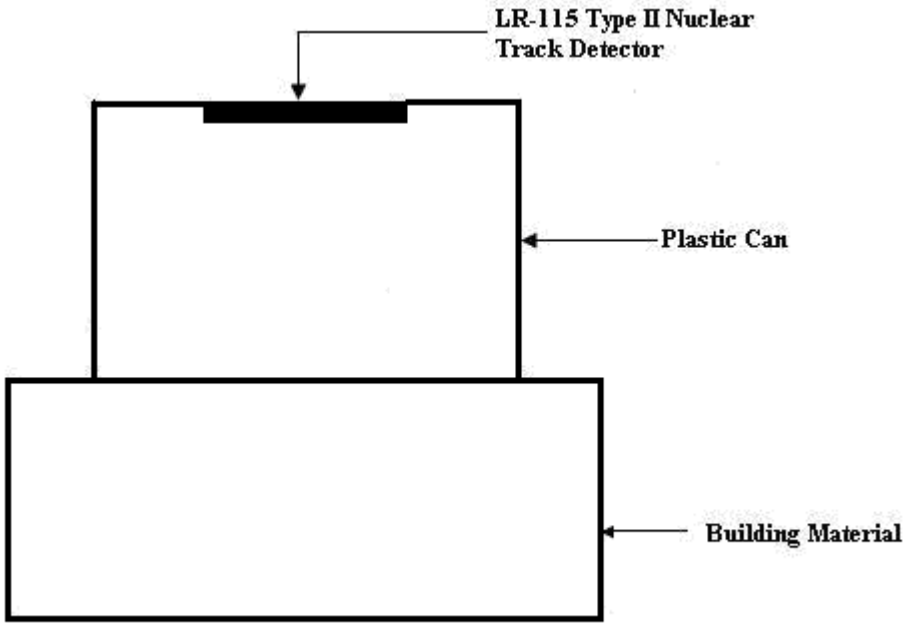

Figure 2.7: Assembly for the measurement of radon exhalation rate using “Can technique"

2.7.2 SMART RADON MONITOR (SRM) TECHNIQUE

The accumulation chamber based technique (Sahoo et.al 2007) was adopted to measure the radon exhalation rate. Radon mass exhalation measurements were performed using BARC developed Smart Radon Monitor (SRM). About 100 gram of sample was taken in the accumulation chamber for carrying out measurements. For Radon mass exhalation rate measurement, radon build up in the accumulation chamber is sampled into the scintillation cell (153 cc) of the Smart Radon Monitor through a "progeny filter" for eliminating radon progenies. The Photomultiplier tube and the related counting electronics continuously counts alpha particles emitted from the radon and its decay products in the cell for a user-programmable counting period. Obtained alpha particles are processed through a microprocessor unit and the corresponding algorithm displays the concentration of radon. The buildup radon concentration was measured at a time intervals of 1 hour till to achieve saturation of radon concentration in the samples.

The expression gives the radon concentration at time *t* inside the chamber (Sahoo et.al 2007):

$$C(t)= \frac{J_m M}{V\lambda_e}\left[1-e^{-\lambda_e t}\right]+C_0 e^{-\lambda_e t} \qquad (2.4)$$

Where,

C = Radon concentration per unit volume of air in Bqm^{-3}

J_m = Radon mass exhalation rate in $mBqkg^{-1}h^{-1}$

V = Effective volume in m^3 (Container volume + Detector volume (153 cc) – volume of sample)

M = Mass of the sample in Kg

C_0 = Radon concentration in Bqm^{-3} present in the chamber at $t = 0$.

λ_e = Effective decay constant for Radon (Sum of the leak rate (if existing) and the radioactive decay constant of Radon in h^{-1}).

Figure 2.8: Radon exhalation measurement set up (SRM)

2.8 CONSTANT TEMPERATURE WATER BATH

The most commonly used etching method for subsequent track counting by spark counting system and Optical microscopy for SSNTDs is chemical etching. Constant temperature water bath shown in figure 2.9 was used in present study. It provides an accurate and precise temperature control of the etching solution which results in the optimal track etching.

Figure 2.9: Etching bath

2.9 OPTICAL MICROSCOPE

Optical binocular optical research microscope (magnification of 400 ×) shown in figure 2.10 is used for the counting of alpha tracks of etched detectors It has motion along three mutually perpendicular directions.

Figure 2.10: Optical microscope (magnification of 400 ×)

2.10 SPARKCOUNTER

The spark counting system was invented by Tommasino. Generally, tracks etched in solid state nuclear track detectors are done by optical microscope. But spark counting method is time-consuming and rather expensive. Spark counting technique is a convenient cheap and fast method for counting of etched tracks and also applicable to plastic detectors. Thin etched track detector is placed between two electrodes forming a capacitor in spark counter system. The etched track detector is placed on the conductive electrode and covered with a one side aluminum coated foil. Spark takes place through the track hole pre-enlarged by chemical etching of plastic detector by applying high voltage across the capacitor C. The voltage pulse generated across the resistor R can easily counted by a scalar. The spark has enough energy to evaporate the thin layer of aluminum coating which passing through the tracks hole and generates a large hole in the aluminum electrode. For track counting operating applied voltage is usually around 500V. Pre-sparking has been carried out at 1000V before actual track counting.

Figure 2.11: Spark Counting System

2.11 MEASUREMENT OF NATURAL RADIOACTIVITY

2.11.1 GAMMA-RAY SPECTROSCOPY

Gamma spectroscopy involves the spectroscopy of gamma ray emission from radionuclides. Among the various techniques for the measurement of natural radioactivity gamma-ray spectroscopy, is the best technique as far as analysis of radionuclides present in the substance. Most of the radioactive sources produce gamma rays of different energies and intensities. When these emissions are collected and analyzed with a gamma spectroscopy system, spectrum of gamma energy can be produced. Gamma spectroscopy measures the energy and count rate of gamma rays emitted by radioactive substances. The detector is used to convert gamma ray energy into electric signal. Weak signal produced by the detector is amplified by the amplifier. The amplitude of electric pulse is proportional to the corresponding gamma ray energy. For measuring the distribution of input signals consisting of pulses Multi Channel Analyzer is used. The amplitude of an incoming analog pulse is digitized by the analog to digital converter. The spectrum of number of counts v/s channel number displays on computer screen, which is used to find out the energies and intensities of particular gamma rays.

In this study the measurement of. ^{226}Ra, ^{232}Th, ^{40}K in soil, fly ash coal and cement samples is used gamma-ray spectroscopy technique using NaI (TI) detector

2.11.2 GAMMA RAY SPECTROSCOPY TECHNIQUE USING NaI (TI) DETECTOR

A low level gamma spectrometric set up at H N B University Garhwal, Uttrakhand state, India was used for measurement of the natural radionuclides, radium (^{226}Ra), thorium (^{232}Th) and potassium (^{40}K) in soil, fly ash and coal samples. Each sample of 250 grams was prepared and packed in plastic containers. There were sealed for four weeks (Shanbhag et.al, 2005) to attain for secular equilibrium between ^{226}Ra, ^{232}Th and decay products and to prevent ^{222}Rn and ^{220}Rn losses. The samples were placed one by one in a shielded gamma ray spectrometer for 3 hours (Ramola et.al, 2008). The

concentration of natural radionuclides radium (^{226}Ra), thorium (^{232}Th) and potassium (^{40}K) in fly ash samples were measured using a NaI (TI) gamma radiation detector of dimensions 63 mm × 63 mm with a multichannel analyzer. Different activities are evaluated i.e. potassium (^{40}K) was evaluated from the 1460 KeV photo peak, ^{226}Ra from the 1764 KeV Gamma lines of ^{214} Bi, and that of ^{232}Th from the 2610 KeV gamma lines of ^{208}TI. This spectral analysis was carried out using software SPTR-ATC (AT-1315). The peak energy of gamma spectra was measured in reference to the 661 KeV photo peak of ^{137}Cs. Thereafter, activity concentration of soil, fly ash, coal and cement samples were calculated from the intensity of each line in the spectrum, considering the mass, the counting time, the geometry of samples and efficiency of the detector.

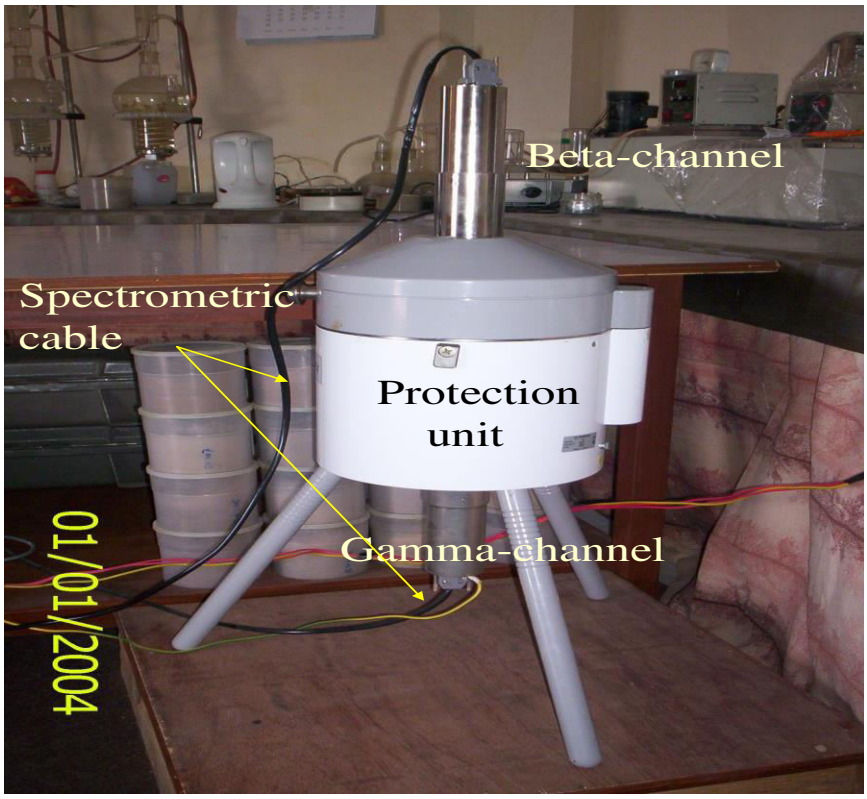

Figure 2.12 Gamma spectrometric set up at H N B University Garhwal

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CHAPTER-3

MEASUREMENT OF INDOOR RADON, THORON AND THEIR PROGENIES IN INDIAN DWELLINGS AND ENVIRONMENT

3.1 GENERAL

Radon is the progeny of uranium decay series formed from heavier radioactive decay of radium in the environment is present in trace amounts almost everywhere on the earth, being distributed in the soil and ground water and in the lower atmosphere. Radon is the heaviest known gas, nine times heaver than air. It is the only gas in the long decay chain of the heavy metal elements. The major contribution of dose from natural radiation in normal background region arise due to inhalation of radon and its progeny, and to a certain extent, due to thoron and its progeny (prostendorfer, 1994; UNSCEAR, 2000).

It is observed that high level of radon inhaled causes lung cancer. The occurrence of lung cancer and the respiratory functional changes have been found due to continuous exposure of population to high radon concentration and its daughters (BEIR, 1999). Radon monitoring has become a global phenomenon due to its health hazard effect on population (Radiation workers and general public). Radon is the leading source of natural radiation exposure and the second leading cause of lung cancer. It exists in various geological formations in soil, rocks, water and air. Primordial sources i.e. terrestrial radionuclides (^{238}U, ^{232}Th and ^{40}K) and cosmogenic radiation (formed as a result of cosmic ray interactions) are the main natural radioactive sources in the universe which are the cause of radiation doses. Natural radiation is of particular importance because this is the largest contributors to the collective dose of world population (NCRP, 1987). Worldwide average annual effective dose from cosmic ray is 0.38 mSv (UNSCEAR, 1993; 2000). In general the range of individual annual effective dose from cosmic ray is 0.26 to 2.0 mSv.

Artificial sources of radiation include radioactive minerals in crushed rock, phosphate fertilizers and building materials, radiation-emitting components of television sets, smoke detectors, and various other consumer products; radioactive fallout from nuclear weapons and radiation released in nuclear power

production. The radiation exposure to workers can either be external or internal and is mainly due to beta and gamma rays. External exposure is caused due to radioactive sources external to the body where as internal exposure is due to radioactive materials entering the human body through inhalation, food, ingestion and injection. The world wide average dose received by a person is 2.2 mSv y^{-1}. The international standards allow upto 20.0 mSv y^{-1} for those who work with and around radioactive materials. Average exposures for radiation workers in different field are in range of 2.0 to 8.0 mSv y^{-1} (NCRP, 1987).

3.2 MEASUREMENT OF INDOOR RADON, THORON AND THEIR PROGENY IN INDIAN DWELLINGS USING DOUBLE DOSIMETER CUPs FITTED SSNTDs

Concentration of radon/thoron and their progeny in the dwellings were measured using double dosimeter cups fitted with Solid State Nuclear Track Detector (SSNTD) of 12 μm thick. Cellulose nitrate based LR-115 type-II pelicullable SSNTDs film was manufactured by Kodak Pathe, France. Double dosimeter cup has been developed at Bhabha Atomic Research Centre (BARC), Mumbai.

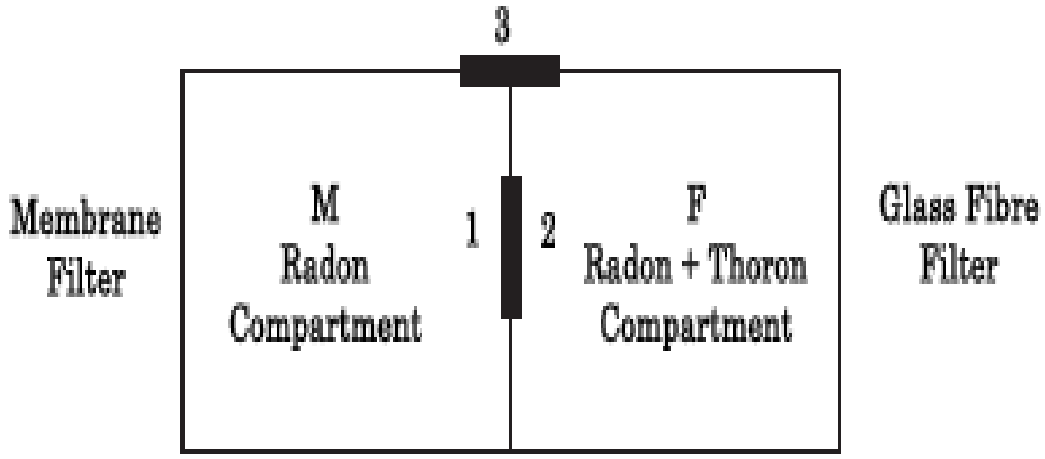

Figure 3.1 Radon-Thoron twin chamber dosimeter cup system

The height of each cylindrical chamber has 4.1 cm and radius 3.1 cm. The size of detector film (SSNTDs) is 3.0 cm× 3.0 cm each placed in membrane, filter compartment and bare. The membrane compartment (M) which diffuses through 25 μm thick membrane (Semi-permeable) having diffusion coefficient of the order of 10^{-8} to 10^{-7} cm^{-2} s^{-1} into it from ambient air (Eappen and Mayya, 2004) allows 90% buildup of radon gas in the compartment whereas concentration of thoron gas is suppressed by more than 99% in it. The mean time about 4.5 hours is required for the radon to reach the steady-state concentration inside the dosimeter. 0.56 mm thick glass fibre filter in the compartment F may allow both radon and thoron gases to diffuse in and hence the tracks formed on second detector film fixed in the chamber may provide the concentration of both radon and thoron. Third detector film piece exposed which is in bare mode registers alpha tracks due to radon and thoron gases and their alpha emitting progenies (^{218}Po, ^{216}Po, ^{214}Po and ^{212}Po). In LR-115 type-II SSNTDs, tracks do not produce originating from the alpha progeny, deposited on them (Mayya et al., 1998; Nikolaev and Ilic, 1999; Durrani, 1997) and therefore is perfectly suited for measurement of radioactive gas concentration. Double dosimeter cups fitted with LR-115 type-II films of size 3.0 cm × 3.0 cm each were fixed in different dwellings for 100 days. After the exposure of the detector for 100 days, the exposed films were etched in 2.5N NaOH solution at 60^0C for 70 min in a water bath. Etching process reduces the bulk thickness of detector from 8.0 μm to 4.0 μm. Detectors were pre-sparked using the spark counter as shown in Figure 2.11 (Cross and Tommasino, 1970) at 900 V for the full development of the partially etched tracks. For the counting of the tracks the voltage corresponding to the plateau region of the counter (450 V) was applied.

In the present research work an efforts has been made for the measurement of indoor radon/thoron levels in the some dwellings of India by using SSNTDs twin chamber dosimeter cups.

Functional coal based big thermal power plants are situated in Delhi and Kasimpur near Aligarh. Higher levels of uranium were found after burning of coal (Jojo et al., 1993) the ambient radiation level has been enhance due to the subsequent emission to the environment. Estimations were carried out in the some dwellings around the thermal power plants.

Concentration of radon and thoron are calculated by putting the appropriate sensitivity factors discover from the controlled experiments (Mayya et al., 1998; Sannapa et al., 2003; Sonkawade et al., 2005).

$$C_R = \frac{T_m}{d \times S_m} \quad \text{---------- (3.1)}$$

$$C_T = \frac{(T_f - d \times C_R \times S_{rf})}{d \times S_{tf}} \quad \text{---------- (3.2)}$$

Where,

C_R is radon concentration in Bq m^{-3}

C_T is thoron concentration in Bq m^{-3}

T_m is the track density in membrane compartment

T_f is the track density in filter compartment and d is Exposure time

Sensitivity factor for membrane chamber (S_m) is 0.019±0.003 Trc m^{-2} d^{-1}/Bq m^{-3}

Sensitivity factor for Radon in filter chamber (S_{rf}) is 0.020±0.004 Trc m^{-2} d^{-1}/Bq m^{-3}

Sensitivity factor for Thoron in filter chamber (S_{tf}) is 0.016±0.005 Trc m^{-2} d^{-1}/Bq m^{-3}

The inhalation dose was calculated using the expression:

$$D = \{ 0.17 + 9F_R) C_R + (0.11 + 32F_T) C_T\} \times 7000 \times 10^{-6} \quad \text{---------- (3.3)}$$

Where,

D = Inhalation dose

F_R = Equilibrium factor for radon and F_T is equilibrium factor for thoron.

The values were taken 0.4 for F_R and 0.1 for F_T (UNSCEAR, 2000).

Radon/thoron and their progenies concentration were described the potential Alpha Energy Concentration (mWL). Radon/thoron gas and their progenies concentrations is related to the track density by bare mode. The Potential Alpha Energy Concentration (mWL) was also calculated by using the values of radon/thoron and their progenies concentration. Estimated values of radon/thoron concentrations are converted into equilibrium equivalent concentration which was again converted into Potential Alpha Energy Concentration (PAEC) by using the following expression.

$$C_R or C_T = \frac{PAEC\,(WL) \times 3700}{F} \qquad \text{---------- (3.4)}$$

Where,

F is equilibrium factor; C_R and $_{CT}$ are the concentration of radon/thoron

3.9 mSv per WLM is the radon progenies dose conversion factor where as 3.4 mSv per WLM is effective dose equivalent for thoron (ICRP, 1993).

3.3 RESULT AND DISCUSSION:

3.3.1 STUDY OF INDOOR RADON/THORON AND INHALATION DOSE IN SOME DWELLINGS OF DWARKA, SECTOR-16C, DELHI

Measured values of radon/thoron and inhalation dose in the dwellings of Dwarka Sector-16 Delhi State of India is presented in Table-3.1.The values of radon concentration vary from 4.4 to 29.8 Bq m^{-3} with an average value of 14.4 Bq m^{-3} whereas, thoron concentration ranged from 2.7 to 13.6 Bq m^{-3} with an average value of 7.0 Bq m^{-3}. Inhalation dose vary from 0.18 to 0.95 mSv y^{-1} with a mean value of 0.54 mSv y^{-1}.

