ASSESSMENT OF FACTORS AFFECTING INDOOR RADON -222 CONCENTRATION IN DOME AND ITS ENVIRONS - GREATER ACCRA REGION OF GHANA

BY

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A Thesis submitted to the Department of Nuclear Science and Applications,
School of Nuclear and Allied Sciences,
University of Ghana

In partial fulfillment of the requirements for the award of the degree of

MASTER OF PHILOSOPHY

IN

NUCLEAR AND ENVIRONMENTAL PROTECTION

JULY, 2018

DECLARATION

This thesis is the result of research work done in Dome and its environs on the factors affecting indoor radon - 222 concentrations by Rita Kpordzro of the Department of Nuclear Science and Application, Graduate School of Nuclear and Allied Sciences, University of Ghana, under the supervision of Dr. Joseph K. Gbadago and Prof. Aba Bentil Andam.

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ABSTRACT

The objective of this study was to evaluate the contributions of the main factors of indoor radon concentration. This was achieved by measuring indoor and soil gas radon in three localities (Dome Afghanistan, Achimota Mile7 and Achimota ABC) in and around Ga East. 60 houses were selected in the three localities for the indoor measurements. Five sites were located in each of the localities for soil radon measurement at 75 cm depth. LR-115-type II plastic track detectors were used for the measurement in two different seasons – dry and wet. The indoor radon concentration measurement was carried out for three months in each season and the soil measurement was also carried out in a 14-day cycle for four cycles. The LR- 115-type II plastic track detectors were collected, etched at 60 ^{0}C and counted using the image j software and v-600 perfection scanner. The track densities obtained were converted into radon concentrations. The International Commission on Radiological Protection (ICRP) publication 115 model was used to estimate the annual absorb dose and effective dose to the lungs. Significant seasonal variations were observed in the radon concentrations of the dwellings studied. Indoor radon concentrations for the rainy season showed relatively high values than that of the dry season. This was expected as the sliding windows used for the dwellings are not opened during the rainy season. This might have resulted in the accumulation of radon gas in the rooms. Regular opening of windows and other means of providing air exchanges in the rooms during the dry season could have also accounted for the low levels of indoor radon concentration. The mean indoor radon concentration in the rainy season for Dome Afghanistan, Achimota Mile7 and Achimota ABC were determined to be 165 Bq/m^3, 115 Bq/m^3 and 119 Bq/m^3 respectively. The corresponding dry seasons were 71

Bq/m^3, 73 Bq/m^3 and 66 Bq/m^3 respectively for the three localities. The annual effective dose (AED) in the dwellings for Afghanistan ranges from 4.8 mSv/y to 20.2 mSv/y and that of Achimota Mile7 and Achimota ABC ranged from 3.23 to 13.9 mSv/y and 3.5 to 10.74 mSv/y respectively. According to ICRP Publication 115 (2010) statement on radon, the upper value for radon reference level of 300 Bq/m^3 corresponds to an AED of 17 mSv/y. Thus the three localities are generally found to fall within the ICRP (2010) limit; however, dwelling AF H17 of Dome Afghanistan recorded indoor radon concentration of 334.10 Bq/m^{-3} with a corresponding AED of 20.2 mSv/y. These are relatively higher than the ICRP limit. The soil radon measured in both seasons was higher than the corresponding indoor radon concentrations. The concentration ranges from 0.37 to 1.19 kBq/m^3 and 1.43 to 4.23 kBq/m^3 in the rainy and dry seasons respectively. The concrete floors and blocks of the dwellings seemed to have provided shielding and prevented high radon diffusion from the ground and outdoor into the dwellings. Works already done on the same building materials showed that the radon exhalation rate from these materials ranged from 17.5 to 42.6 Bq/m^3. This suggested that the major possible contributing factor to indoor radon concentration in dwellings is lack of ventilation which leads to the build-up or accumulation of radon. A linear correlation analysis for the influence of soil radon concentration on indoor radon concentration in rainy and dry season, gave an R-squared value of 0.0032 and 0.0021 respectively, indicating a weak negative correlation between soil radon concentration and indoor radon concentrations. This confirms that the indoor radon concentration is weakly linked to the soil radon, possibly as a result of the concrete floor and blocks which provided good shielding.

DEDICATION

This work is dedicated to all the members of my family, more especially to my lovely husband Mr. Isaac Yaw Kpordzro and my beautiful children Rita Asomaning, Malvin Selasi Kwame Kpordzro and Christabel Awuraabena Mawuena Kpordzro, my grandmother, Lady Grace Amoh and my parents, Mr and Mrs Odei.

ACKNOWLEDGEMENTS

Firstly, I would like to thank the Almighty God, for given me the strength throughout this journey to another level of my education. My sincere gratitude goes to my supervisors Dr. Joseph K. Gbadago and Prof. Aba Bentil Andam for making time and reading through this thesis, God bless you so much. Dr. Irene Nshiah Akoto, I will never forget the immense contribution you made for this thesis to become a success, God bless you. My Special thanks goes to Dr.Okoh Kpeglo, Dr.Oscar Adukpo, Dr. Francis Otoo, Mr. Samuel Osei and all other Senior colleagues working at the Radiation Protection Institute, may God give you grace to continue the good work. I also thank Mrs. Patience Safo, Mr. Maruf Abubakar, Ms. Lillian Attah Agyeman, Ms. Bernice Konadu Agyeman and Mr. Mawulie Ameho for all the assistance you gave me during the laboratory analysis. I will forever be grateful. To the Scientists and Technicians at the Nuclear Track Detection Laboratory of the National Nuclear Research Institute (NNRI) of GAEC for all the encouragement you gave me, God bless you. I am indebted to my husband and children for their diverse contribution throughout this journey, I will forever be grateful. My sincere thanks goes to the Assemblymen of Dome, Achimota Mile7 and Achimota ABC who helped me with personnel to go to the field during sampling, I say God bless you all. Finally to all my lecturers at the School of Nuclear and Allied Science (SNAS) especially Rev. Dr. Akoto Bamford, Dr. Klutse, Dr. Gyampo and all my course mates, may the almighty God bless us all.

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ABREVIATIONS AND ACRONYOMS

AED : Annual Effective Dose

Bq/m^3: Becquerel per cubic meter

Bq/kg: Becquerel per kilogram

BEIR: Biological Effects of Ionizing Radiation

CONC: Concentration

GPS : Global Positioning System

IAEA: International Atomic Energy Agency

ICRP: International Commission on Radiological Protection

MDA: Minimum Detectable Activity

Ra 222: Radon

U-238: Uranium-238

UNSCEAR: United Nation Scientific Committee on the Effect of Atomic Radiation

WHO: World Health Organization

SSNDTs: Solid State Nuclear Tracks Detectors

NAS: National Academy of science

EPA: Environmental Protection Agency

USEPA: United State Environmental protection Agency

M.Phil. Master of philosophy

R.P.I: Radiation Protection Institute

CHAPTER 1

INTRODUCTION

1.1 Background

Radon is a noble gas according to the periodic table. It does not interact with other compounds (very few chemical removal processes occur) and tends to travel significant distances in air water or soil, especially if the soil is porous (Cember, 2000). At a standard temperature and pressure (STP) of around 1.217 kg/m^3 at sea level, the density of radon is about 8 times that of the Earth's atmosphere. This makes radon gas stands out, being the heaviest among the other noble gases (Ameyibor and Wiredu, 1989). Radon comes naturally from the parent, radionuclide radium- 226, and from the uranium-238 break down series it is the fifth. It takes 3.82 days for it to lose half of its activity in the environment, thereby making it easier to diffuse through the soil even into the air before decaying by emitting alpha particles (Darby, 2006). Radon has three natural isotopes, namely, radon-222, radon-220 and radon-219 (^{222}Rn, ^{220}Rn and ^{219}Rn). ^{222}Rn (radon-222) is the most stable isotope amongst them. The commonest Earth radioactive elements are uranium and thorium, with long half-life ranging from about three minutes to 4.4 billion years, As a result, radon will remain in ages to come due to the regeneration from its ore (US EPA, 1999). Relatively high levels of radon emissions are associated with particular types of bedrock and unconsolidated deposits, for example, some granites, uranium-enriched phosphatic rocks, and shales rich in organic materials. Uranium concentrations also sometimes occur in limestones, sedimentary ironstones, and permeable sandstones Appleton, (2007).