3.3.2 STUDY OF INDOOR RADON/THORON AND INHALATION DOSE IN SOME DWELLINGS OF DWARKA, SECTOR-18, DELHI

The measured radon/thoron and inhalation dose in the dwellings of Dwarka Sector-18 Delhi State of India is presented in Table-3.2, indicate that the concentration of radon ranged from 4.3 to 23.9 Bq m^{-3} with an average value of 12.4 Bq m^{-3} whereas concentration of thoron ranged from 3.8 to 22.4 Bq m^{-3} with an average value of 12.3 Bq m^{-3}. Inhalation dose is found to vary from 0.21 to 1.03 mSv y^{-1} with an average value of 0.61 mSv y^{-1}.

3.3.3 STUDY OF INDOOR RADON/THORON AND INHALATION DOSE IN SOME DWELLINGS OF ALIGARH, UTTAR PRADESH

Solid State Nuclear Track Detectors based twin chamber dosimeter cups were used for measuring Radon (^{222}Rn) and Thoron (^{220}Rn) gases concentration in the dwellings of Aligarh, Utter Pradesh state near Kasimpur power plant. The values measured for Radon and Thoron concentration and inhalation dose are given in Table-3.3. It can be seen that the concentration of radon ranged from 5.7 to 19.2 Bqm^{-3} with an average value of 12.9 Bqm^{-3} whereas concentration of thoron ranged from 3.7 to 17.6

Bqm^{-3} with a mean value of 9.4 Bqm^{-3}. Inhalation dose is found is found to vary from 0.28 to 0.88 $mSvy^{-1}$ with a mean value of 0.56 mSv y^{-1}.

3.3.4 MEASUREMENT OF INDOOR RADON/THORON AND INHALATION DOSE IN SOME DWELLINGS OF JAIPUR CITY, RAJASTHAN

Concentration of Radon (^{222}Rn), Thoron (^{220}Rn) and inhalation dose using Solid State Nuclear Track Detectors based doulbe dosimeter cups in the dwellings of Jaipur city, Rajasthan state are given in Table-3.4. The concentrations of radon vary from 4.6 to 27.4 Bq m^{-3} with a mean value of 13.0 Bq m^{-3} whereas concentration of thoron ranged from 3.8 to 22.9 Bq m^{-3} with an average value of 10.7 Bq m^{-3}. An inhalation doses are found is found to vary from 0.21 to 0.97 mSv y^{-1} with a mean value of 0.59 mSv y^{-1}.

Table-3.1

Radon and Thoron concentration and inhalation dose in dwellings of Dwarka, Sector-16 Delhi, India

Locations	T_m (Tr cm^{-2})	T_f (Tr cm^{-2})	C_R (Bq m^{-3})	C_T (Bq m^{-3})	D Inhalation dose (mSv y^{-1})
Flat-1	38.0	46.0	22.2	4.1	0.68
Flat-2	36.5	52.0	21.3	9.4	0.78
Flat-3	24.0	40.6	14.0	10.6	0.61
Flat-4	18.0	32.0	10.5	9.0	0.48
Flat-5	26.0	38.0	15.2	7.3	0.57
Flat-6	29.0	42.0	16.9	7.9	0.63
Flat-7	12.6	18.6	7.3	3.7	0.28
Flat-8	40.0	56.0	23.3	9.6	0.84
Flat-9	20.0	32.0	11.6	7.6	0.48
Flat-10	29.0	44.5	16.9	9.7	0.67
Flat-11	14.0	32.0	8.1	11.9	0.49
Flat-12	9.6	22.0	5.6	8.2	0.33
Flat-13	22.0	28.5	12.8	3.7	0.42
Flat-14	28.6	42.0	16.7	8.2	0.63
Flat-15	8.6	14.0	5.0	3.4	0.21
Flat-16	7.6	12.0	4.4	2.7	0.18
Flat-17	17.0	24.0	9.9	4.2	0.36
Flat-18	21.0	29.0	12.2	4.7	0.4
Flat-19	37.0	52.0	21.6	9.0	0.78
Flat-20	28.0	36.5	16.3	4.8	0.54
Flat-21	26.0	47.0	15.2	13.6	0.71
Flat-22	49.0	56.6	28.6	3.4	0.83
Flat-23	51.0	64.0	29.8	7.1	0.95
Flat-24	8.0	14.0	4.6	3.8	0.21
Flat-25	19.0	26.5	11.1	4.5	0.39
Flat-26	27.0	43.0	15.7	10.1	0.65
Flat-27	12.6	22.0	7.3	6.0	0.33
Flat-28	48.0	63.0	28.0	8.6	0.94
Flat-29	9.0	15.0	5.2	3.8	0.22
Flat-30	21.0	34.0	12.2	8.2	0.51
Flat-31	14.0	21.0	8.1	4.3	0.31
Flat-32	37.0	53.0	21.6	9.7	0.79
Average Value Maximum Minimum	24.6 51.0 7.6.0	36.0 64.0 12.0	14.4 29.8 4.4	7.0 13.6 2.7	0.54 0.95 0.18

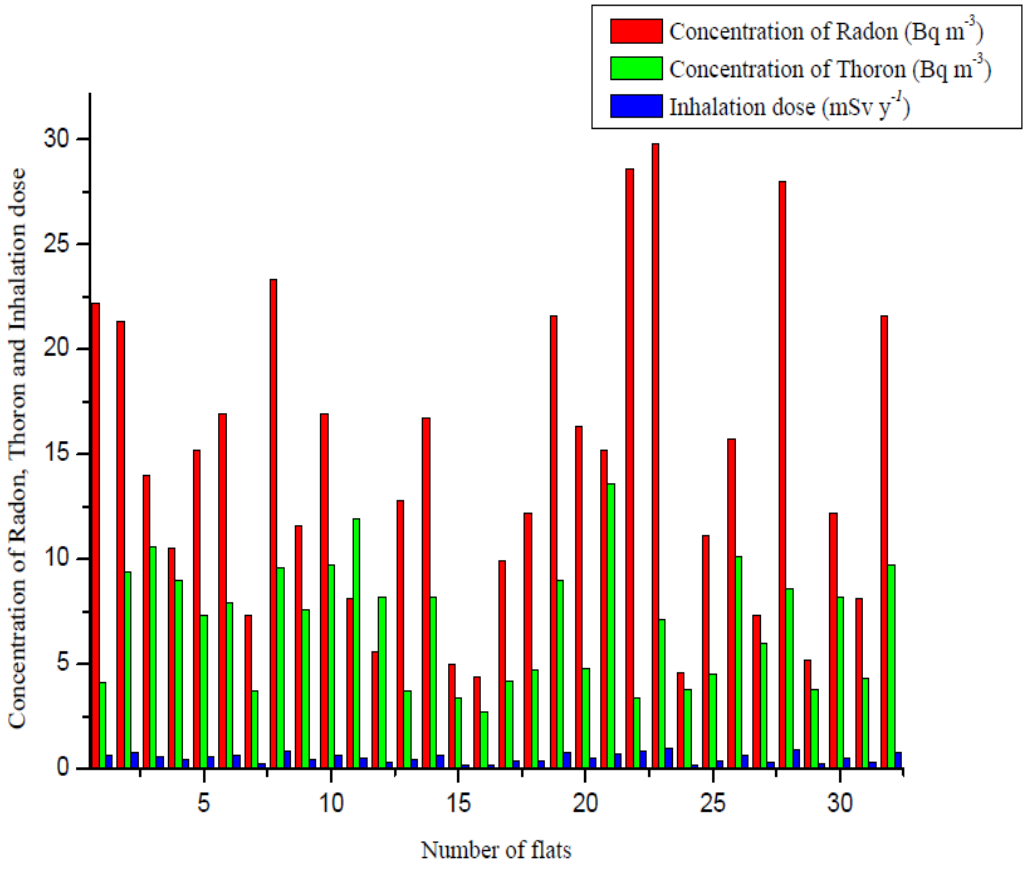

Figure 3.2 Bar diagram showing concentration of radon/thoron and inhalation dose in dwellings of Dwarka, Sector-16 Delhi

Table-3.2

Radon and Thoron concentration and inhalation dose in dwellings of Dwarka, Sector-18, Delhi, India

Locations	T_m (Tr cm^{-2})	T_f (Tr cm^{-2})	C_R (Bq m^{-3})	C_T (Bq m^{-3})	D Inhalation dose (mSv y^{-1})
Flat-1	40.5	56.0	23.6	9.2	0.84
Flat-2	22.5	37.0	13.1	9.2	0.56
Flat-3	41.0	59.0	23.9	11.0	0.88
Flat-4	23.0	39.0	13.4	10.2	0.59
Flat-5	17.5	38.0	10.2	13.5	0.58
Flat-6	13.0	32.0	7.6	12.7	0.49
Flat-7	8.0	14.0	4.6	3.8	0.21
Flat-8	19.0	41.0	11.1	14.5	0.63
Flat-9	18.5	36.0	10.8	11.4	0.55
Flat-10	21.0	47.0	12.2	17.2	0.72
Flat-11	18.0	35.0	10.5	11.1	0.53
Flat-12	14.0	29.0	8.1	9.9	0.44
Flat-13	20.5	43.0	11.9	14.8	0.66
Flat-14	8.5	17.0	4.9	5.5	0.26
Flat-15	39.0	68.0	22.8	18.7	1.03
Flat-16	11.0	23.0	6.4	7.9	0.35
Flat-17	19.0	39.5	11.1	13.5	0.60
Flat-18	27.5	56.5	16.0	19.1	0.86
Flat-19	31.0	65.0	18.1	22.4	0.99
Flat-20	26.5	49.5	15.4	15.0	0.75
Flat-21	16.0	35.0	9.3	12.6	0.53
Flat-22	7.5	18.0	4.3	7.0	0.27
Flat-23	22.0	38.0	12.8	10.3	0.57
Flat-24	9.0	21.0	5.2	8.0	0.32
Flat-25	12.5	27.0	7.3	9.6	0.41
Flat-26	9.5	22.0	5.5	8.3	0.33
Flat-27	16.5	34.0	9.6	11.5	0.52
Flat-28	33.5	59.0	19.5	16.4	0.89
Flat-29	36.0	61.0	21.0	16.0	0.92
Flat-30	38.0	67.5	22.2	19.0	1.02
Average Value	21.3	40.2	12.4	12.3	0.61
Maximum	41.0	68.0	23.9	22.4	1.03
Minimum	7.5	14.0	4.3	3.8	0.21

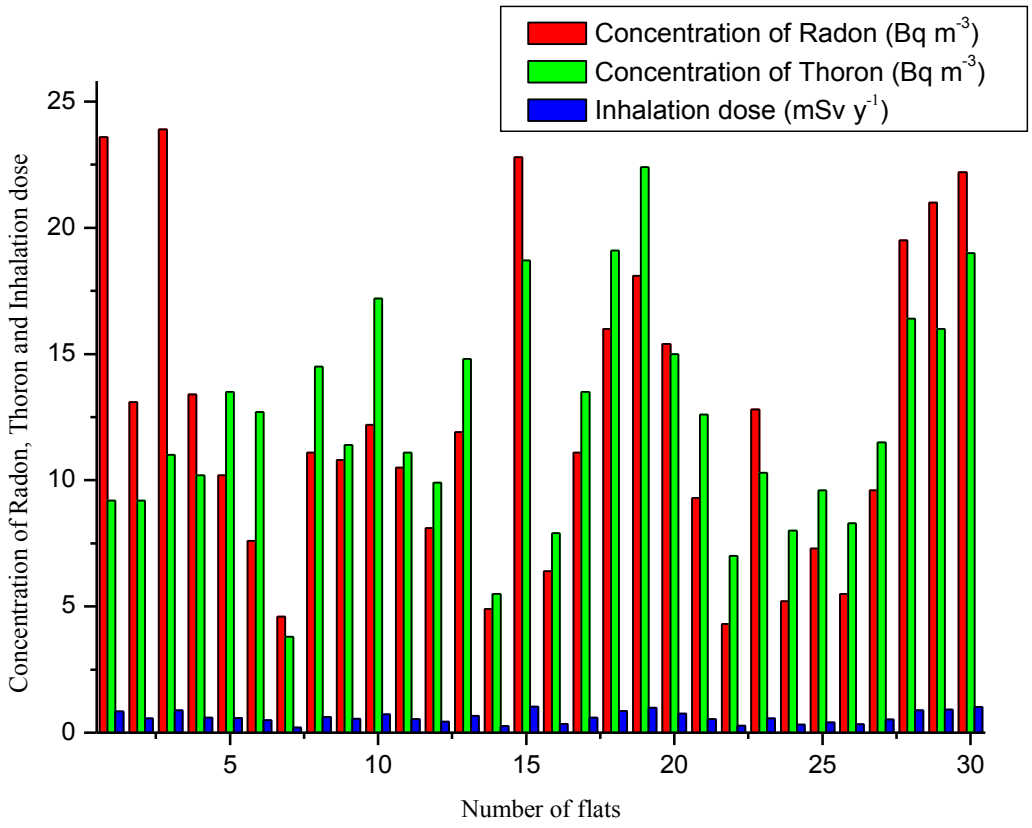

Figure 3.3 Bar diagram showing concentration of radon/thoron and inhalation dose in dwellings of Dwarka, Sector-18 Delhi

Table-3.3

Radon and Thoron concentration and inhalation dose in dwellings of Aligarh city of Uttar Pradesh state of India

Locations	T_m (Tr cm^{-2})	T_f (Tr cm^{-2})	C_R (Bq m^{-3})	C_T (Bq m^{-3})	D Inhalation dose (mSv y^{-1})
L-1	27.0	42.0	15.7	9.4	0.63
L-2	22.5	39.0	13.1	10.6	0.59
L-3	24.0	38.0	14.0	8.8	0.57
L-4	16.0	28.0	9.3	7.7	0.42
L-5	21.5	32.0	12.5	6.5	0.48
L-6	26.0	36.0	15.2	5.9	0.54
L-7	12.6	18.6	7.3	3.7	0.28
L-8	31.0	47.0	18.1	9.9	0.70
L-9	18.6	32.0	10.8	8.6	0.48
L-10	25.0	44.5	14.6	12.6	0.67
L-11	10.2	22.0	5.9	7.8	0.33
L-12	16.0	29.0	9.3	8.4	0.44
L-13	17.0	28.5	9.9	7.3	0.43
L-14	28.6	42.0	16.7	8.2	0.63
L-15	31.0	58.0	18.1	17.6	0.88
L-16	9.8	21.0	5.7	7.4	0.32
L-17	22.0	38.5	12.8	10.6	0.58
L-18	28.0	49.0	16.3	13.5	0.74
L-19	33.0	56.0	19.2	14.7	0.85
Average Value	22.0	36.9	12.9	9.4	0.56
Maximum	33.0	58.0	19.2	17.6	0.88
Minimum	9.8	18.6	5.7	3.7	0.28

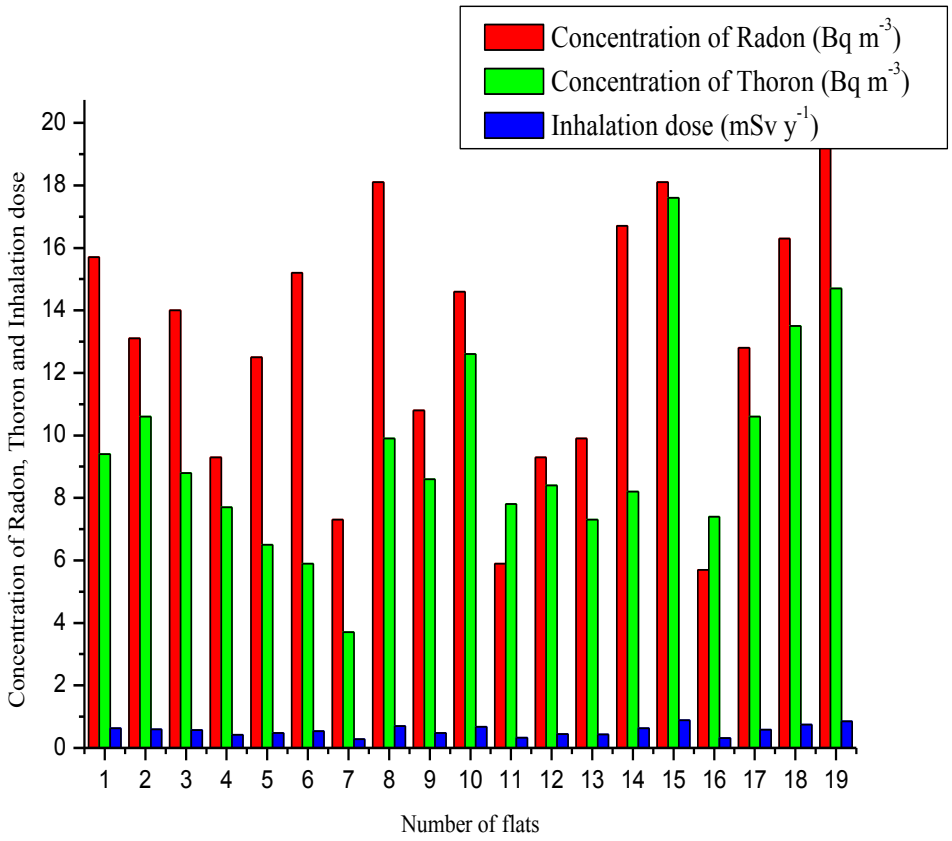

Figure 3.4 Bar diagram showing concentration of radon/thoron and inhalation dose in dwellings of Aligarh, Uttar Pradesh

Table-3.4

Radon and Thoron concentration and inhalation dose in dwellings of Jaipur city of Rajasthan state of India

Locations	T_m (Tr cm^{-2})	T_f (Tr cm^{-2})	C_R (Bq m^{-3})	C_T (Bq m^{-3})	D Inhalation dose (mSv y^{-1})
L-1	19.4	36.5	11.3	11.1	0.55
L-2	20.0	47.0	11.6	18.0	0.72
L-3	41.0	56.6	23.9	9.3	0.84
L-4	47.0	64.0	27.4	10.0	0.95
L-5	8.0	14.0	4.6	3.8	0.21
L-6	15.0	34.0	8.7	12.6	0.52
L-7	27.0	43.0	15.7	10.1	0.65
L-8	10.24	22.0	5.9	7.7	0.33
L-9	28.4	63.0	16.6	22.9	0.97
L-10	19.0	29.5	11.1	6.5	0.44
L-11	22.0	37.0	12.8	9.6	0.56
L-12	10.8	21.0	6.3	6.6	0.32
L-13	26.0	44.0	15.2	11.5	0.66
L-14	23.4	39.0	13.6	9.9	0.59
L-15	18.0	33.5	10.5	10.1	0.51
Average Value	22.3	38.9	13.0	10.7	0.59
Maximum	47.0	64.0	27.4	22.9	0.97
Minimum	8.0	14.0	4.6	3.8	0.21

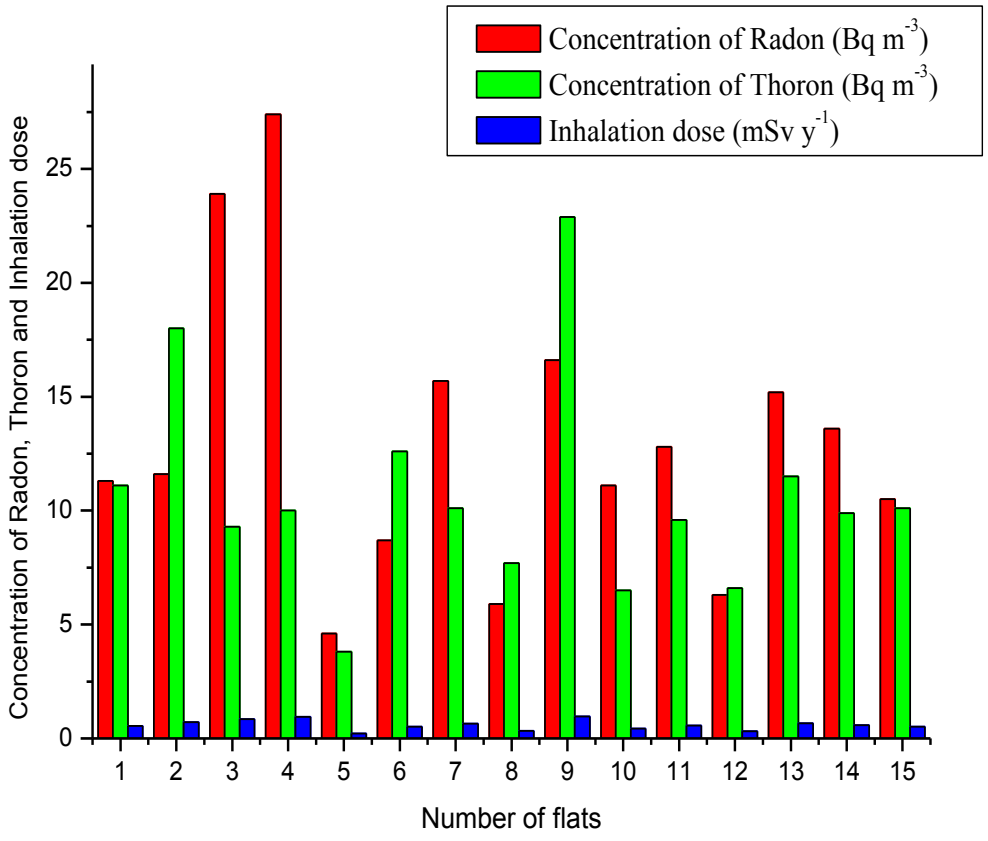

Figure 3.5 Bar diagram showing concentration of radon/thoron and inhalation dose in dwellings of Jaipur, Rajasthan

3.4 MEASUREMENT OF RADON AND ITS PROGENY IN INDIAN DWELLINGS

Many surveys of radon studies have been carried out; an international study which examined the data on 68,000 underground miners who were exposed to high level of Radon was led by the National Cancer Institute, USA which is the largest study. It concludes that the deaths due to lung cancer are more than five times than expected for the general population. A large number of surveys have been done in Europe and North America. (Samet et al., 1989; McGregor et al., 1980; Swedjemark et al., 1984; Nero et al., 1986; Cohen et al., 1995) it is found that some countries have high Radon concentration in many of their houses and offices.

3.5 MATERIALS AND METHODS

LR-115 type-II, Solid State Nuclear Track Detectors, was used for measuring the Potential Alpha Energy Concentration (PAEC) of radon daughters in Working Level. The detector film of size 2.5 cm × 2.5 cm were exposed in bare mode for 100 days fitted in double dosimeter cups which were hanging in dwellings. After the exposure the films were etched in 2.5N NaOH solution at 60^0C for 70 minutes in water bath. Alpha tracks were counting by using a spark counting system or binocular optical research microscope with a magnification of 400×.

Track density countered in bare mode detector will be a function of 'radon daughters' concentration in air. The radon concentration (Bqm^{-3}) is calculated from Working Level by the following expression (Kumar et al., 2003; Mahur, et al., 2006; Kumar and Prasad, 2005).

$$C_{Rn}\left(Bqm^{-3}\right) = \frac{WL \times 3700}{F} \tag{3.5}$$

Where,

F is equilibrium factor which vary in the range of 0.38 to 0.7 with the mean value of 0.45 for Indian dwellings. The value 0.4 is suggested by UNSCEAR, 2000 for finding the radon concentration.

It is essential to calculate Potential Alpha Energy Concentration (mWL) of radon daughters that the detector films should be calibrated with a slandered radon concentration under the same conditions which prevail in Indian dwellings. The detectors LR-115 type II was calibrated in radon exposure chamber in Environmental Assessment Division of Bhabha Atomic Research Centre at Mumbai. The mean calibration factor for LR-115 type II detector was found to be 442 tracks cm^{-2} d^{-1}per WL (Jojo et al., 1994; Singh et al., 1997).

3.6 ACTION LEVEL LIMITS

The action level is defined as the radon concentration at which measurement is required to be undertaken to reduce radon exposures. As per the IAEA report, 2003; average concentration of action level for radon at workplace occupancy of 2000 hours and corresponding effective dose is about 6.0 mSv as yearly is 1000 Bq m^{-3}. It is the midpoint of concentration range 500-1500 Bq m^{-3} recommended by International Commission on Radiological Protection, and some regulatory bodies take 500 Bq m^{-3}. The values given by ICRP were based on considered equilibrium factor between radon concentration and its progeny of 0.4. For adopting single value of action level which may be applied as an equilibrium factor in all situation, is a practical advantage. In IAEA report, 2003 stated if the equilibrium factor is different from 0.4 other action levels may be appropriate. For example if the equilibrium factor is 0.8 corresponding action level might be 500 Bq m^{-3}.

3.7 RESULT AND DISCUSSION

3.7.1 RADON LEVELS AND ANNUAL EFFECTIVE DOSE IN SOME DWELLINGS OF DWARKA DELHI, ALIGARH, UTTAR PRADESH, JAIPUR, RAJASTHAN

The measured values of Potential alpha activity, Radon activity along with annual effective dose are given in Table 3.5 to 3.8. The value of potential alpha activity in the studied region of Dwarka sec-16 & sec-18 vary from 7.2 to 40.7 mWL and 9.7 to 39.8 mWL with a mean value of 21.5 and 22.4 mWL respectivily. Values of radon activity concentration were found to vary from 59.5 to 334.8 Bq m^{-3} with an average value of 176.7 Bq m^{-3} and 79.9 to 327.4 Bq m^{-3} with an average values of 184.9 Bq m^{-3} respectively whereas the annual effective dose due to exposure to Radon and progeny in the flats of study were found to vary from 2.2 to 12.5 mSv with an average value of 6.7 mSv and 3.0 to 12.4 mSv with a mean value of 7.0 mSv. Potential alpha activity in the dwellings of Aligarh varies from 6.3 to 27.1 mWL with an average value of 15.7 mWL. Radon activity concentration ranged from 52.0 to 223.2 Bqm^{-3} with a mean value of 129.2 Bqm^{-3} whereas the annual effective dose vary from 1.9 to 8.5 mSv with an average value of 4.9 mSv.

Calculated value of potential alpha activity in the dwellings of Jaipur were found to vary from 6.3 to 20.5 mWL with a mean value of 13.3 mWL. Radon activity concentration varies from 52.0 to 169.2 Bq m^{-3} with a mean value of 109.3 Bq m^{-3} whereas the annual effective dose ranged from 1.9 to 6.4 mSv with an average value of 4.1 mSv.

Table 3.5

Indoor Radon levels in dwellings of Dwarka, Sector-16, Delhi state of India

Locations	Potential alpha activity (mWL)	Radon activity (Bq m^{-3})	Annual effective dose (mSv)
Flat-1	19.2	158.1	6.0
Flat-2	15.1	124.6	4.7
Flat-3	9.7	79.9	3.0
Flat-4	17.1	141.3	5.3
Flat-5	23.5	193.4	7.3
Flat-6	12.6	104.1	3.9
Flat-7	32.1	264.1	10.0
Flat-8	16.2	133.9	5.1
Flat-9	28.9	238.1	9.0
Flat-10	21.0	173.0	6.5
Flat-11	30.5	251.1	9.5
Flat-12	22.8	187.8	7.1
Flat-13	36.8	303.2	11.1
Flat-14	7.23	59.5	2.2
Flat-15	12.2	100.4	3.8
Flat-16	16.0	132.0	5.0
Flat-17	15.3	126.4	4.8
Flat-18	18.0	148.8	5.6
Flat-19	27.6	226.9	8.6
Flat-20	34.8	286.4	10.9
Flat-21	40.7	334.8	12.7
Flat-22	37.1	305.0	11.6
Flat-23	11.9	98.5	3.7
Flat-24	19.9	163.7	6.2
Flat-25	25.7	212.0	8.0
Flat-26	17.4	143.2	5.4
Flat-27	8.5	70.6	2.6
Flat-28	16.0	132.0	5.0
Flat-29	22.8	187.8	7.1
Flat-30	18.3	150.6	5.7
Average Value	21.5	176.7	6.7
Maximum	40.7	334.8	12.5
Minimum	7.2	59.5	2.2

Table-3.6

Indoor Radon levels in dwellings of Dwarka, Sector-18, Delhi state of India

Locations	Potential alpha activity (mWL)	Radon activity (Bq m^{-3})	Annual effective dose (mSv)
Flat-1	25.7	212.0	8.0
Flat-2	21.9	180.4	6.8
Flat-3	31.6	260.4	9.9
Flat-4	37.5	308.7	11.7
Flat-5	19.9	163.7	6.2
Flat-6	39.8	327.4	12.4
Flat-7	28.0	230.6	8.7
Flat-8	24.8	204.6	7.7
Flat-9	21.2	174.8	6.6
Flat-10	15.3	126.4	4.8
Flat-11	18.0	148.8	5.6
Flat-12	13.1	107.8	4.1
Flat-13	33.4	275.3	10.4
Flat-14	34.3	282.7	10.7
Flat-15	11.7	96.7	3.6
Flat-16	16.7	137.6	5.2
Flat-17	13.5	111.6	4.2
Flat-18	10.1	83.7	3.1
Flat-19	26.6	219.5	8.3
Flat-20	29.4	241.8	9.2
Flat-21	11.5	94.8	3.6
Flat-22	14.9	122.7	4.6
Flat-23	9.7	79.9	3.0
Flat-24	23.9	197.1	7.5
Flat-25	11.5	94.8	3.6
Flat-26	38.4	316.2	12.0
Flat-27	21.7	178.5	6.8
Flat-28	18.5	152.5	5.8
Flat-29	16.9	139.5	5.3
Flat-30	33.4	275.3	10.4
Average Value	22.4	184.9	7.0
Maximum	39.8	327.4	12.4
Minimum	9.7	79.9	3.0

Table-3.7

Indoor Radon levels in dwellings of Aligarh city of Utter Pradesh state of India

Locations	Potential alpha activity (mWL)	Radon activity (Bq m^{-3})	Annual effective dose (mSv)
L-1	22.1	182.3	6.9
L-2	27.1	223.2	8.5
L-3	18.5	152.5	5.8
L-4	13.1	107.8	4.1
L-5	17.4	143.2	5.4
L-6	14.4	119.0	4.5
L-7	10.8	89.2	3.4
L-8	7.6	63.2	2.4
L-9	19.4	159.9	6.0
L-10	12.2	100.4	3.8
L-11	6.3	52.0	1.9
L-12	15.1	124.6	4.2
L-13	23.9	197.1	7.5
L-14	18.7	154.3	5.8
L-15	9.5	78.1	2.9
L-16	14.2	117.1	4.4
L-17	17.4	143.2	5.4
L-18	18.3	150.6	5.7
L-19	11.7	96.7	3.6
Average Value	15.7	129.2	4.9
Maximum	27.1	223.2	8.5
Minimum	6.3	52.0	1.9

Table-3.8

Indoor Radon levels in dwellings of Jaipur city of Rajasthan state of India

Locations	Potential alpha activity (mWL)	Radon activity (Bq m^{-3})	Annual effective dose (mSv)
L-1	13.1	107.8	4.1
L-2	7.0	57.6	2.1
L-3	14.2	117.1	4.4
L-4	19.9	163.7	6.2
L-5	20.5	169.2	6.4
L-6	17.4	143.2	5.4
L-7	9.5	78.1	2.9
L-8	8.8	72.5	2.7
L-9	11.9	98.5	3.7
L-10	15.3	126.4	4.2
L-11	6.3	52.0	1.9
L-12	10.6	87.4	3.3
L-13	11.5	94.8	3.6
L-14	13.3	109.7	4.1
L-15	19.6	161.8	6.1
Average Value	13.3	109.3	4.1
Maximum	20.5	169.2	6.4
Minimum	6.3	52.0	1.9

3.8 Conclusions

- From the present study it has been concluded that the radon concentration values in the dwellings are very low than the world average of 40 Bq m^{-3}.
- From the present investigation the inhalation dose received by the residents lie in the action levels (0.54-0.61 mSv y^{-1}).
- From the present investigation the annual effective dose received by the residents lie nearly in the action levels (3-10 mSv).
- In general the radon concentration is low for well ventilated dwellings as compared to partially ventilated and poorly ventilated dwellings. But in the some cases the high values of radon concentration in well ventilated dwellings were measured. This might be due to use of building materials having high concentration of radon or the rate of emanation of radon beneath the soil, but a detail investigation is required to reach a final conclusion. It was determined that the radon exhalation rates from the soil are high. This might be due to the high porosity of soil.
- Overall from the present investigations it is concluded that for reducing the quantity of radon in an accommodation, some means of blocking radon exhalation from the soil i.e. gap sealing and ventilation of accommodation are needed.

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CHAPTER-4

STUDY OF TERRESTRIAL RADIOACTIVITY (^{226}Ra, ^{232}Th, ^{40}K) AND RADIATION DOSE IN SOLIDS AND BUILDING CONSTRUCTION MATERIALS

4.1 GENERAL

Study on natural environment radiation and natural radioactivity are of high importance in radiation physics and health physics. Effect of the ionizing radiation originates from both natural as well as manmade source of radiation. The natural sources are cosmic rays and the natural radioactivity is present in the rocks, soil and fly ash etc. Whereas the manmade sources of radiation are nuclear explosion, nuclear installations, radiation sources and radionuclides used in industry, agriculture and medicine, air travel and various types of electronic devices. Natural, "background" radiation has been with us since the birth of the universe. Radon is the leading source of natural radiation exposure and the second leading cause of lung cancer. It exists in various geological formations in soil, rocks, water and air. Primordial sources i.e. terrestrial radionuclides (^{238}U, ^{232}Th, and ^{40}K) and cosmogenic radiation (formed as a result of cosmic ray interactions) are the main natural radioactive sources in the universe which are the cause of radiation doses. Natural radiation is of particular importance because this is the largest contributor to the collective dose of world population (NCRP, 1987). Worldwide average annual effective dose from cosmic ray is 0.38 mSv (UNSCEAR 1993; 2000). In general the range of individual annual effective dose from cosmic ray is 0.26-2.0 $mSvy^{-1}$.

The radiation exposure to workers can either be external or internal and is mainly due to beta and gamma rays. External exposure is caused due to radioactive sources external to the body where as internal exposure is due to radioactive materials entering the human body through inhalation, food, ingestion and injection. The world wide average dose received by a person is 2.2 mSv y^{-1}. The international standards allow up to 20.0 mSv y^{-1} for those who work with and around radioactive materials. Average exposures for radiation workers in different field are in range of 2 to 8 $mSvy^{-1}$ (NCRP, 1987).

To evaluate the radon risk in a given atmosphere it is necessary to identify and localize its sources.

In the present study a low level gamma spectrometric set up at the H N B Garhwal University Uttrakhand, India has been used for the estimation of ^{238}Ra, ^{232}Th and ^{40}K concentration in the coal, fly ash, soil and cement samples.

Measurements were carried out on the following material samples having wide applications, collected from different places and part of the country.

1: Coal and fly ash samples collected from different places, sun dried ash ponds used as disposal ponds by Kolaghat thermal power plant and Kasimpur thermal power station, Aligarh, Uttar Pradesh states of India. Measurements have been made to estimate the enhancement of natural radioactivity in fly ash due to coal combustion. The thermal power plants all over the country produce a large quantity of fly ash which is not utilized or properly disposed off, will become one of the greatest menaces to the nation and its inhabitants.

2: Soil samples, collected from Kasimpur power station Uttar Pradesh and NTPC, Badarpur, Delhi State of India.

3: Different types of cement sample collected from Aligarh region, Uttar Pradesh state of India.

4.2 RADIATION EFFECT AND NATURAL RADIOACTIVITY MEASUREMENT IN FLY ASH, COAL AND SOIL SAMPLES

About 72% of power produced in India is from coal based thermal power plants. Indian coal is of bituminous type, having high ash content with 55-60 % ash and it has been estimated that ~ 100 million tones of fly ash is produced per annum (Prasad et al., 1990; Vijayan and Behra, 1999; Baba, 2002). Coal is also found in nature, contains radionuclides like uranium (^{238}U), thorium (^{232}Th) and potassium (^{40}K). Release of the radionuclides and their daughters by natural radiation in the surrounding area of thermal power plants are enhanced by combustion of coal. Owing to its small size and large surface area, the ash has a greater tendency to be an absorbed trace element that is transferred

from coal to waste products during combustion (Gulec et al., 2001). In our previous measurements (Jojo et al., 1993a; 1993b) fly ash has been found to contain enhanced level of uranium as compared to coal. Apart from inhalation, an additional radiation hazard can be the solids fall out, resulting in increased activity concentration of ^{238}U, ^{232}Th and ^{40}K in the surface soils around the thermal power plants (Bem et al., 2002). In recent years collected fly ash has becomes a subject of worldwide interest because of its diverse use in manufacture of cement, clay ash bricks, cellular concrete blocks, asbestos products, in replacement of sand and cement in building materials for filling of underground cavity, rain forced earth wall sand mine filling etc. Earlier studies (Mishra and Ramchandran., 1991) on coal and fly ash have shown that Indian coals contained 1.8-6.0 ppm ^{238}U and 6.0-15.0 ppm of ^{232}Th. But, recent studies have indicated it as high as 50 ppm ^{232}Th and 10 ppm of ^{238}U in the pond ash generated from coal combustion (Mandal and Sengupta, 2003). Radioactivity properties of fly ash are of importance as some construction materials might raise the concentration of air borne radioactivity in indoor air to unacceptable levels, especially in places having low ventilation rates (Rawat et al., 1991 and Khan et al., 1992). As soil is the main ingredient used for the construction materials used in India. Estimation of the radiation risk to the population is quit important. This can be estimated from the activities of the natural radionuclides present in the building materials samples.

In the present study, estimation of ^{226}Ra, ^{232}Th and ^{40}K concentration in the fly ash, coal and soil samples collected from Kasimpur thermal power stations, Aligarh, Uttar Pradesh, states of India, have been done. Radiation doses and health effect have been also estimated from the ^{226}Ra, ^{232}Th and ^{40}K concentrations.

4.3 NATURAL RADIOACTIVITY IN CEMENT SAMPLES

Radioactivity content (^{238}U, ^{232}Th and ^{40}K) in construction material is very important for assessment of the radiation exposure in human being. In dwellings building material acts as a source of radiation and

also shield against outdoor radiation. Indoor absorbed dose rate mainly depends on the activity concentration of natural radionuclides in building materials. Building materials are made from natural sources i.e. soil and rock and some time from waste products i.e. coal fly ash, phosphogypsum, alum shale, oil shale ash, some rare minerals and certain slags. In uranium series, radon, a daughter product of radium is radiological important to study the radiation level in building materials. Radon and Thoron gases are present in dwellings with the presence of their parent nuclide (uranium and thorium) indifferent type of building materials. Contribution of these gases is more than 50% of radiation doses received by individuals from natural radiation source (UNSCEAR, 2000). Building material (Cement) used as a construction material is considered as a major source of these radioactive gases in indoor environment have been studied for radon exhalation rate. The measurement of possible radiation exposure of the population as the people spends about 80% of their life inside offices and houses, the knowledge of basic radiological parameters like radioactive contents and attenuation coefficients in building materials samples is important. The development of standards and guidelines for the use of these materials are essential (Damla D et.al, 2010). It has been observed in some building materials with low level natural radioactivity give rise to external as well as indoor exposure. The study of radiological parameter in building materials is quit important to the possible radiation exposure of the population, since the people spend about 80% of their life inside offices and houses.