However, areas having a higher concentration of uranium in their soil and rocks

beneath, may record a low indoor radon concentration in their dwellings. On the other hand those dwellings where the soil and rocks beneath contains low uranium concentrations can have high indoor radon concentrations.

(https://certmapper.cr.usgs.gov/data/PubArchives/radon/georadon/3.html)

In the 1970s, alum shale (vine J.D et al., 1970) was discovered in some building materials in which high amount of radium was found. Aside the indoor radon generated by these building materials, radon infiltration through soil was also discovered as an additional source. Outdoor radon also adds up to indoor radon but its concentration is of minor importance (WHO, 2009). Natural energy sources such as gas and coal used for cooking were also found to contain traces of Uranium-238. Water stored in dwellings, also adds up to the high health risk to indoor radon inhalation in homes (Cothern, 1987). Radon can also be found in well water which is used in various ways by individuals at home; for bathing, washing of clothes, dishes, and flushing of toilet and sometimes drinking. In carrying out these activities, radon is released from the water and contributes to the health hazards. UNSCEAR (2000) established that, the progenies of radon, for example $^{210}P_b$ and $^{210}P_o$ discharge along the inner walls of the thoracic which serves as the entering point to the bronchial epithelium (Kendall et al., 2002). For this reason, countries worldwide have reasoned together for standardized radon concentration levels above which measures are taken (WHO, 2009). Numerous studies have been done globally in order to determine radon levels. An investigation of factors influencing indoor radon concentrations in dwellings of Northern Rajasthan, India has been done. Efforts have been made to find possible relationships of indoor radon levels with building construction materials, ventilation condition of dwellings and soil gas radon levels. Indoor radon measurements were made using LR-115 type II cellulose nitrate films and the

concentrations were estimated by knowing the track density of films through optical microscope. Soil gas radon levels were measured using RAD7; this study sheds light on the seasonal indoor radon activities in Rajasthan dwellings. Maximum values of the indoor radon concentration were observed during the winter and minimum during the summer season. Results show that ventilation rate is inversely proportional to radon level. Highest level of indoor radon concentration was found in the mud type dwellings compared with dwellings made of concrete, cement and marble. A positive correlation (R^2 = 0.45) between indoor radon and soil gas radon concentration was observed. A weak positive correlation (R^2 = 0.22) was observed between soil gas radon concentration and radium content in soil. Indoor radon concentration was found to be associated with the presence of radon concentration in local soil, building material used for roof, floor and walls, type of ventilation conditions and presence of cracks on the walls/floor. Positive correlation between indoor and soil gas radon concentration suggest the large contribution of local soil towards indoor radon. (Vikas Duggal, 2015). Indoor radon measurements in residential dwellings in Qom, Iran have been studied. This was done with the aim of determining the concentration of indoor radon in the city of Qom located in the central semi-arid region of Iran. 123 dwellings, using passive sampling with CR-39 detectors for 90 days were monitored. Indoor radon concentrations in Qom dwellings ranged from 15–259 Bqm^{-3} The arithmetic mean of indoor radon concentrations on basement, ground floors, first floors and second and upper floors were ,87.94 ,123.43 63.72and 40.69 Bqm^{-3} , respectively. A correlation was found between the distances from fault zones and measured indoor radon concentration. In most cases, radon values were lower in well-ventilated dwellings in comparison with poorly-ventilated ones. Moreover, high radon concentration levels were observed in basements. The results indicated that in