4.4 EXPERIMENTAL

A low level gamma spectrometric set up at H N B University Garhwal, Uttrakhand state, India was used for measurement of the natural radionuclides, radium (^{226}Ra), thorium (^{232}Th) and potassium (^{40}K) in soil, fly ash and coal samples. Each sample of 250 grams was prepared and packed in plastic containers. There were sealed for four weeks (Shanbhag et.al, 2005) to attain for secular equilibrium between ^{226}Ra, ^{232}Th and decay products and to prevent ^{222}Rn and ^{220}Rn losses. The samples were

placed one by one in a shielded gamma ray spectrometer for 3 hours (Ramola et.al, 2008). The concentration of natural radionuclides radium (^{226}Ra), thorium (^{232}Th) and potassium (^{40}K) in fly ash samples were measured using a NaI (TI) gamma radiation detector of dimensions 63 mm × 63 mm with a multichannel analyzer. Different activities are evaluated i.e. potassium (^{40}K) was evaluated from the 1460 KeV photo peak, ^{226}Ra from the 1764 KeV Gamma lines of ^{214} Bi, and that of ^{232}Th from the 2610 KeV gamma lines of ^{208}TI. This spectral analysis was carried out using software SPTR-ATC (AT-1315). The peak energy of gamma spectra was measured in reference to the 661 KeV photo peak of ^{137}Cs. Thereafter, activity concentration of soil, fly ash, coal and cement samples were calculated from the intensity of each line in the spectrum, considering the mass, the counting time, efficiency of the detector and the geometry of samples.

4.5 CALCULATION OF RADIOLOGICAL EFFECTS

Activity concentration of radium (^{226}Ra), thorium (^{232}Th) and potassium (^{40}K) and radiological parameters have been measured in the coal, fly ash, soil and cement samples. The results have the great interest in the study of environmental radiological protection, because all samples are used for construction materials.

4.5.1 RADIUM EQUIVALENT ACTIVITY

Exposure due to radiation has been defined in terms of radium equivalent activity (Bq kg^{-1}) to compare the standard activity of materials having different amount of natural radionuclides (^{226}Ra, ^{232}Th and ^{40}K). Following expression is used to calculate (Yu et al., 1992; Hayambu et al., 1995):

$$Ra_{eq} = C_{Ra} + 1.43\, C_{Th} + 0.07\, C_K \quad \text{----------} \quad (4.1)$$

Where,

$C_{Ra,}$ C_{Th} and C_K are the radioactivity concentration of radionuclides i.e. ^{226}Ra, ^{232}Th and ^{40}K in Bq kg^{-1} respectively. The results may help for the selecting of suitable materials for the purpose of building

construction materials.

4.5.2 ABSORBED GAMMA DOSE (D)

Absorbed gamma dose rate in air at 1m above the ground surface for the uniform distribution of radio nuclides (^{238}U, ^{232}Th and ^{40}K) are calculated on the basis of guidelines given by (UNSCEAR, 2008). The dose conversion factors for converting the activity concentration of ^{238}U, ^{232}Th and ^{40}K into doses (nGy h^{-1} Bq^{-1} kg^{-1}) are 0.462, 0.604 and 0.0417 respectively. Thus

$$D = 0.462\ C_{Ra} + 0.604\ C_{Th} + 0.0417\ C_K\ (nGy\ h^{-1}) \quad \text{---------- (4.2)}$$

Measurement of the annual effective dose rate E, following conversion coefficient proposed by UNSCEAR (2000) were used from absorbed dose in air to effective dose (0.7 Sv Gy^{-1}) and outdoor occupancy factor (0.2). Following expression is use to calculate the effective dose rate:

$$E = \text{Dose rate } (nGy\ h^{-1}) \times 8760h \times 0.2 \times 0.7\ Sv\ Gy^{-1} \times 10^{-6}\ (mSv\ y^{-1}) \quad \text{---------- (4.3)}$$

4.5.3 EXTERNAL AND INTERNAL HAZARD INDICES

External hazard index can be calculated by the following expression (Beretka and Mathew, 1985)

$$H_{ex} = \frac{C_{Ra}}{370} + \frac{C_{Th}}{259} + \frac{C_K}{4810} \leq 1 \quad \text{---------- (4.4)}$$

Where,

C_{Ra}, C_{Th} and C_K are the estimated radioactivity concentration of each nuclide in the building materials, which was assumed to produce the same gamma dose rate i.e. 370 $Bqkg^{-1}$ for ^{226}Ra, 259 $Bqkg^{-1}$ for ^{232}Th and 481 $Bqkg^{-1}$ for ^{40}K.

Internal exposure to Radon and its radioactive progeny is controlled by the internal hazard index (Cotton, 1990):

$$H_{in} = \frac{C_{Ra}}{185} + \frac{C_{Th}}{259} + \frac{C_K}{4810} \leq 1 \quad \text{---------- (4.6)}$$

4.6 RESULT AND DISCUSSION

4.6.1 ACTIVITY CONCENTRATION AND ABSORBED GAMMA DOSE RATE IN FLY ASH AND COAL SAMPLES (KASIMPUR)

The value of radioactivity concentrations of radionuclides ^{226}Ra, ^{232}Th and ^{40}K in fly ash and coal samples from Kasimpur thermal power plant and radiation doses and health risk have been measured from the ^{226}Ra, ^{232}Th and ^{40}K are presented in Table 4.1, 4.2, 4.3 and 4.4. In fly ash samples Activity concentration of ^{226}Ra ranged from 20.0 ± 8.5 to 30.0 ± 9.7 Bq kg^{-1} with an average value 23.4 ± 9.0 Bq kg^{-1}, ^{232}Th ranged from 17.0 ± 9.9 to 69.0 ± 13.8 Bq kg^{-1} with an average value of 46.5 ± 12.1 Bq kg^{-1} and ^{40}K ranged from 130.0 ± 7.2 to 332.0 ± 11.1 Bq kg^{-1} with an average value of 177.0 ± 8.1 Bq kg^{-1}. While in coal samples radioactivity concentration of ^{226}Ra ranged from 12 to 39 Bq kg^{-1} with an average value 24.9 Bq kg^{-1}, ^{232}Th ranged from 15 to 49 Bq kg^{-1} with an average value of 32.6 Bq kg^{-1} and ^{40}K ranged from 157 to 460 Bqkg^{-1} with an average value of 253.4 Bq kg^{-1}. Radium equivalent activity has been found to vary from 59.8 to 138 Bq kg^{-1} with an average value of 107.6 Bq kg^{-1}, The absorbed gamma dose rates (D) in air at 1 m above the ground surface for the uniform distribution of radionuclides (^{226}Ra, ^{232}Th and ^{40}K) are calculated on the basis of guidelines given by UNSCEAR (2000). Absorbed dose rate varies from 27.5 to 61.2 nGy h^{-1} with an average value of 48.1 nGy h^{-1} and corresponding outdoor annual effective dose varies from 0.033 to 0.075 mSv y^{-1} with an average value of 0.058 mSv y^{-1}. While in coal samples Radium equivalent activity varies from 50.8 to 118 Bq kg^{-1} with an average value of 90.9 Bq kg^{-1}, The absorbed gamma dose rates (D) varies from 24 to 53.2 $nGyh^{-1}$ with an average value of 41.7 nGy h^{-1} and corresponding outdoor annual effective dose varies from 0.029 to 0.065 mSv y^{-1} with an average value of 0.050 mSv y^{-1}.The calculated values of H_{ex} and H_{in} for the fly ash and coal samples from Kasimpur thermal power plant studies in this work, varies from 0.16 to 0.37 with an average value of 0.28 and 0.19 to 0.44 with an average value of 0.32

respectively. While in coal samples varies from 0.13 to 0.31 with an average value of 0.24 and 0.16 to 0.41 with an average value of 0.30 respectively.

4.6.2 ACTIVITY CONCENTRATION AND ABSORBED GAMMA DOSE RATE IN SOIL SAMPLES (KASIMPUR)

Natural radionuclides (^{226}Ra, ^{232}Th and ^{40}K) activity concentration from soil samples collected from around the Kasimpur thermal power plant Aligarh, Uttar Pradesh state of India are given in Table-4.5. The value of Radium equivalent activity, absorbed gamma dose rate, annual effective dose rate, external hazard index and internal hazard index for soil samples are given in Table-4.6. Radioactivity concentration of ^{226}Ra ranged from 12.0 ± 7.0 to 49.0 ± 16 Bqkg^{-1} with an average value 30.0 ± 12 Bq kg^{-1}, ^{232}Th ranged from 24.0 ± 10 to 49.0 ± 14 Bq kg^{-1} with an average value of 39.0 ± 11 Bq kg^{-1} and ^{40}K ranged from 135.0 ± 3.0 to 546.0 ± 13 Bq kg^{-1} with an average value of 318.0 ± 7.0 Bq kg^{-1}

Radium equivalent activity in soil samples varies from 80 to 143.7 Bq kg^{-1} with an average value of 109.7 Bq kg^{-1} ,The absorbed gamma dose rates (D) in air at 1 m above the ground surface for the uniform distribution of radionuclides (^{226}Ra, ^{232}Th and ^{40}K) are calculated on the basis of guidelines given by (UNSCEAR, 2000).Gamma absorbed dose rate varies from 36.1 to 66.4 nGy h^{-1} with an average value of 50.4 nGy h^{-1} and corresponding outdoor annual effective dose varies from 0.044 to 0.081 mSv y^{-1} with an average value of 0.061 mSv y^{-1}. The calculated values of H_{ex} and H_{in} for the soil samples from Kasimpur thermal power plant studies in this work, varies from 0.21 to 0.38 with an average value of 0.29 and 0.27 to 0.50 with an average value of 0.37 respectively.

4.6.3 ACTIVITY CONCENTRATION AND ABSORBED GAMMA DOSE RATE IN SOIL SAMPLES WITH DIFFERENT AMOUNT OF FLY ASH (EXPRESSED IN % BY WEIGHT) FROM NTPC, BADARPUR, DELHI, INDIA

The effect of fly ash as an additive to building materials has been studied by several groups and conflicting results have been reported by different workers (Stranden, 1983; Maraziotis, 1985) reported a reduction in concrete with fly ash as additive. The value of Activity concentration of ^{226}Ra almost gradual increase has been observed in the samples having fly ash as an additive in the soil samples. The results for homogeneous mixture soil with fly ash in different proportion are given in Table- 4.7 and Table-4.8. This shows that values of mixture increases if additive has greater activity concentration that the base material. This may due to the emanation power of different materials and grain size also. Radium equivalent activity in these samples found to vary from 81.4 to 154.8 Bq kg^{-1} with an average value of 111.1 Bq kg^{-1} ,The absorbed gamma dose rates (D) in air at 1 m above the ground surface for the uniform distribution of radionuclides (^{226}Ra, ^{232}Th and ^{40}K) are calculated on the basis of guidelines given by (UNSCEAR, 2000). Gamma absorbed dose rate varies from 37.8 to 73.6 nGy h^{-1} with an average value of 52.7 nGy h^{-1} and corresponding outdoor annual effective dose varies from 0.019 to 0.064 mSv y^{-1} with an average value of 0.045 mSv y^{-1}. The calculated values of H_{ex} and H_{in} vary from 0.22 to 0.42 with an average value of 0.30 and 0.27 to 0.55 with an average value of 0.39 respectively.

4.6.4 ACTIVITY CONCENTRATION AND ABSORBED GAMMA DOSE RATE IN CEMENT SAMPLES

In the present study, different types of cement samples have been collected from different manufactures. Radionuclides content in different building materials varying depend on chemical composition with corresponding to its geological source and its chemical characteristics Radon

exhalation rate is measured using Sealed Can Technique for cement samples. Radioactivity content ^{226}Ra, ^{232}Th and ^{40}K was using a low level gamma ray spectrometry. Different radiological parameters such as radium equivalent activity, absorbed dose, internal and external hazard index etc. were determined to find the radiological implication of population exposure. Natural radionuclides (^{226}Ra, ^{232}Th and ^{40}K) activity concentration from cement samples are given in Table-4.9. The value of Radium equivalent activity, absorbed gamma dose rate, annual effective dose rate, external hazard index and internal hazard index for cement samples are given in Table-4.10. The activity concentration of ^{226}Ra varies from 9.0 ± 4.0 Bq kg^{-1} to 28 ± 10 Bq kg^{-1} and ^{232}Th varies from 21.0 ± 9.0 Bq kg^{-1} to 43 ± 13 Bq kg^{-1} whereas ^{40}K varies from 280 ± 8.0 Bq kg^{-1} to 573 ± 14 Bq kg^{-1}.Cement samples used in this study, the activity of ^{226}Ra is found minimum for ACC and maximum for Bhiwani, ^{232}Th concentration is minimum for ACC and maximum for Ultratech and activity of ^{40}K is found minimum for Ultratech and maximum for Bangur. There is no health risk to the people from these cement samples that spend more time in building, all the values reported in this study are below to permissible limits, recommended by the Atomic Energy Regulatory Board of India. Radium equivalent activity in cement samples varies from 60.8 to 121 Bq kg^{-1}. The minimum was found for ACC and maximum for Bangur. The absorbed gamma dose rates (D) and corresponding outdoor annual effective dose varies from 28.6 to 57.3 nGy h^{-1} and 0.07 to 0.14 mSv y^{-1} respectively. The minimum dose was found for ACC while maximum was for Rockstone cement. The calculated values of H_{ex} and H_{in} for these cement samples studies in this work, varies from 0.16 to 0.32 and 0.18 to 0.39 respectively. The minimum value of H_{ex} and H_{in} was found for ACC and maximum was for Bangur. Since all values for H_{ex} are lower than unity.

4.7 CONCLUSIONS

- The investigated samples of the present study do not pose any health risk, since all the reported values are well below the permissible limits, stipulated as per the guidelines of Atomic Energy Regulatory Board of India.
- The presence of natural radioactivity level in all the samples have been found to well below the permissible limits of 1000 Bq kg^{-1}, 1000 Bq kg^{-1} and 4000 Bq kg^{-1} for ^{226}Ra, ^{232}Th and ^{40}K respectively.
- The calculated values of external hazard index in the studied samples are less than the recommended safe levels i.e. unity.
- The effective and absorbed dose values are well below the permissible limits.
- The calculated values of indoor and outdoor annual effective dose due to natural radioactivity of studied samples are lower than the average world recommended level of 1 mSv y^{-1} for the individual member of public.
- In the present study, results of natural radionuclides in soil samples were compared with other measured samples and were found to the values of ^{226}Ra, ^{232}Th are lower whereas for ^{40}K to lie in the range of Indian soil samples.
- It has been found from the present study, activity concentration of ^{226}Ra, ^{232}Th and ^{40}K are approximately same for all the cement samples, in comparison of the earlier study.

Table-4.1

Activity concentration values For ^{226}Ra,^{232} Th and ^{40}K in fly ash samples from Kasimpur thermal power plant (Uttar Pradesh) using Gamma ray Spectrometry

Samples	Activity Concentration (Bq kg^{-1})		
	^{226}Ra	^{232}Th	^{40}K
FLYA-1	23 ± 9.0	69 ± 13.8	213 ± 8.8
FLYA-2	30 ± 9.7	55 ± 13.8	157 ± 7.7
FLYA-3	20 ± 8.5	44 ± 11.6	130 ± 7.2
FLYA-4	26 ± 9.1	65 ± 13.8	235 ± 9.1
FLYA-5	28 ± 9.7	39 ± 11.4	332 ± 11.1
FLYA-6	20 ± 8.5	39 ± 11.4	131 ± 7.2
FLYA-7	25 ± 9.1	17 ± 9.9	137 ± 7.2
FLYA-8	30 ± 9.7	46 ± 12.1	168 ± 8.0
FLYA-9	23 ± 9.5	43 ± 11.6	134 ± 7.2
FLYA-10	29 ± 9.7	58 ± 13.8	233 ± 9.1
Average Value Maximum Value Minimum Value	23.4 ± 9.0 30.0 ± 9.7 20.0 ± 8.5	46.5 ± 12.1 69.0 ± 13.8 17.0 ± 9.9	177.0 ± 8.1 332.0 ± 11.1 130.0 ± 7.2

Table-4.2

Activity concentration values for ^{226}Ra, ^{232}Th and ^{40}K in coal samples from Kasimpur thermal power plant (Uttar Pradesh) using Gamma ray Spectrometry

Samples	Activity Concentration (Bq kg^{-1})		
	^{226}Ra	^{232}Th	^{40}K
Coal-1	27	34	160
Coal-2	14	15	225
Coal-3	33	38	327
Coal-4	20	23	345
Coal-5	30	49	234
Coal-6	39	44	157
Coal-7	23	48	166
Coal-8	29	32	460
Coal-9	22	28	234
Coal-10	12	15	226
Average Value	24.9	32.6	253.4
Maximum Value	39	49	460
Minimum Value	12	15	157

Table-4.3

Absorbed gamma dose rate, annual effective dose rate, Radium equivalent activity, (external, internal) hazard index in fly ash samples from Kasimpur thermal power plant (Uttar Pradesh)

Details of samples	Radium equivalent activity Ra_{eq} (Bq kg^{-1})	Absorbed gamma dose rate D (nGy h^{-1})	annual effective dose rate (mSv y^{-1})	External hazard index H_{ex}	Internal hazard index H_{in}
FLYA-1	138.0	61.2	0.075	0.37	0.43
FLYA-2	120.7	53.6	0.065	0.32	0.40
FLYA-3	92.9	41.2	0.050	0.25	0.30
FLYA-4	137.0	61.0	0.074	0.37	0.44
FLYA-5	109.3	50.3	0.061	0.29	0.37
FLYA-6	85.8	38.2	0.046	0.23	0.28
FLYA-7	59.8	27.5	0.033	0.16	0.19
FLYA-8	108.7	48.6	0.059	0.29	0.37
FLYA-9	94.8	42.2	0.051	0.25	0.31
FLYA-10	129.8	58.1	0.071	0.35	0.42
Avg. Value	107.6	48.1	0.058	0.28	0.33
Max. Value	138.0	61.2	0.075	0.37	0.44
Min. Value	59.8	27.5	0.033	0.16	0.19

Table-4.4

Absorbed gamma dose rate, annual effective dose rate, Radium equivalent activity, (external, internal) hazard index in coal samples from Kasimpur thermal power plant (Uttar Pradesh)

Details of samples	Radium equivalent activity Ra_{eq} (Bq kg^{-1})	Absorbed gamma dose rate D (nGy h^{-1})	annual effective dose rate (mSv y^{-1})	External hazard index H_{ex}	Internal hazard index H_{in}
Coal-1	87.9	39.7	0.048	0.23	0.31
Coal-2	52.7	24.9	0.030	0.14	0.18
Coal-3	112.5	51.8	0.063	0.30	0.39
Coal-4	79.4	37.5	0.046	0.21	0.26
Coal-5	118.0	53.2	0.065	0.31	0.40
Coal-6	114.0	51.1	0.062	0.30	0.41
Coal-7	104.4	46.5	0.057	0.28	0.34
Coal-8	110.1	51.9	0.063	0.29	0.37
Coal-9	80.0	36.8	0.045	0.21	0.27
Coal-10	50.8	24.0	0.029	0.13	0.16
Avg. Value	90.9	41.7	0.050	0.24	0.30
Max. Value	118.0	53.2	0.065	0.31	0.41
Min. Value	50.8	24.0	0.029	0.13	0.16

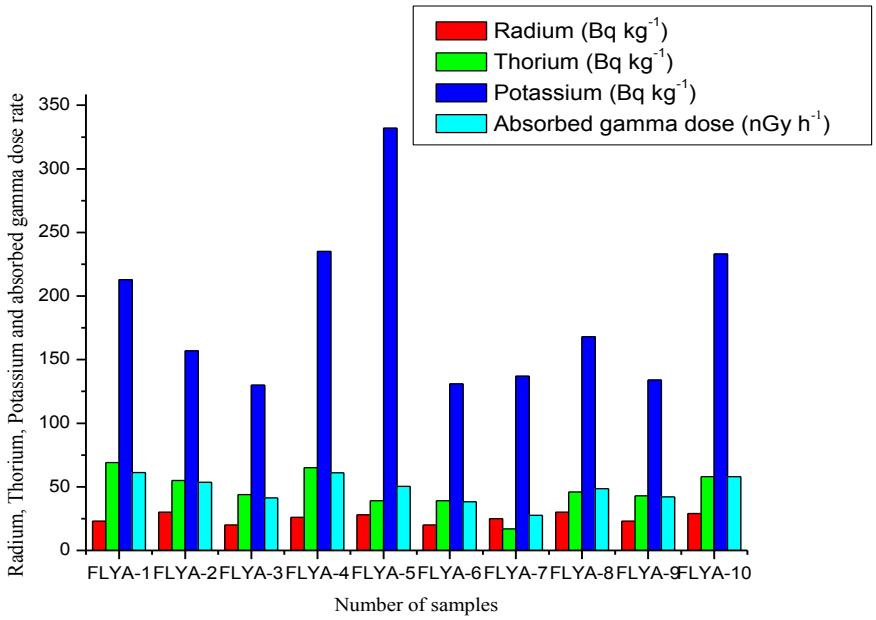

Figure 4.1 Bar diagram showing Radioactivity concentration of ^{226}Ra, ^{232}Th and ^{40}K and absorbed gamma dose rate in fly ash (Kasimpur) samples.

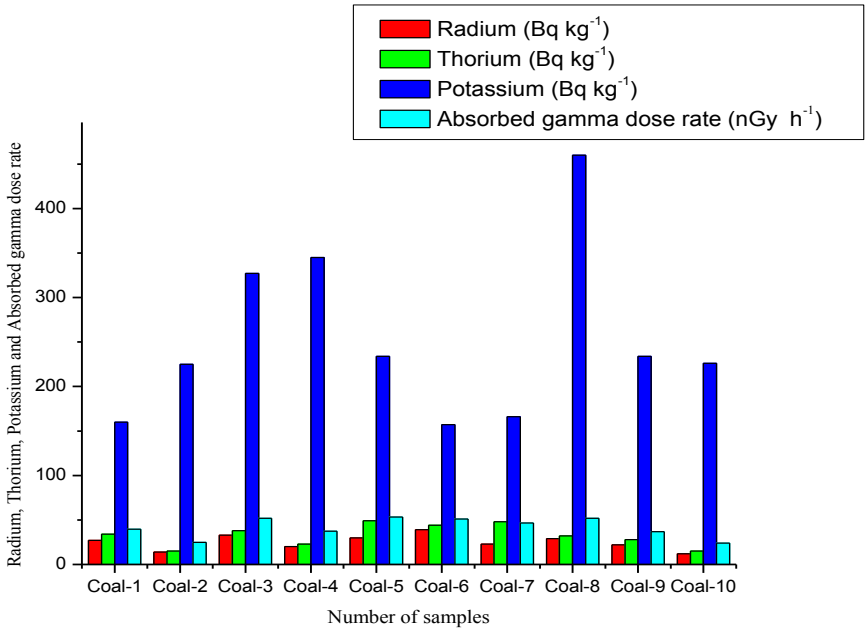

Figure 4.2 Bar diagram showing Radioactivity concentration of ^{226}Ra, ^{232}Th and ^{40}K and absorbed gamma dose rate in coal (Kasimpur) samples.

Table-4.5

Activity concentration values for ^{226}Ra,^{232}Th and ^{40}K in soil samples from Kasimpur thermal power plant (Uttar Pradesh) using Gamma ray Spectrometry.

Details of Samples	Activity Concentration (Bq kg^{-1})		
	^{226}Ra	^{232}Th	^{40}K
S-1	17 ± 9	43 ± 12	329 ±7
S-2	46 ± 15	24 ± 10	355 ± 8
S-3	45 ± 15	24 ± 10	268 ± 5
S-4	24 ± 10	48 ± 14	546 ± 13
S-5	43 ± 15	47 ± 14	435 ± 12
S-6	23 ± 10	42 ± 12	135 ± 3
S-7	22 ± 10	32 ± 10	160 ± 4
S-8	49 ± 16	28 ± 9	398 ± 10
S-9	22 ± 10	49 ± 14	398 ± 10
S10	12 ± 7	48 ± 14	154 ± 4
Average Value	30 ± 12	39 ± 11	318 ± 7
Maximum Value	49 ± 16	49 ± 14	546 ± 13
Minimum Value	12 ± 7	24 ± 10	135 ± 3

Table-4.6

Absorbed gamma dose rate, annual effective dose rate, Radium equivalent activity, (external, internal) hazard index in soil samples from Kasimpur thermal power plant (Uttar Pradesh)

Details of samples	Radium equivalent activity (Ra_{eq}) Bq kg^{-1}	Absorbed gamma dose rate (D) (nGy h^{-1})	annual effective dose rate mSv y^{-1}	External hazard index H_{ex}	Internal hazard index H_{in}
S-1	103.8	47.5	0.058	0.28	0.32
S-2	107.6	50.5	0.062	0.29	0.41
S-3	99.9	46.5	0.057	0.27	0.39
S-4	134.6	62.8	0.077	0.36	0.42
S-5	143.7	66.4	0.081	0.38	0.50
S-6	93.4	41.6	0.051	0.25	0.31
S-7	80.0	36.1	0.044	0.21	0.27
S-8	119.6	56.1	0.068	0.32	0.45
S-9	122.7	56.3	0.069	0.33	0.39
S1-0	92.4	40.9	0.050	0.24	0.28
Avg. Value	109.7	50.4	0.061	0.29	0.37
Max. Value	143.7	66.4	0.081	0.38	0.50
Mini. Value	80.0	36.1	0.044	0.21	0.27

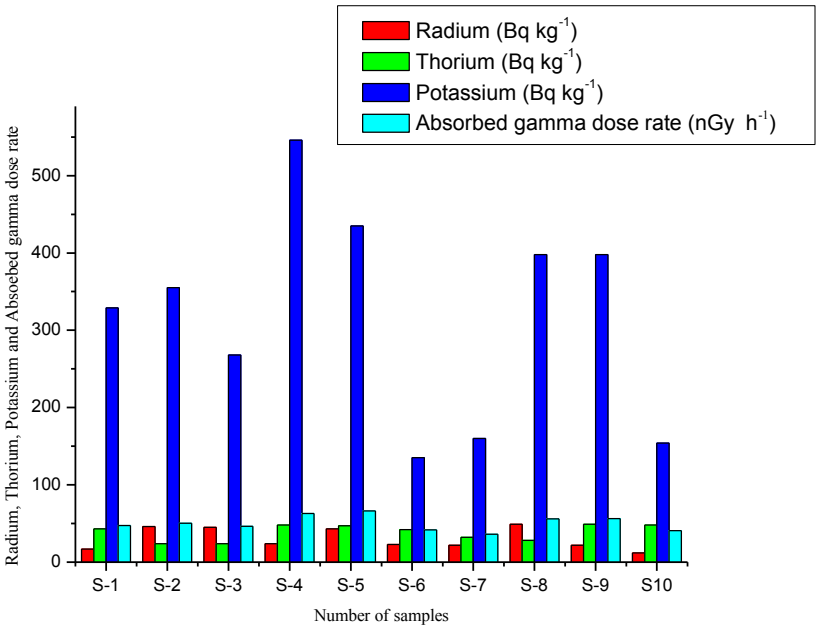

Figure 4.3 Bar diagram showing Radioactivity concentration of ^{226}Ra, ^{232}Th and ^{40}K and absorbed gamma dose rate in soil (Kasimpur) samples

Table-4.7

Activity concentration values for ^{226}Ra, ^{232}Th and ^{40}K in soil samples with different amount of fly ash (expressed in % by weight) substitute into samples of equal total weight from the surrounding areas of NTPC Badarpur, Delhi, India.

Samples	Fly ash additive (%)	^{226}Ra (Bq kg^{-1})	^{232}Th (Bq kg^{-1})	^{40}K (Bq kg^{-1})
S-1	10	12	32	413
S-2	20	16	42	380
S-3	30	21	45	211
S-4	40	28	29	430
S-5	50	35	43	416
S-6	60	39	22	156
S-7	70	42	34	342
S-8	80	46	37	424
S-9	90	39	36	387
S10	100	48	49	524
Average Value		32.6	36.9	368.3
Maximum Value		48	49	524
Minimum Value		12	22	156

Table-4.8

Radium equivalent activity, absorbed gamma dose rate, annual effective dose rate and hazard index (external, internal) in soil samples with different amount of fly ash (expressed in % by weight) substitute into samples of equal total weight from NTPC Badarpur, Delhi, India.

Details of samples	Radium equivalent activity (Ra_{eq}) Bq kg^{-1}	Absorbed gamma dose rate (D) nGy h^{-1}	annual effective dose rate mSv y^{-1}	External hazard index H_{ex}	Internal hazard index H_{in}
S-1	86.7	42.1	0.050	0.24	0.27
S-2	102.7	48.6	0.046	0.28	0.32
S-3	100.1	45.7	0.025	0.27	0.33
S-4	99.6	48.4	0.052	0.27	0.35
S-5	125.6	59.5	0.051	0.34	0.44
S-6	81.4	37.8	0.019	0.22	0.32
S-7	114.6	54.2	0.041	0.31	0.42
S-8	128.6	61.3	0.051	0.35	0.47
S-9	117.6	55.9	0.047	0.32	0.43
S1-0	154.8	73.6	0.064	0.42	0.55
Avg. Value	111.1	52.7	0.045	0.30	0.39
Max. Value	154.8	73.6	0.064	0.42	0.55
Mini. Value	81.4	37.8	0.019	0.22	0.27

Table-4.9

Activity concentration values for ^{226}Ra, ^{232}Th and ^{40}K in cement samples using Gamma ray Spectrometry

Details of Samples	^{226}Ra (Bq kg^{-1})	^{232}Th (Bq kg^{-1})	^{40}K (Bq kg^{-1})
BHIWANI	28.0 ± 10	40.0 ± 12	341.0 ± 10
JKSUPESS	10 .0 ± 4	34.0 ± 10	430.0 ± 12
ACC	9.0 ± 4	21.0 ± 9	284.0 ± 8
BANGUR	24.0 ± 10	37.0 ± 11	573.0 ± 14
AMBUJA	18.0 ± 9	33.0 ± 10	457.0 ± 12
SHREEULTRA	19.0 ± 9	36.0 ± 11	443.0 ± 12
ULTRATACH	25.0 ± 10	43.0 ± 13	280.0 ± 8
ROCKSTONE	16.0 ± 8	39.0 ± 12	554.0 ± 13
BIRLASAME	13.0 ± 6	32.0 ± 10	299.0 ± 9

Table-4.10

Absorbed gamma dose rate, annual effective dose rate, Radium equivalent activity, (external, internal) hazard index in cement samples

Details of samples	Radium equivalent activity (Ra_{eq}) Bq kg^{-1}	Absorbed gamma dose rate (D) nGy h^{-1}	annual effective dose rate mSv y^{-1}	External hazard index H_{ex}	Internal hazard index H_{in}
BHIWANI	111.4	51.3	0.13	0.30	0.37
JKSUPESS	91.7	43.0	0.11	0.24	0.27
ACC	60.8	28.6	0.07	0.16	0.18
BANGUR	121.0	57.3	0.14	0.32	0.39
AMBUJA	100.3	47.3	0.12	0.27	0.31
SHREEULTRA	104.5	49.0	0.12	0.28	0.33
ULTRATACH	108.0	49.2	0.13	0.29	0.35
ROCKSTONE	114.4	54.0	0.14	0.30	0.35
BIRLASAME	81.7	37.8	0.10	0.22	0.25

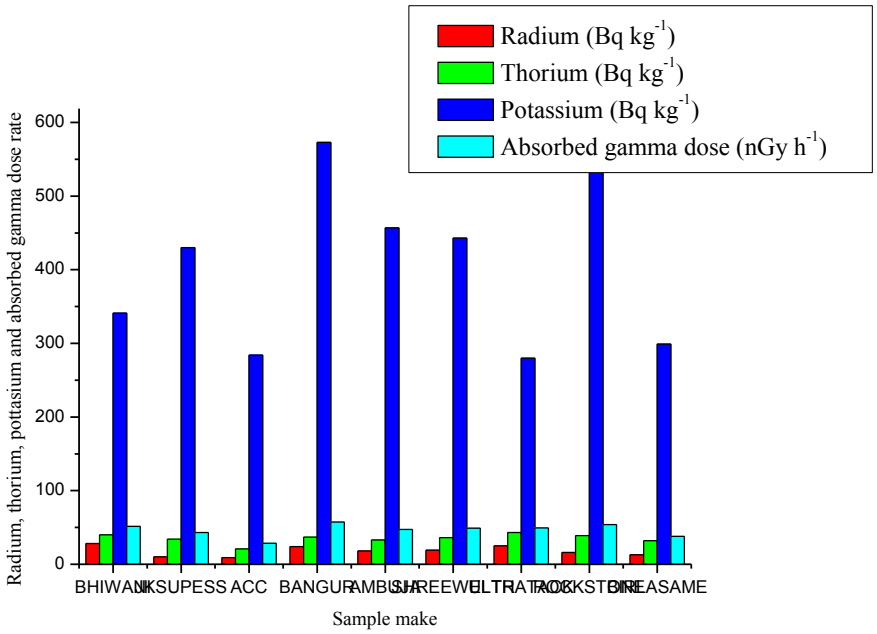

Figure 4.4 Bar diagram showing Radioactivity concentration of ^{226}Ra, ^{232}Th and ^{40}K and absorbed gamma dose rate in Cement samples

Table-4.11

Comparison of mean activity concentration for ^{226}Ra, ^{232}Th and ^{40}K in fly ash samples from Kasimpur Thermal Power Station compared with other Indian Thermal Power Plants.

Thermal power station (India)	Activity concentrations (Bq kg^{-1})			References
	^{226}Ra	^{232}Th	^{40}K	
Durgapur (W.B.)	97.3	107.5	123.0	Mandal et. al., 2006
Durgapur (W.B.)	99.3	112.9	308.9	Lalit et. al., 1986
	98.3	110.2	312.3	
Bandel (W.B.)	126.9	106.3	321.8	Mandal et. al., 2006
Kolaghat (W.B.)	111.4	140.2	350.7	Mandal et. al., 2006
Bokaro (Bihar)	70.3	118.4	252.0	ICRP 1987
Amarkantak (M.P.)	49.2	106.2	329.3	ICRP 1987
Badarpur (Delhi)	75.5	88.1	286.4	Vijayan et. al., 1999
Bakreshwar (W.B.)	76.3	87.5	288.1	
Allahabad (Uttar Pradesh)	78.4	89.1	362.7	
Kasimpur (Uttar Pradesh)	*23.4*	*46.5*	*177.0*	*Present study*

Table-4.12

Comparison of mean activity concentration for ^{226}Ra, ^{232}Th and ^{40}K and radium equivalent activity in soil samples from Kasimpur Thermal Power Station compared with other soil of Indian.

S.No.	Location	^{226}Ra (Bq kg^{-1}) Range	^{232}Th (Bq kg^{-1}) Range	^{40}K (Bq kg^{-1}) Range	Ra_{eq} (Bq kg^{-1}) Range	References
1	Upper Siwaliks, Northern India	28.3-81.0	61.2-140.3	363.4-1002.2	149.4-351.8	Singh et al. (2009)
2	Some cities of Uttar Pradesh	13.6-35.8	-	-	-	Kumar et al. (2006)
3	Some cities of Rajasthan	11.1-21.0	-	-	-	Kumar et al. (2006)
4	Some cities of Punjab	35.9-64.8	49.5-95.3	80.4-165.1	113.0-213.1	Singh et al. (2005)
5	Some cities of Himachal Pradesh	18.2-90.3	34.8-124.7	81.9-181.4	74.3-281.9	Singh et al. (2005)
6	Delhi	30.0	20.0	200.0	-	Sonkawade et al. (2008)
7	Sirsa district of Haryana	26.48-40.31	61.32-89.54	223.22-313.32	127.31-178.97	Mehra et al. (2010)
8	Around NTPC, Dadri, Uttar Pradesh	32.16-120.93	19.25-44.56	195.42-505.4	73.37-214.74	Mahur et al. (2013)
9	***Around KTPP, Kasimpur, Uttar Pradesh***	***30.3***	***38.5***	***317.8***	***109.7***	***Present study***

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CHAPTER-5

MEASUREMENT OF RADON EXHALATION RATE IN SOLID AND BUILDING CONSTRUCTION MATERIALS

5.1 GENERAL

Radon exhalation rate is of prime importance for the estimation of radiation risk from various materials. Emission of radon per unit area per unit time is known as radon exhalation rate. Radon exhalation rates are two types: surface exhalation rate and mass exhalation rate. Radon exhalation rate depends upon the radium concentration in the material, emanation factor of radon from the material, porosity, permeability, density of the material, diffusion coefficient of the radon in material, moisture content and temperature. The radon exhaling properties of porous materials, both naturally occurring like soil, sand and rocks and man-made like mining wastes, fly ash and many building construction materials etc have been the subject of several investigations (Jonassen, 1983; Kumar et al., 2005; Karmadoost et al., 1988).

There is a need for developing simple and efficient measuring method and performing intensive studies for getting representative data about the radiation levels due to waste and building construction materials for predication of the level of radiation risk from various solid samples. The radionuclides present in fly ash obtained from the combustion of coal may migrate to the underlying ground water body from the waste disposal site. The accumulation of the radionuclides may be accumulated in the top soil giving sufficient chances for being enriched in soil. The radiation risk is quite important to measure for the population from the radioactivity of soil. Theory of the radon exhalation rate is the same whether the radon comes from the soil or from porous solid samples like coal, fly ash, sand and rocks etc. However, some features of the exhalation process are very different in two cases. For exhalation from the soil, the measurements are limited to exhalation from very small part of the exhaling surface, although the sample can be considered to be extended indefinitely in the exhalation direction.

"Sealed Can Technique" was used for the measurement of radon exhalation from solids has been widely used also in combination with several active measuring techniques (Stranden, 1983; Somogyi et al., 1986). In all these techniques where a limited amount of emanating specimen is used in a closed container, it is expected that the exhalation rate depends upon the material and its amount as well as on the geometry & dimension of the can. The reduction in radon exhalation from a sample under steady state condition in a sealed can has been reported and is attributed to "back-diffusion" phenomenon. As the exhalation depends, also on the texture and grain-size composition of the samples as well as on the moisture content, etc., it is difficult to predict the radon exhalation rate from the concentration of decay products only in the sample (Kumar, et. al, 2006).

In this chapter radon exhalation rate and indoor internal exposure due to radon inhalation have been calculated in fly ash, soil, sand and building materials.

5.2 MATERIALS AND METHODS

5.2.1 MEASUREMENT OF RADON EXHALATION RATE

"Sealed Can Technique" using LR-115 type II solid state nuclear tracks detectors (Fleischer et al, 1978; Mahur et al., 2008) was adopted for radon exhalation measurements. Collected samples (fly ash, soil, sand and building construction materials) were dried and sieved through a 100 mesh sieve. Equal amount of samples (100 gm) were placed in the Cans (diameter 7.0 cm and height 7.5 cm) for 100 days. After the exposure time, the detectors were etched in 2.5N NaOH at 60^0C in a fix temperature water bath for 90 minutes. Alpha-particle tracks formed in detector were counted using spark counting system. From the track density the radon activity was obtained using a calibration factor of 0.056 trackcm^{-2} d^{-1} (Bq m^{-3})$^{-1}$ obtained from an earlier calibration experiment (Singh et al., 1997) and recalibration afterwards.