30 places (24.3% of cases), the radon concentrations were higher than the reference levels recommended by the World Health Organization (100 Bqm^{-3}). Assessment of seasonal indoor radon concentration in dwellings of Western Haryana using the LR-115 Type II plastic track detectors in bare mode were used for the measurement of indoor radon. This was done annually. The calculated annual average indoor radon concentration values vary from 126.3 Bq m^{-3} to 172.1 Bq m^{-3} with an average value of 145.21 Bq m^{-3}, which is less than the recommended action level (200–300 Bq m^{-3}). The values of annual effective dose vary from 2.16 mSv/**y** to 2.94 mSv/**y** which is less than the lower limit of the recommended action level (3–10 mSv). The measured values of lifetime fatality risk vary from 1.67 to 2.27 with an average value of 1.92. The winter to summer ratio calculated for the studied dwellings ranges from 0.86 to 2.15 with an average of 1.46. The results indicate**d** that**,** the indoor radon concentration is higher in winter season than in the summer season. An attempt has also been made to find a correlation between the ventilation conditions and the measured values of indoor radon concentration. In most of the cases the radon values are less in well ventilated houses than partially/poorly ventilated houses. The measured indoor radon concentration values for the studied area are on the higher side than the world average of 40 Bq m^{-3} (Mehra et al., 2011). Similarly, a Radon-222 measurement was carried out in the offices of the university campus of Nigeria. Measurements were done using the passive type radon monitors (CR-39) this was done between a period of three months, and at the end of the arithmetic mean and standard deviation of the Radon-222 levels as 293.3 +9.6 Bqm^{-3}, respectively. The geometric mean was 283.6 Bqm^{-3}. All the values were lower the action level recommended by the ICRP (1993) for workplaces. The mean annual effective dose to the public from Radon-222 was known to be 1.85mSv/y (Obed, et

al, 2010). Thus the presence of indoor radon in homes and workplace can occur in different ways apart from uranium exhalation from underlying rocks and soils. There is therefore the need for a holistic approach to indoor radon concentration measurements.

In Ghana, not much research has been done on radon. There are ongoing data compilations for future mapping of radon. Preliminary studies on indoor radon measurements have been carried out in some selected Adobe houses in the Kassena Nankana in the Upper East Region. Measurements were done using the Solid-State Nuclear Track Detector (SSNTD). The results obtained from these were that 38% of the Adobe houses had increased levels of indoor radon concentration. And the increase level was attributed to construction materials used, poor ventilation, and the lifestyle of occupants were cited. Indoor radon concentration survey was also carried out in some selected homes in Aburi municipality, and the results indicated progressive monthly variation. Most of these values were within the action level set by the ICRP (1993), but some homes may require some mitigation when compared with the WHO reference value of 100 Bqm^{-3}.These high radon concentrations were also attributed to the poor ventilation, The construction materials used for the building, the age of building, then dust accumulation in rooms (Yeboah, et al., 2014).

Natural background radiation monitoring in some selected modern and traditional residences in Dome, Ga East municipal, using SSNTD technique was carried out in three phases within a period of nine months (Oppon et al., 1990). At the end of the survey, an average of twenty eight percent of the total residences monitored in all the three phases had radon level indoor exceeding the 150 Bq/m^3 (ICRP, 1993). Based on these results, a confirmatory study on indoor radon levels was done in three months in some selected modern homes using the same methodology (Nsiah-Akoto et al., 2010).

The outcome confirmed that indoor radon concentrations in all the modern homes were above the recommended action level (ICRP, 1993). In all these studies, it was clear that the indoor radon concentration may be influenced by a host of factors including air leakage from the outdoor, window and doors to indoor; construction materials indoor, and emanation from soil and rock beneath. This research is a follow-up to the work done by Nsiah-Akoto et al., (2010), and it intends to focus on the radon emanation from ground. This will be done by carrying out soil radon measurement, at 75cm depths and indoor radon concentration measurement. Thus, the presence of indoor radon in a home and workplace can occur from divisors ways, there is therefore the need for a holistic approach to indoor radon concentration measurement, to understand and appreciate to some extent the major source of indoor radon in dome and the other environs.