Following expressions give the surface exhalation rate and mass exhalation rate (Khan et al., 1992, Fleischer and Morgo-campero, 1978 and Mahur et al., 2008).

$$E_X = \frac{CV\lambda}{A\left[T + \frac{1}{\lambda}\left\{e^{-\lambda T} - 1\right\}\right]} \qquad (\text{Bq m}^{-2}\text{ h}^{-1}) \qquad (5.1)$$

$$E_M = \frac{CV\lambda}{M\left[T + \frac{1}{\lambda}\left\{e^{-\lambda T} - 1\right\}\right]} \qquad (\text{Bq kg}^{-1}\text{ h}^{-1}) \qquad (5.2)$$

Where, E_x, radon surface exhalation rate (Bq m^{-2} h^{-1}), E_M, radon mass exhalation rate (Bq kg^{-1} h^{-1}); C is a radon exposure as measured by LR -115 solid state nuclear track detector (Bq m^{-3} h) ;V is the effective volume of can (m^3); λ is the decay constant for radon (h^{-1}); T is the exposure time (in hour); A is the area of the can (m^2) and M is mass of the sample.

5.2.2 INDOOR INTERNAL EXPOSURE DUE TO RADON INHALATION

The contribution of indoor radon concentration from fly ash samples can be calculated from the following expression (Gupta et al., 2013).

$$C_{Rn} = \frac{E_X \times S}{V \times \lambda_v} \qquad (5.3)$$

Where, C_{Rn} is the radon concentration (Bq m^{-3}); E_x is radon exhalation rate (Bq m^{-2} h^{-1}); S is radon exhalation area (m^2); V is room volume (m^3), and λ_v is air exchange rate (h^{-1}) .The maximum radon concentration from the building material was assessed by assuming the room as a cavity with S/V = 2.0 m^{-1} and air exchange rate of 0.5 h^{-1}. The annual exposure to potential alpha energy E_p (effective dose equivalent) is then related to the average radon concentration C_{Rn} given as.

$$E_P\left[WLM.y^{-1}\right]=\frac{8760\times n\times F\times C_{Rn}}{170\times 3700} \quad (5.4)$$

C_{Rn} is in Bq m^{-3}; n is the fraction of time spent indoors; 8760 is the number of hours per year; 170, the number of hours per working month and F is the equilibrium factor for radon and is taken as 0.4 as suggested by UNSCEAR, 2000. Radon progeny equilibrium is the most important quantity, where dose calculations are to be made on the basis of the measurement of radon concentration, it may have value 0<F<1. Thus, the values of n = 0.8 and F = 0.4 were used. From radon exposure the indoor inhalation exposure (radon) effective dose were estimated by using a conversion factor of 3.88 mSv $(WLM)^{-1}$ (ICRP, 1993).

5.2.3 MEASUREMENT OF RADON MASS EXHALATION RATE

"Smart Radon Monitor Technique" (Sahoo B.K.et.al 2007) was used to measure the radon mass exhalation rate. It was developed at BARC Mumbai. For measurements of mass exhalation rate, collected samples (Fly ash, Soil) about 100 gram was taken in the accumulation chamber. For Radon mass exhalation rate measurement, radon build up in the accumulation chamber is sampled into the scintillation cell (153 cc) of the Smart Radon Monitor through a "progeny filter" for eliminating radon progenies. The Photomultiplier tube and the related counting electronics continuously counts alpha particles emitted from the radon and its decay products in the cell for a user-programmable counting period. Obtained alpha particles are processed through a microprocessor unit and the corresponding algorithm displays the concentration of radon. The buildup radon concentration was measured at a time intervals of 1 hour till to achieve saturation of radon concentration in the samples.

The expression gives the radon concentration at time *t* inside the chamber (Sahoo et.al 2007):

$$C(t)=\frac{J_m M}{V\lambda_e}\left[1-e^{-\lambda_e t}\right]+C_0 e^{-\lambda_e t} \quad (5.5)$$

Where,

C = Radon concentration per unit volume of air in Bqm^{-3}

J_m = Radon mass exhalation rate in $mBqkg^{-1}h^{-1}$

V = Effective volume in m^3 (Container volume + Detector volume (153 cc) – volume of sample)

M = Mass of the sample in Kg

C_0 = Radon concentration in Bqm^{-3} present in the chamber at $t = 0$.

λ_e = Effective decay constant for Radon (Sum of the leak rate (if existing) and the radioactive decay constant of Radon in h^{-1}).

Upon linear fitting measured radon build up data to the linear growth equation available in the software origin

$$Y=A+BX \qquad (5.6)$$

Calculated fitting parameters *A,* B and X. Comparing Eq (5.5) and Eq (5.6), and obtained radon mass exhalation rate $J_m = B\ V / M$**.**

5.3 RESULT AND DISCUSSION

5.3.1 MEASUREMENTS OF RADON ACTIVITY, RADON EXHALATION RATE AND INDOOR INHALATION EXPOSURE EFFECTIVE DOSE IN SAND SAMPLES (RUSHIKULYA BEACH)

Sand samples were collected from Rushikulya beach. The Rushikulya is one of the major rivers of Odisha state of India. The geographical coordinates are of 84.01 to 85.06 E and 19.07 to 20.19 N. Radon exhalation rate and indoor inhalation exposure (radon) effective doses have been estimated from the radon exhalation rates. The results of the radon activity, radon exhalation rates and effective doses from the sand are given in Table 5.1. Radon activity has been found to vary from 388.5 ± 23.7 to 997.1 ± 37.9 Bq m^{-3} with an average value of 686.1 ± 20.4 Bq m^{-3}. Radon exhalation rate varies from 139.7 ± 8.5 to 358.5 ± 13.6 mBq m^{-2} h^{-1} with an average value of 246.6 ± 11.5 mBq m^{-2} h^{-1}, whereas mass exhalation rate is found to vary from 5.3 ± 0.3 to 13.8 ± 0.5 mBq kg^{-1} h^{-1} with an average value of 9.4 ± 0.4 mBq kg^{-1} h^{-1}. Calculated values of indoor inhalation exposure (radon) effective dose have been found to vary from 16.4 ± 1.1 to 42.2 ± 1.1 μSv y^{-1} with an average value of 29.0 ± 1.1 μSv y^{-1}.

5.3.2 MEASUREMENTS OF RADON ACTIVITY, RADON EXHALATION RATE AND INDOOR INHALATION EXPOSURE EFFECTIVE DOSE IN SAND SAMPLES (GOPALPUR BEACH)

Sand samples have been collected from the Gopalpur beach. It is a commercial port and famous sea beach around 15 Km from Berhampur, located in Odisha state of India. Radon exhalation rate and indoor inhalation exposure (radon) effective doses have been estimated from the radon exhalation rates. The results of the radon activity, radon exhalation rates and effective doses from the sand are given in Table 5.2. Radon activity has been found to vary from 371.4 ± 23.0 to 800.0 ± 33.7 Bq m^{-3} with an average value of 549.1± 28.3Bq m^{-3}. Radon exhalation rate vary from 133.3 ± 8.2 to 287.7 ±

12.1 mBq $m^{-2}h^{-1}$ with an average value of 197.1 ± 10.1 mBq $m^{-2}h^{-1}$, whereas mass exhalation rate has been found to vary from 5.1 ± 0.3 to 11.0 ± 0.4 mBq $kg^{-1}h^{-1}$ with an average value of 7.5 ± 0.3 mBq kg^{-1} h^{-1}. Calculated values of indoor inhalation exposure (radon) effective dose has been observed to vary from 15.7 ± 1.1 to 33.9 ± 1.0 μSv y^{-1} with an average value of 23.2 ± 1.0 μSv y^{-1}.

5.3.3 MEASUREMENTS OF RADON ACTIVITY, RADON EXHALATION RATE AND INDOOR INHALATION EXPOSURE EFFECTIVE DOSE IN CEMENT SAMPLES

Present study carried out measurements for radon exhalation rate in different cement samples mostly used for building construction. Samples were collected from different manufacturers and construction sites. Radon activity, Radon exhalation rate and mass exhalation rate measured in cement samples are given in Table-5.3. The Radon activity varies from 4.4 ± 0.6 to 17.9 ± 1.3 Bq m^{-3}. Radon exhalation rate and mass exhalation rate is found to vary from 28.7 ± 4.4 to 115.0 ± 8.8 mBq m^{-2} h^{-1} and 1.1 ± 0.1 to 4.4 ± 0.3 mBq kg^{-1} h^{-1} respectively. Whereas calculated values of indoor inhalation exposure (radon) effective dose are vary from 3.3 ± 0.5 to 13.5 ± 0.8 μSv y^{-1}. The Radon activity is found minimum for BIRLASAME and maximum for ULTRATECH. The exhalation rate and mass exhalation rate are found minimum for BIRLASAME and maximum for ULTRATECH. The value of indoor inhalation exposure (radon) effective dose has been found lower for BIRLASAME and higher for ULTRATECH also.

5.3.4 MEASUREMENT OF RADON ACTIVITY, RADON EXHALATION RATE, MASS EXHALATION RATE AND INDOOR INHALATION EXPOSURE EFFECTIVE DOSE IN FLY ASH SAMPLES (KOLAGHAT)

Coal is important material for power generation. In India more than 70% power generation contributes by thermal power generation. Indian coal is of bituminous type with 50-60% ash content amounting to 100 million tones of fly ash per year (Vijayan and Behra, 1999). Fly ash is also used in cement bricks and land filling. In recent years due to the use of fly ash in building materials, it has become a subject of worldwide interest. Radon exhalation rate is most important for the measurement of radiation risk in coal and fly ash. In our study coal and fly ash samples were collected from around Kolaghat thermal power plant that is one of the largest in eastern India. Situated 60 km WSW of Kolkata, the plant's installed capacity is 1260 MW (6 units, each unit of 210 MW capacities). Four ash ponds are present which operates alternately throughout the year. The neighboring area has high population density residing in localities present within a radius of few meters from the ash ponds. The results of the radon activity, radon exhalation rates and effective doses from the fly ash and coal samples are given in Table 5.4. Radon activity has been found to vary from 182.9 ± 18.6 to 262.9 ± 22.3 Bq m^{-3} with an average value of 217.7 ± 20.2 Bq m^{-3}. Radon exhalation rate vary from 66.0 ± 6.7 to 95 ± 8.0 mBq$m^{-2}h^{-1}$ with an average value of 78.4 ± 7.2 mBq m^{-2} h^{-1}, whereas mass exhalation rate is found to be vary from 2.5 ± 0.2 to 3.6 ± 0.3 mBq$kg^{-1}h^{-1}$ with an average value of 2.9 ± 0.2 mBq kg^{-1} h^{-1}. Calculated values of indoor inhalation exposure (radon) effective dose vary from 7.7 ± 0.7 to 11.1 ± 0.9 µSv y^{-1} with an average value of 9.1 ± 0.8 µSv y^{-1} in the fly ash samples around Kolaghat. The activity concentration of uranium (^{238}U) has been found to vary from 5.9 to 11.0 ppm with an average value of 7.6 ppm. Figure-5.2 shows the variation of uranium concentration and Radon exhalation rate in these fly ash samples. It seems positive correlation.

5.3.5 MEASUREMENT OF RADON ACTIVITY, RADON SURFACE EXHALATION RATE AND EFFECTIVE DOSES IN BUILDING MATERIALS

In the present study has been carried out measurements for radon exhalation rate in different building materials i.e. paints, fired unfired and plastered bricks, mostly used for building construction. Samples were collected from different manufacturers and construction sites. Radon activity and Radon exhalation rate estimated in building materials mostly used for building construction are given in Table 5.5. Radon activities are found to vary from 897.4 Bq m^{-3} (Red colour) to 1514.6 Bq m^{-3} (Yellow colour) with an average value of 1117.5 Bq m^{-3} Radon exhalation rate varies from 537.1 mBq m^{-2} h^{-1} to 906.5 mBq m^{-2} h^{-1} with an average value of 669.5 mBq m^{-2} h^{-1} whereas the indoor inhalation exposure (Radon) effective dose varies from 63.3 μSv y^{-1} (Red colour) to 106.8 μSv y^{-1} (Yellow colour) with an average value of 78.9 μSv y^{-1}. The result shows highest Radon exhalation rate 4162.8 mBq m^{-2} h^{-1} from unfired bricks. In the case of unfired bricks, there may be many voids and emanation can escape from inside i.e. from few cm below the surface and thus the amount of Radon that can escape should depend on the internal surface area while in plastered brick with different brands color of paints the number of voids are reduced to large extent and the Radon may be emanated from the surface layer only. The Radon exhalation rate from building materials varies appreciably from one building to another. This may due to the differences in radium content (Ramchandran et.al. 1989) and porosity (Folkerts et.al. 1984). As the exhalation depends, also on the texture and grain-size composition of the samples as well as on the moisture content, etc., it is difficult to predict the radon exhalation rate from the concentration of decay products only in the sample (Tufail M et.al. 1991).

5.3.6 MEASUREMENTS OF RADON ACTIVITY, RADON SURFACE EXHALATION AND MASS EXHALATION RATE IN FLY ASH SAMPLES (KASIMPUR)

The measured values of radon activities and radon exhalation rate in fly ash samples collected from Kasimpur thermal power plant are given in Table-5.6. Radon activities vary from 158.9 ± 14.9 to 332.1 ± 21.2 Bq m^{-3} with an average value of 243 ± 18.2 Bq m^{-3}.Radon exhalation rate were found to vary from 57.1 ± 5.3 to 119.4 ± 7.7 mBq m^{-2} h^{-1} with an average value of 87.3 ± 5.8 mBq m^{-2} h^{-1} whereas, mass exhalation rates (E_M) found to vary from 2.1 ± 0.3 to 4.5 ± 1.3 mBq kg^{-1} h^{-1} with mean value of 3.3 ± 0.7 mBq kg^{-1} h^{-1}.

5.3.7 MEASUREMENTS OF RADON ACTIVITY, RADON SURFACE EXHALATION AND MASS EXHALATION RATE IN SOIL SAMPLES (KASIMPUR)

The calculated values of radon activities, radon surface exhalation rates and mass exhalation rates in the soil samples collected from the surrounding area of Kasimpur thermal power plant, are presented in Table-5.7. Radon activities vary from 92.9 to 556.8 Bq m^{-3} with mean value of 279.8 Bq m^{-3}. Surface exhalation rates (E_X) in these samples are found to vary from 33.4 to 200.2 mBq m^{-2} h^{-1} with an average value of 100.5 mBq m^{-2} h^{-1} whereas, mass exhalation rates (E_M) vary from 1.2 to 7.7 mBq kg^{-1} h^{-1} with an average value of 3.8 mBq kg^{-1} h^{-1}.

5.3.8 MEASUREMENTS OF RADON ACTIVITY, RADON SURFACE EXHALATION, MASS EXHALATION RATE AND INDOOR INHALATION EXPOSURE IN SOIL SAMPLES (NTPC, BADARPUR)

Measured values of radon activities, radon surface exhalation rates, mass exhalation rates and Indoor inhalation exposure (radon) effective dose rates in the soil samples collected from surrounding area of NTPC (National Thermal Power Corporation), situated at Badarpur, Delhi are presented in Table- 5.8. Radon activities vary from 137.1 ± 17.1 to 485.7 ± 38.0 Bq m^{-3} with an average value of 303.93 ± 30.1

Bq m^{-3}. Surface exhalation rates in these samples are found to vary from 49.3 ± 6.3 to 174.7 ± 13.6 mBq m^{-2} $h^{-1}$with an average value of 109.3 ± 10.3 mBq m^{-2} h^{-1}, whereas, mass exhalation rates vary from 1.9 ± 0.2 to 6.7 ± 0.6 mBq kg^{-1} h^{-1} with a mean value of 4.2 ± 0.3 mBq kg^{-1} h^{-1}. Indoor inhalation exposure (radon) effective dose vary from 8.4 ± 0.5 to 29.6 ± 1.5 µSv y^{-1} with an average value 18.5 ± 1.1 µSv y^{-1}.

5.3.9 MEASUREMENT OF RADON MASS EXHALATION RATE IN SOIL AND FLY ASH SAMLPES (KASIMPUR)

Soil is also important environmental component of the source of continuous radiation exposure to human beings. It is widely used as building construction material in India like bricks formation and as filling materials etc. Coal produces large amount of fly ash after burning in the coal fired power stations. This fly ash is spread in surrounding area by air and may be deposited on the soil surface. Since coal contains ^{226}Ra, ^{232}Th and ^{40}K radionuclide so almost all naturally existing radionuclides are present in fly ash and hence may increase in the soil of the surrounding area. Thus it is quite important to measure the radon mass exhalation rate in the soil around the thermal power plant for the estimation of radiation risk to the habitants there. Soil samples were collected different increasing distances at the interval of 500 meters from the Kasimpur thermal power station as the amount of spread fly ash deposited on the soil. The measured values of radon mass exhalation rates in the soil and fly ash samples are given in Table- 5.10 and 5.11. The values vary from 9.5 mBq$kg^{-1}h^{-1}$ to 28.2 mBq $kg^{-1}h^{-1}$ with an average value of 17.7 mBq $kg^{-1}h^{-1}$. As shown in Table-5.10, that there is a linear decrease of radon mass exhalation value which favors that radon mass exhalation value decrease with distance. Figure-5.7 shows the variation of counts with time in hours in these soil samples. It seems positive correlation. The histogram plot of radon exhalation of the samples collected from various locations is

shown in Fig. 5.8. Whereas in fly ash samples radon mass exhalation rate varied from 10.3 mBq kg^{-1} h^{-1} to 17.6 mBq kg^{-1} h^{-1} with an average value of 13.5 mBq kg^{-1} h^{-1}.

5.4 CONCLUSIONS

- The Study of radon exhalation rate from all the building materials is essential to understand the individual contribution of each material component to the total indoor radon exposure.
- Present study concludes that the radon effective dose is lower than the action level i.e. 1 mSv for all the reported samples.
- It is found from the present study, that radon exhalation rates are lower for all the sand samples in comparison of other investigated samples.
- In the present study, radon exhalation rates are also lower for all the fly ash samples in comparison of the earlier studies samples.
- It has been found from the present study, radon exhalation rates are approximately same for all the cement samples, in comparison of the earlier study
- In this study the values of mass exhalation rate measured by Smart Radon Monitor are higher than measured by Sealed Can Technique.
- Large number of building construction material were investigated and found wide variation in radon exhalation rates and in effective dose. Unfired brick samples shows higher radon exhalation rates than fired brick samples. In the case of unfired bricks, there may be many voids and the emanation can escape from within bulk i.e. from few centimeters below the surface and thus the amount of radon that can escape should depend on the internal surface area while in fired brick the number of voids are reduced to a large extent and the radon may be emanated from the surface layer only.

Table-5.1

Sand Samples from Rushikulya beach place deposit

Samples	Track Density ($Trcm^{-2}d^{-1}$)	Radon Activity ($Bq\ m^{-3}$)	Radon Exhalation ($mBq\ m^{-2}\ h^{-1}$)	Mass Exhalation ($mBq\ kg^{-1}\ h^{-1}$)	Indoor inhalation exposure (radon)-effective dose ($\mu Sv\ y^{-1}$)
Sand-1	21.8 ± 1.3	388.5 ± 23.7	139.7 ± 8.5	5.3 ± 0.3	16.4 ± 1.1
Sand-2	28.0 ± 1.4	500.0 ± 26.5	179.8 ± 9.5	6.9 ± 0.3	21.0 ± 1.0
Sand-3	22.9 ± 1.3	408.6 ± 24.1	146.3 ± 8.6	5.6 ± 0.3	17.2 ± 1.1
Sand-4	29.6 ± 1.5	528.6 ± 27.5	190.0 ± 9.9	7.3 ± 0.3	22.4 ± 1.0
Sand-5	26.4 ± 1.4	471.4 ± 25.9	169.5 ± 9.3	6.5 ± 0.3	19.9 ± 1.2
Sand-6	32.8 ± 1.6	585.7 ± 28.7	210.6 ± 10.3	8.1 ± 0.3	24.8 ± 1.5
Sand-7	49.6 ± 1.9	885.7 ± 35.4	318.4 ± 12.7	12.2 ± 0.4	37.5 ± 1.3
Sand-8	50.9 ± 2.0	908.6 ± 36.3	326.6 ± 13.1	12.5 ± 0.5	38.5 ± 1.5
Sand-9	42.9 ± 1.8	765.7 ± 32.9	275.3 ± 11.8	10.5 ± 0.4	32.4 ± 1.6
Sand-10	54.1 ± 2.0	965.7 ± 36.7	347.2 ± 13.2	13.3 ± 0.5	40.9 ± 1.4
Sand-11	55.8 ± 2.1	997.1 ± 37.9	358.5 ± 13.6	13.8 ± 0.5	42.2 ± 1.1
Sand-12	46.4 ± 1.9	828.6 ± 34.8	297.9 ± 12.5	11.4 ± 0.4	35.1 ± 1.1
Avg. Value	38.4 ± 1.6	686.1 ± 20	246.6 ± 11.5	9.4 ± 0.4	29.0 ± 1.1
Max Value	55.8 ± 2.1	997.1 ± 37.9	358.5 ± 13.6	13.8 ± 0.5	42.2 ± 1.1
Min Value	21.8 ± 1.3	388.5 ± 23.7	139.7 ± 8.5	5.3 ± 0.3	16.4 ± 1.1

Table-5.2

Sand Samples from Gopalpur beach place deposit

Samples	Track Density ($Trcm^{-2}\ d^{-1}$)	Radon Activity ($Bq\ m^{-3}$)	Radon Exhalation ($mBq\ m^{-2}\ h^{-1}$)	Mass Exhalation ($mBq\ kg^{-1}\ h^{-1}$)	Radon effective dose ($\mu Sv\ y^{-1}$)
Sand-1	44.8 ± 1.8	800.0 ± 33.7	287.7 ± 12.1	11.0 ± 0.4	33.9 ± 1.0
Sand-2	25.6 ± 1.4	457.1 ± 25.5	164.0 ± 9.1	6.3 ± 0.3	19.3 ± 1.0
Sand-3	25.6 ± 1.4	457.1 ± 25.5	164.0 ± 9.1	6.3 ± 0.3	19.3 ± 1.2
Sand-4	35.2 ± 1.6	628.5 ± 29.9	225.7 ± 10.7	8.6 ± 0.4	26.6 ± 1.2
Sand-5	33.6 ± 1.6	600.0 ± 29.2	215.0 ± 10.5	8.2 ± 0.4	25.3 ± 1.1
Sand-6	28.8 ± 1.5	514.2 ± 27.2	184.7 ± 9.7	7.1 ± 0.3	21.7 ± 1.1
Sand-7	30.4 ± 1.5	542.8 ± 27.7	194.9 ± 9.9	7.5 ± 0.3	22.9 ± 1.2
Sand-8	32.0 ± 1.6	571.4 ± 28.5	205.2 ± 10.2	7.9 ± 0.3	24.2 ± 0.9
Sand-9	20.8 ± 1.2	371.4 ± 23.0	133.3 ± 8.2	5.1 ± 0.3	15.7 ± 1.1
Avg. value	30.75 ± 1.5	549.1 ± 27.8	197.1 ± 9.9	7.5 ± 0.3	23.2 ± 1.1
Max value	44.8 ± 1.8	800.0 ± 33.7	287.7 ± 12.1	11.0 ± 0.4	33.9 ± 1.0
Min value	20.8 ± 1.2	371.4 ± 23.0	133.3 ± 8.2	5.1 ± 0.3	15.7 ± 1.1

Table-5.3

Radon activity, exhalation rate and indoor inhalation exposure (Radon) effective dose in different cement samples

Sample make	Track Density ($Trcm^{-2}\ d^{-1}$)	Radon Activity ($Bq\ m^{-3}$)	Radon Exhalation ($mBq\ m^{-2}\ h^{-1}$)	Mass Exhalation ($mBq\ kg^{-1}\ h^{-1}$)	Radon effective dose ($\mu Sv\ y^{-1}$)
BHIWANI	15.3 ± 1.2	274.2 ± 22.7	98.5 ± 8.1	3.7 ± 0.3	11.6 ± 0.8
JKSUPESS	12.8 ± 1.1	228.5 ± 20.8	81.9 ± 7.4	3.1 ± 0.2	9.6 ± 0.5
ACC	4.8 ± 0.6	85.7 ± 12.7	30.5 ± 4.5	1.1 ± 0.1	3.6 ± 0.8
BANGUR	11.2 ± 1.9	200.0 ± 19.5	71.9 ± 7.0	2.7 ± 0.2	8.4 ± 0.8
AMBUJA	12.0 ± 1.1	214.2 ± 20.1	76.9 ± 7.2	2.9 ± 0.2	9.0 ± 1.1
SHREEWELTH	10.8 ± 1.0	194.2 ± 19.2	69.7 ± 6.9	2.6 ± 0.2	8.2 ± 0.7
ULTRATACK	17.9 ± 1.3	320.0 ± 24.6	115.0 ± 8.8	4.4 ± 0.3	13.5 ± 0.8
ROCKSTONE	9.6 ± 1.0	171.4 ± 17.9	61.4 ± 6.4	2.3 ± 0.2	7.24 ± 0.9
BIRLASAME	4.4 ± 0.6	80.0 ± 12.3	28.7 ± 4.4	1.1 ± 0.1	3.3 ± 0.5
JP	13.6 ± 1.2	242.8 ± 21.4	87.0 ± 7.7	3.3 ± 0.2	10.2 ± 0.8

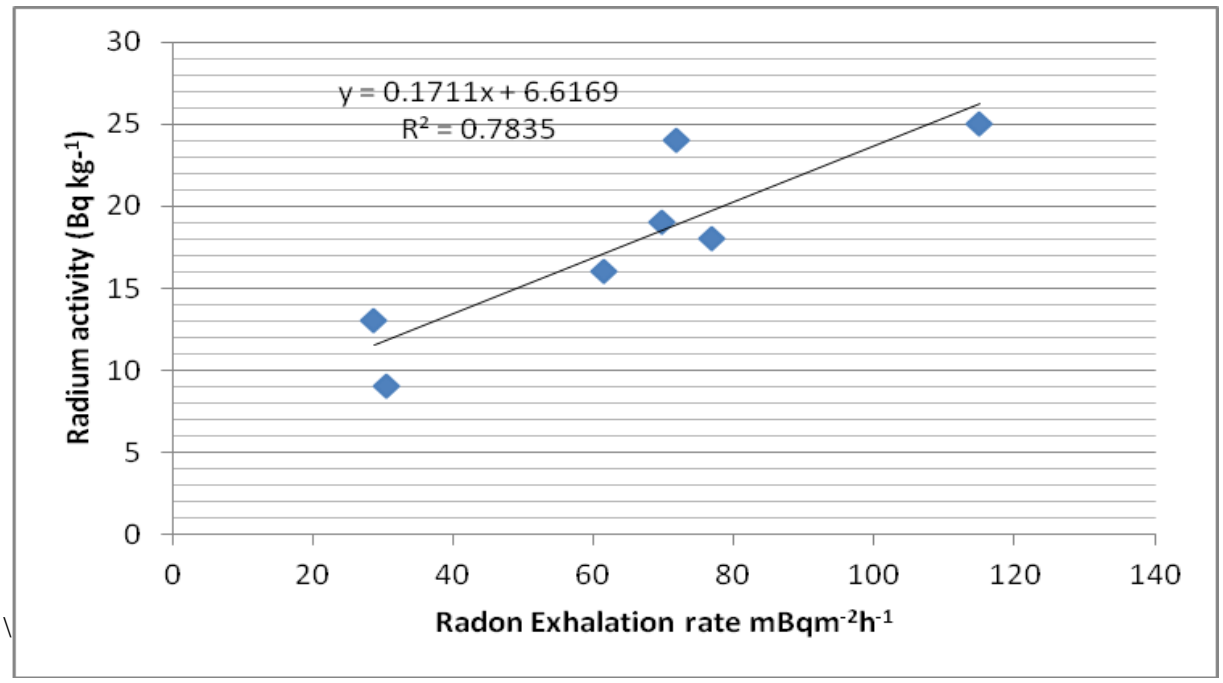

Figure-5.1 Linear regression coefficient between radon exhalation rate and radium activity of cement

Table-5.4

Radon activity, exhalation rate, indoor inhalation exposure (Radon) effective dose and activity concentration values for ^{238}U, in samples collected from the sun dried ash used as disposal ponds by Kolaghat Thermal Power Plant.

Samples	Track Density ($Trcm^{-2}\ d^{-1}$)	Radon Activity ($Bq\ m^{-3}$)	Radon Exhalation ($mBq\ m^{-2}\ h^{-1}$)	Mass Exhalation ($mBq\ kg^{-1}\ h^{-1}$)	Radon effective dose ($\mu Sv\ y^{-1}$)	^{238}U (ppm)
Kol_Slr	10.0 ± 1.0	182.9 ± 18.6	66.0 ± 6.7	2.5 ± 0.2	7.7 ± 0.7	6.6
Kol_1.1	14.0 ± 1.2	248.6 ± 21.7	89.3 ± 7.8	3.4 ± 0.3	10.5 ± 0.9	7.5
Kol_1.2	14.7 ± 1.2	262.9 ± 22.3	95.0 ± 8.0	3.6 ± 0.3	11.1 ± 0.9	11.0
Kol_1.3	11.0 ± 1.0	188.6 ± 18.9	68.0 ± 6.8	2.6 ± 0.2	7.9 ± 0.8	5.9
Kol_2.1	12.0 ± 1.1	205.7 ± 19.7	74.0 ± 7.1	2.8 ± 0.2	8.7 ± 0.8	7.3
Avg. value	12.2 ± 1.1	217.7 ± 20.2	78.4 ± 7.2	2.9 ± 0.2	9.1 ± 0.8	7.6
Max value	14.7 ± 1.2	262.9 ± 22.3	95.0 ± 8.0	3.6 ± 0.3	11.1 ± 0.9	11.0
Mini value	10.0 ± 1.0	182.9 ± 18.6	66.0 ± 6.7	2.5 ± 0.2	7.7 ± 0.7	5.9

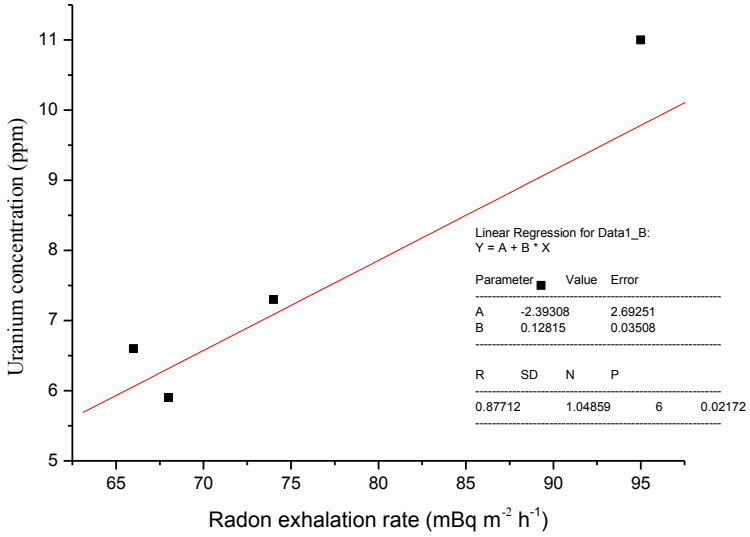

Figure-5.2 Linear regression coefficient between radon exhalation rate and uranium activity

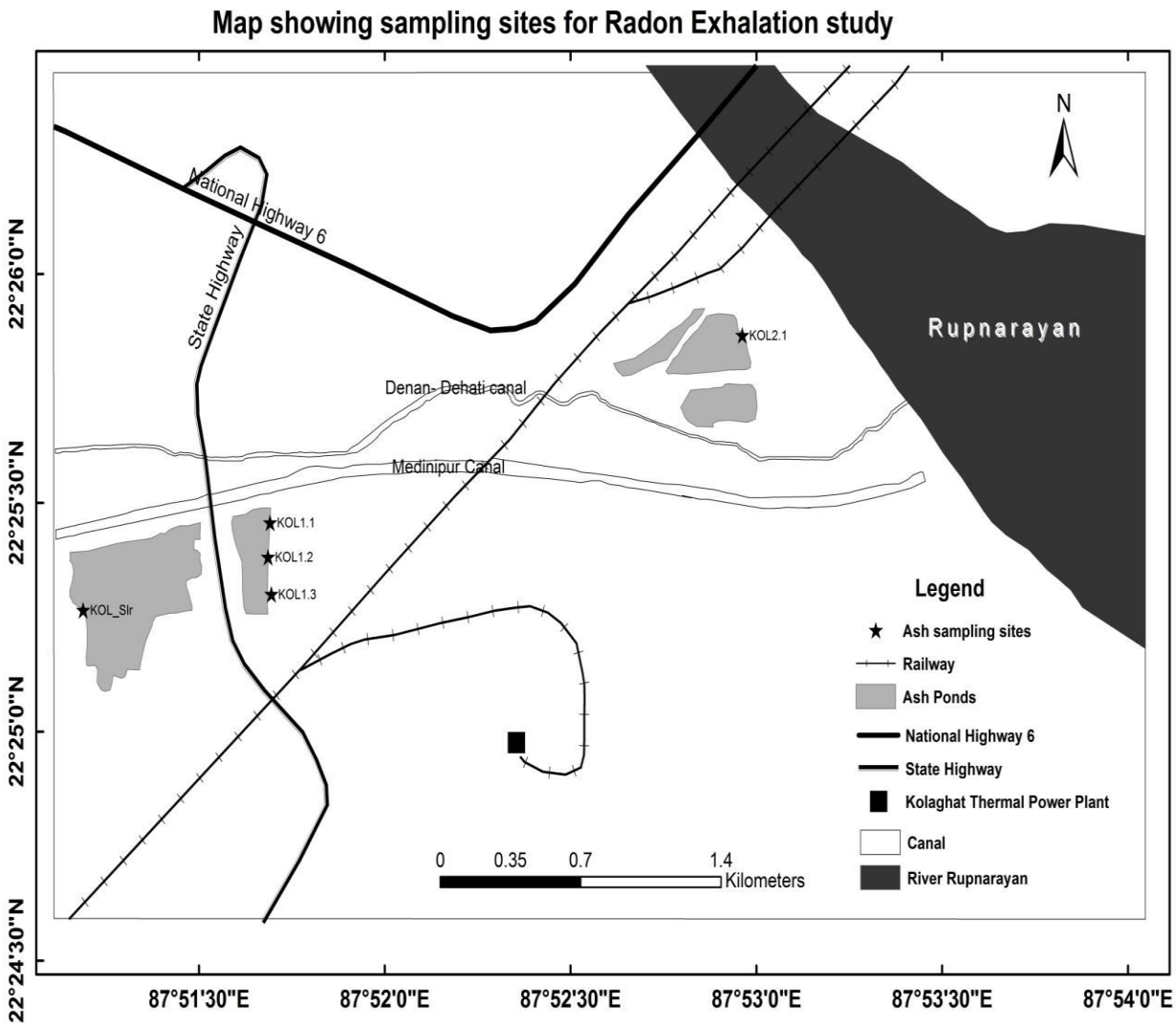

Figure 5.3 Map showing sampling sites for radon exhalation study

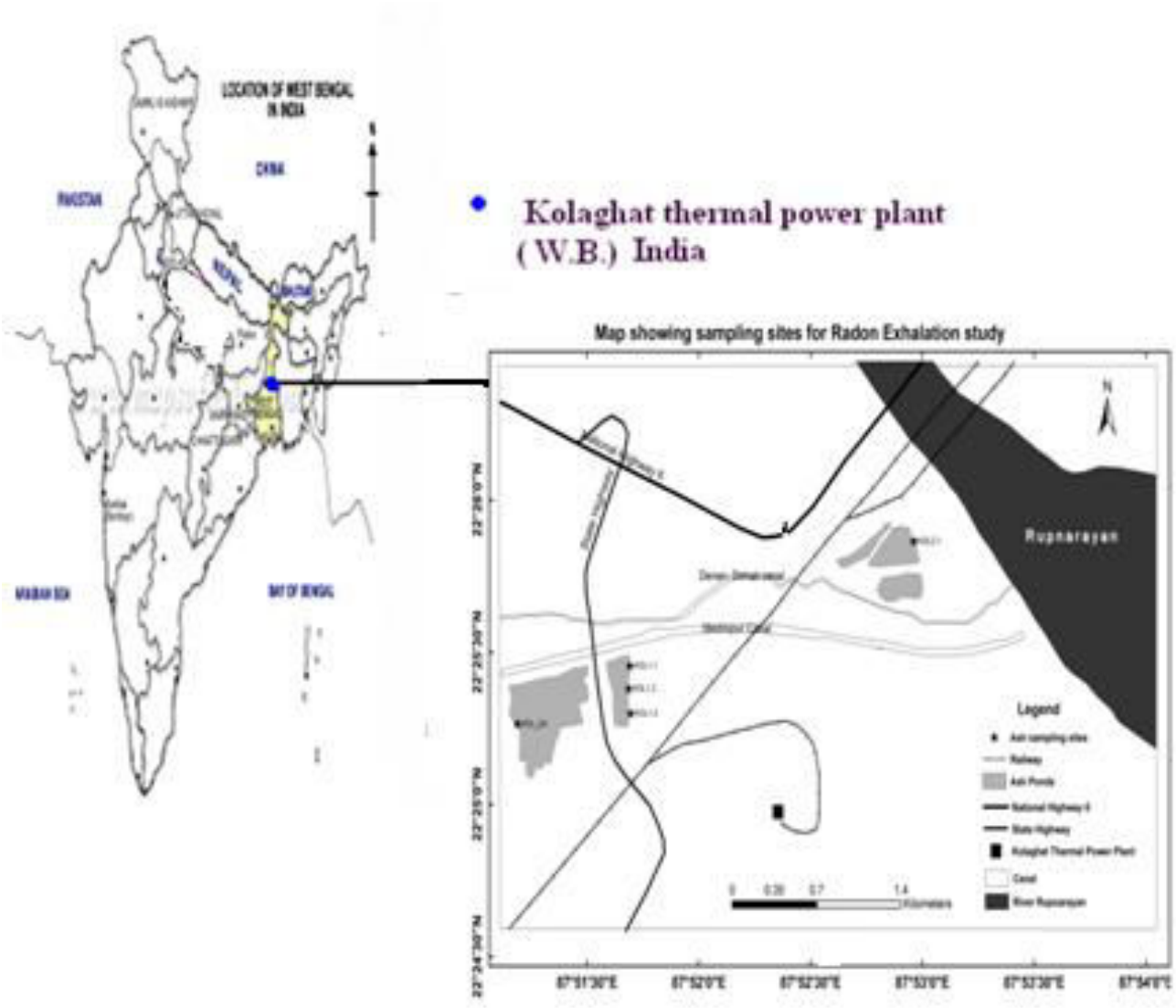

Figure 5.4 Location map of Kolaghat Thermal Power Plant (W.B.) India

Table-5.5

Track density, Radon activity, Radon exhalation rate, Indoor inhalation exposure (radon)-effective dose from paint, plastered, fired brick and unfired brick

Brand/Colors of Paint	Track Density ($Trcm^{-2}\ d^{-1}$)	Radon Activity ($Bq\ m^{-3}$)	Radon Exhalation ($mBq\ m^{-2}\ h^{-1}$)	Indoor inhalation exposure (radon)-effective dose ($\mu Sv\ y^{-1}$)
Unfired brick	385.5	6885..7	4162..8	490.8
Fired brick	47.6	850.7	514.3	60.6
Plastered brick	60.1	1073.0	648.7	76.4
Black	62.1	1108.2	663.3	78.2
Yellow	84.8	1514.6	906.5	106.8
Green	65.8	117.15	703.3	83.0
Red	50.2	897.4	537.1	63.3
Blue	53.6	956.6	572.5	67.5
Orange	72.1	1288.3	771.1	90.9
White	58.5	1044.0	624.8	73.7
Silver	56.0	1000.3	598.7	70.6
Avg. value	62.6	1117.5	669.5	78.9
Max value	385.5	6885.7	4162.8	490.8
Min value	50.2	850.7	514.3	60.6