1.2 Problem Statement

Modern residences are constructed with materials which may aid radon exhalation. Glasses used for windows remain closed in the absence of occupants throughout the day and this prevents exchange of air between indoor and outdoor. Radon-222 gas transported from the ground by pressure induced convective flows or diffusion may find its way into a dwelling through fractures in concrete slabs, pores and fractures in concrete blocks, mortar joints, loose fitting pipe penetrations and stored water amongst others. Thus, indoor radon-222 concentration may be influenced by four major factors, diffusion from the ground, diffusion from outdoor, exhalation from building materials and, ventilation and air leakage from outdoor to indoor (Abdallal and Jastaniah, 2013). Measuring indoor radon concentration gives a gross idea on the contribution of all these factors; however, a good mitigation approach can only be put

in place if the contribution from each of the sources or factors is known. Oppon et al., (1990) and Nsiah-Akoto et al., 2010 measured indoor radon concentrations in some selected modern residences in Dome, Ga East Municipal. According to them, concentrations of radon indoor which was measured exceeded the reference level of 200-600 Bq/m^3 (ICRP, 1993).However; no thorough investigation was done on any of the sources or factors that might have contributed to this level of concentration. The potential long term hazards associated with indoor radon calls for concern and there is therefore the need to investigate the contributing sources or the factors in order to make the appropriate recommendations to regulatory bodies including Town and Country Planning and the Ministry of Local Government who has an oversight responsibility over the district assemblies.

1.3 Relevance of Work

This study will help generate data on radon emanating from the ground in the study area and also help to some extent in understanding the effectiveness of all the other factors such as the floor concrete, nature of ventilation, exhalation from building materials and diffusion from outdoor. This information could be useful to the land use and spatial Planning Authority on the specifications for building designs. The data obtained will add to the available data base on radon to aid in the formulation of radiation protection guidelines and reference values for radon and progenies. It will also breed more research into indoor radon in the other parts of the country.

1.4 Objective of the study and tasks to be performed

The objective of this work is to evaluate the contributions of the main factors of

indoor radon concentration in Dome and its environs of the Ga East Municipality. Evaluation of the main factors would help in the estimation of their total contribution to the indoor concentration. The evaluation was done by soil radon measurement using SSNTD at 75 cm deep. The SSNTD would be hanged in the buildings about 1.5 m from the floor, an average breathing level. The difference between the soil and indoor radon measurements could help in determining the contribution of the main factors to indoor radon concentration.

1.5 Scope and Limitation of Work

Major factors that could be covered in the measurements of indoor radon concentration are diffusion from the ground soil, diffusion from outdoor, exhalation from building materials, water and, ventilation and air leakage from indoor to outdoor (Abdallal and Jastaniah, 2013). However, this work is limited to measuring radon from the soil and indoor. The measurement will be done using SSNTDs in the soil at 75 cm deep and indoor. The other factors will be estimated from the values obtained and from other studies. The study area covers parts of Dome Afghanistan, part of Achimota-ABC and Achimota-mile7. These areas were chosen because of the previous works done.

1.6 Structure of Thesis

This research work is delivered in chapters of one up to five Chapter 1 covers the background of work, the problem statement, objectives, relevance of the work, scope and limitations. The chapter two is on literature review. Materials and methods in chapter three, Results and discussions in chapter four, then finally, the conclusion and recommendations are presented in chapter the five.

CHAPTER 2

LITERATURE REVIEW

2.1 Radon

Radon is a colorless chemically-uncreative inert gas. The atomic radius is 1.34 angstroms and it is the heaviest known gas. Radon is nine times denser than air. Because it is a single atom gas, it easily penetrates many common materials like paper, leather, low-density plastic most paints, and building materials like gypsum board, concrete block, mortar, sheathing paper, wood paneling, and most insulation (Radon Fact Sheet, 2018). Radon-222 is known to be the largest contributor to population exposure to radiation and might be responsible for a large number of lung cancer cases each year. It forms about 55 % of natural sources of radiation (NCRP, 1984). Radon is also fairly soluble in water and organic solvents. Although reaction with other compounds is comparatively rare, it is not completely inert and forms stable molecules with highly electronegative materials. It is considered a noble gas that occurs in several isotopic forms and only two are found in significant concentrations in the human environment: radon-222, and radon-220. Radon-220 originates from the decay chain of thorium-232 and radon-222 from uranium238. Radon-220 is difficult to measure because of its short half-life of 55.6 seconds. This makes emanation of radon-220 from the soil into a building difficult.Radon-222 most readily occurs in the environment and this study is focused on radon-222.