Table-5.6

Radon activity and radon exhalation rate in fly ash samples from Kasimpur thermal power plant, Aligarh, Uttar Pradesh, India

Samples	Radon activity ($Bq\ m^{-3}$)	Radon exhalation rate ($mBq\ m^{-2}\ h^{-1}$)	Mass exhalation rate ($mBq\ kg^{-1}\ h^{-1}$)
FLYA-1	210.7 ± 17.2	75.7 ± 6.2	2.9 ± 0.5
FLYA-2	307.1 ± 20.0	110.4 ± 7.5	4.2 ± 1.1
FLYA-3	158.9 ± 14.9	57.1 ± 5.3	2.1 ± 0.3
FLYA-4	275.0 ± 19.8	98.8 ± 7.1	3.8 ± 0.9
FLYA-5	262.5 ± 19.1	94.3 ± 6.8	3.6 ± 0.7
FLYA-6	166.0 ± 11.9	59.7 ± 4.2	2.2 ± 0.3
FLYA-7	219.6 ± 17.5	78.9 ± 6.3	3.0 ± 0.7
FLYA-8	332.1 ± 21.1	119.4 ± 7.7	4.5 ± 1.3
FLYA-9	182.1 ± 16.2	65.4 ± 5.7	2.5 ± 0.5
FLYA-10	316.0 ± 21.1	113.6 ± 7.6	4.3 ± 1.1
Average Value	243.0 ± 18.2	87.3 ± 5.8	3.3 ± 0.7
Maximum Value	332.1 ± 21.1	119.4 ± 7.7	4.5 ± 1.3
Minimum Value	158.9 ± 14.9	57.1 ± 5.3	2.1 ± 0.3

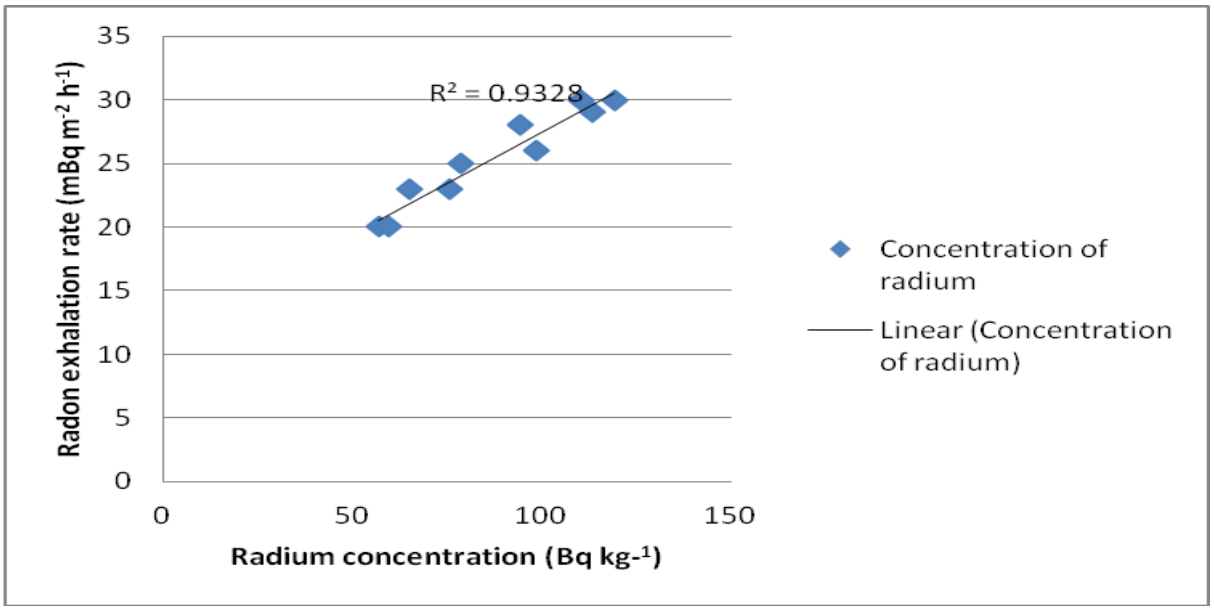

Figure-5.5 Linear regression coefficient between radon exhalation rate and radium activity of fly ash

Table–5.7

Radon activity, radon surface exhalation and mass exhalation rate in soil samples collected from the surrounding areas of KTPP, Kasimpur, Aligarh (U.P.), India.

Details of Samples	Radon activity (Bq m^{-3})	Radon surface Exhalation (mBq m^{-2} h^{-1})	Mass exhalation (mBq kg^{-1} h^{-1})
S-1	116.7	41.9	1.6
S-2	449.6	161.6	6.2
S-3	418.0	150.2	5.7
S-4	178.6	64.2	2.4
S-5	493.4	177.4	6.8
S-6	163.4	58.7	2.2
S-7	181.5	65.2	2.5
S-8	556.8	200.2	7.7
S-9	147.5	53.0	2.0
S-10	92.9	33.4	1.2
Average Value	279.8	100.5	3.8
Maximum Value	556.8	200.2	7.7
Minimum Value	92.9	33.4	1.2

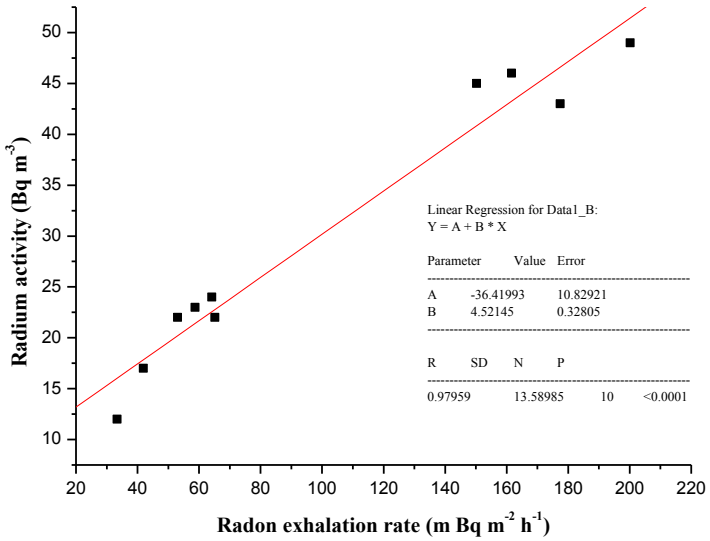

Figure-5.6 Linear regression coefficient between radon exhalation rate and radium activity of soil

Table 5.8

Radon activity and radon exhalation rate in soil samples collected from the surrounding areas of NTPC, Badarpur, Delhi, India.

Samples	Radon activity (Bq m^{-3})	Surface exhalation rate (mBq $m^{-2}h^{-1}$)	Mass exhalation rate (mBq $kg^{-1}h^{-1}$)	Indoor inhalation exposure (radon) effective dose (μSv y^{-1})
S-1	236.7 ± 26.2	85.1 ± 8.7	3.3 ± 0.3	14.4 ± 1.3
S-2	279.6 ± 28.1	100.6 ± 9.9	3.9 ± 0.4	17.0 ± 1.1
S-3	398.0 ± 33.6	143.2 ± 11.8	5.5 ± 0.5	24.3 ± 1.5
S-4	238.4 ± 26.8	85.7 ± 8.7	3.3 ± 0.3	14.5 ± 1.3
S-5	438.7 ± 35.8	157.8 ± 12.7	6.1 ± 0.5	26.8 ± 1.5
S-6	485.7 ± 38.0	174.7 ± 13.6	6.7 ± 0.6	29.6 ± 1.5
S-7	137.1 ± 17.0	49.3 ± 6.3	1.9 ± 0.2	8.4 ± 0.5
S-8	386.9 ± 32.7	139.2 ± 11.1	5.4 ± 0.5	23.6 ± 1.5
S-9	224.5 ± 25.2	80.7 ± 8.2	3.1 ± 0.3	13.7 ± 1.2
S-10	213.7 ± 24.1	76.9 ± 7.8	2.9 ± 0.3	13.0 ± 1.2
Avg. Value	303.9 ± 30.0	109.3 ± 10.3	4.2 ± 0.3	18.5 ± 1.1
Max. Value.	485.7 ± 38.0	174.7 ± 13.6	6.7 ± 0.6	29.6 ± 1.5
Min Value	137.1 ± 17.1	49.3 ± 6.3	1.9 ± 0.2	8.4 ± 0.5

Table-5.9

Comparison of radon exhalation rate in different building materials from other parts of India

S.No.	Sample	Radon exhalation rate(mBq $m^{-2}h^{-1}$)
1	Cement (Aligarh Region)	29.2 ± 3.2 to 122.5 ± 7.5 (Varshney et. al 2010)
2	Sand (W.B.)	1204 ± 25 (Kumar et al., 2008)
3	Fly ash (KAP)	436 ± 15 (Kumar et al., 2005)
4	Soil NTPC, Dadri (U.P.)	63.9 - 210.2 (Mahur et.al., 2013)
1	*Cement*	*28.7 ± 4.4 to 115.0 ± 8.8 (Present study)*
2	*Sand (Rushikulya beach)*	*246.6 ± 11.5 (Present study)*
	Sand (Gopalpur beach)	*197.1 ± 9.9 (Present study)*
3	*Fly ash (Kasimpur Thermal Station)*	*87.3 ± 5.8 (Present study)*
4	*Soil (Kasimpur Thermal Station)*	*100.5*
5	*Soil (NTPC, Badarpur, Delhi)*	*109.3 ± 10.3*

Table-5.10

Radon mass exhalation rate of soil samples

Sample Code	Sample Weight (in grams)	Radon Mass Exhalation Rate (mBq kg^{-1} h^{-1})
KTPSS-1 (inside)	100	28.2
KTPSS-2 (0.5 km)	100	23.8
KTPSS-3 (1.0 km)	100	20.7
KTPSS-4 (1.5 Km)	100	22.4
KTPSS-5 (2.0 km)	100	17.3
KTPSS-6 (2.5 km)	100	13.2
KTPSS-7 (3.0 km)	100	12.1
KTPSS-8 (3.5 Km)	100	9.5
KTPSS-9 (4.0 km)	100	11.2
KTPSS-10 (4.5 km)	100	10.6
Average		17.7

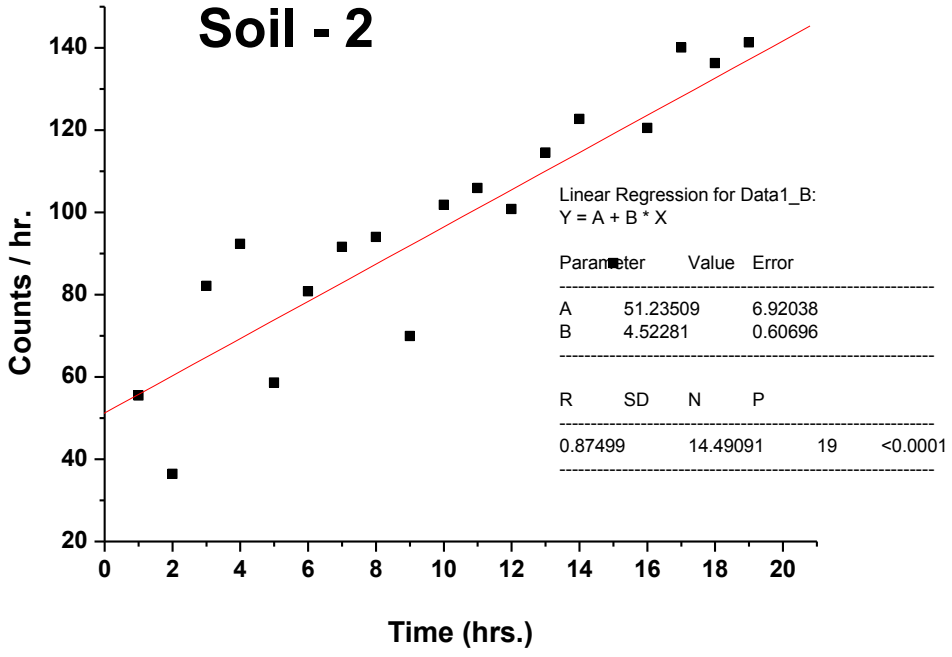

Figure 5.7 variations of count with time in hours in soil samples

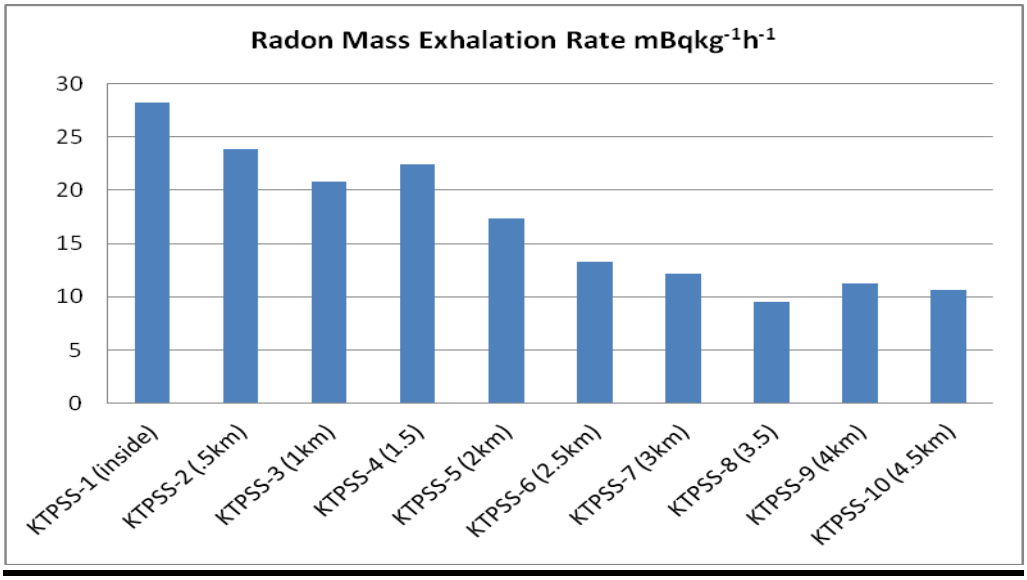

Figure 5.8 Bar diagram showing radon mass exhalation in soil samples from Kasimpur Thermal Power Station

Table-5.11

Radon mass exhalation rate of fly ash samples

Sample Code	Sample Weight (in grams)	Radon Mass Exhalation Rate (mBq kg^{-1} h^{-1})
KTPSFASH-1	100	14.2
KTPSFASH-2	100	17.6
KTPSFASH-3	100	13.7
KTPSFASH-4	100	11.9
KTPSFASH-5	100	16.8
KTPSFASH-6	100	10.3
KTPSFASH-7	100	12.2
KTPSFASH-8	100	15.2
KTPSFASH-9	100	10.8
KTPSFASH-10	100	12.9
Average value		13.5

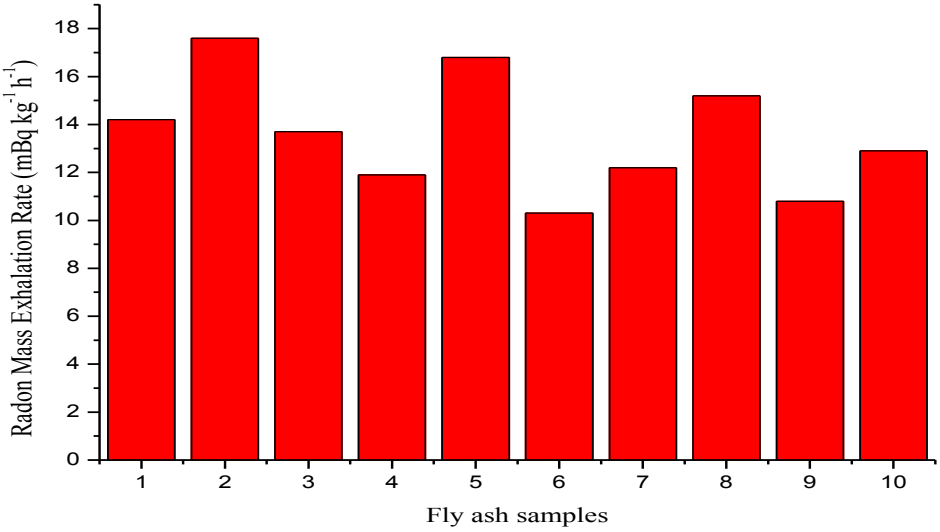

Figure 5.9 Bar diagram showing radon mass exhalation in fly ash samples from Kasimpur Thermal Power Station

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CHAPTER-6

CONCLUSIONS AND FUTURE PERSPECTIVE

Conclusions

Natural radioactivity in the environment is drawing the attention of world community and is of importance due to the toxicity and the cause of lung cancer. The risk of lung cancer in miners, working in uranium mines is known for a long time and has been related to radon exposure. Thus study of radionuclides (^{226}Ra, ^{232}Th and ^{40}K), radon exhalation, radon and its daughters is important for radiation risk assessment and felt necessary to measure the natural environmental radiation levels to have the base line for dose limit of public exposure. The risk of radiation exposure to radon gas and its daughter products from natural background has been highlighted and has becomes a matter of concern. Environmental Protection Agency (EPA) and National Commission on Radiation Protection and Measurements, USA have issued guidelines. International commission on Radiation Protection (ICRP) has put up a limit for radiation exposure.

This thesis elaborates the details of experiments conducted, instrument used and analysis of results in the present study. Gamma-ray spectroscopy technique using NaI (TI) detector at H.N.B. University Garhwal, Uttrakhand state of India was used for the measurement of natural radionuclides (^{226}Ra, ^{232}Th and ^{40}K) concentration (C_{Ra}, C_{Th} and C_K) in soil, fly ash coal and cement samples. Radon exhalation rate is of prime importance for the measurement of radiation risk from the various materials. There is a need for developing simple and efficient measuring method and performing intensive studies for getting representative data about the radiation levels due to waste and building construction materials for predication of the level of radiation risk from various solid samples. “Sealed Can Technique” was adopted for radon exhalation rate measurements in soil, fly ash, sand, cement and building construction materials used in our country. The application of track detectors to the microanalysis of uranium in samples such as soil, building materials, rocks etc. and to measure radon and its daughter products in indoor and outdoor environment is important for finding the source and to find ways to reduce them.

Various waste materials produced by chemical and metallurgical industry, power plants are being commonly used as building materials. The indiscriminate use of waste material may thus cause enhancement of indoor radiation exposure and may be radiation risk to the population. Radon data in some countries is being collected since decades due to its implication in causing lung cancer. But India lacks in having systematic data and our efforts are in this direction. We plan to carry out systematic measurements in our state, neighboring state for the measurement of total risk to human beings.

Future Perspective

In the present study an attempt has been made to carry out the total risk in environment by using different techniques. Prolongation of this study may lead to the various possible aspects in the field of environment risk assessment. Such kind of study needs to be repeated to get the update database for our state as well as our country. A few aspects are given below:

To study the environmental effects and human health risk due to radioactivity.

To study the indoor and outdoor radon concentrations in Indian dwellings

Publications

Anil Sharma, Ajay Kumar Mahur, Manjulata Yadav, R G. Sonkawade, A. C. Sharma, R. C. Ramola and Rajendra Prasad "Measurement of natural radioactivity, radon exhalation rate and radiation hazard assessment in Indian cement samples". **Physics Procedia 80 (2015) 135-139.**

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Ajay Kumar Mahur, **Anil Sharma**, R G. Sonkawade, D Sengupta, A. C. Sharma, and Rajendra Prasad "Measurement of Radon exhalation Rate in Sand samples from Gopalpur and Rushikulya beach Orissa, Eastern India". **Physics Procedia 80 (2015) 140-143.**

Anil Sharma, R G. Sonkawade, and A. C. Sharma. "Natural radioactivity and radiological hazard assessment of coal samples collected from Kasimpur Thermal Power plant, Kasimpur (U.P.), India". **Int. J. Low Radiation, Vol. 10, No. 2, 2015.**