As indicated in table 2.1, the atmospheric releases of radon-222 results in decay product which are able to attach themselves to other airborne materials such as dust and other materials facilitating inhalation (Radon Fact Sheet, 2018)

The primary routes of potential human exposure to radon are inhalation and ingestion. Radon in the ground, groundwater, or building materials enters working and living spaces and disintegrates into its decay products. Although high concentrations of radon in the groundwater may contribute to radon exposure through ingestion, the inhalation of radon released from water is usually more important. Testing is the only way for radon levels to be known in the home. There are no immediate symptoms that will give an alert to the presence of radon. It typically takes years of exposure before any problems surface. The US EPA, Surgeon Generals, American Lung Association, American Medical Association, and National Safety Council recommend measuring radon levels at homes in order to know the extent of its presence. Considering that most people especially the non-occupational group spent about 80% of their time in homes, domestic investigation into radon has become globally accepted.

In the United States of America, radon is seen as a national environmental health problem. Elevated radon levels have been discovered in every state. The United States Environmental Protection Agency (USEPA) estimates that as many as 8 million homes throughout the country have elevated levels of radon. Current state surveys Show that 1 in 5 homes have elevated radon levels. (Radon Fact Sheet, 2018) (Radon Fact Sheet: (https://www.radon.com/radon_facts/) Downloaded on 27/07/2018 at 11.00 am).

Table 2.1: Important Characteristics of the 238U- Decay Series (Gbadago, 2010)

Radionuclide	Half-life*	Main mode of decay	Gamma energies (keV) and intensities (%)
^{238}U	4.5×10^9 y	A	**49.55 (0.06 %), 113.5 (0.01%)**
^{234}Th	24.0 d	β, γ	**63.29 (4.8 %), 92.38-92.8 (5.6%)**
^{234m}Pa	1.2 m	β, γ	**1001.03 (0.837 %)**
^{234}U	2.5×10^5 y	α, γ	**120.9 (0.0342%), 53.22(0.1232%)**
^{230}Th	7.7×10^4 y	α, γ	**67.672 (0.38 %), 253.729 (0.11%)**
^{226}Ra	1.6×10^3 y	α, γ	**186.211 (3.59 %)**
^{222}Rn	3.83 d	A	**510 (0.07 %)**
^{218}Po	3.1 m	A	-
^{214}Pb	27 m	β, γ	**351.932 (37.6 %), 295.22 (19.3%)**
^{214}Bi	20 m	β, γ	**609.312 (46.1 %)**
^{214}Po	1.6×10^{-4} s	α, γ	**799.7 (0.010 %)**
^{210}Pb	22.3 y	β, γ	**46.539 (4.25 %)**
^{210}Bi	5.01 d	β, γ	**265.6 (50.0 %)**
^{210}Po	138 d	A	**803.13 (0.0011%)**
^{206}Pb	**stable**	**None**	-

* y = years, d = days, m = minutes and s = seconds

2.1.1 Parameters contributing to Indoor Radon

In most cases the high level of radon gas in buildings sprang up from areas where the underlying environment is rocky (Castren et al., 1985). When there is an available root linking the soil and the structure, radon can diffuse into the dwelling.

The entry of radon gas from beneath the soil into the dwelling is largely enhanced by pressure induced convective flows or diffusion (de Meijer et al., 1992). Thus air pressure plays significant role in the transportation of radon between the soil and the dwelling. Density of the floor surface of dwellings is another important parameter for soil to dwellings transportation. The rate at which radon gas is released from the soil into the ambient air is also another parameter. When there is a built up of pressure in a room or indoor as a result of poor ventilation between the basement and the ground it can pull radon from the underlying soil into the room. Materials used in most building structures contribute to indoor radon concentration, aside exhalation of radon from the underling soil. Human exposure to radon gas in large buildings like schools, commercial and multiunit residences, may vary according to the structural design. The occupancy rate, temperature in the structure and the ventilation systems play important roles in the design of a structure. All living things are exposed to ionizing radiation depending on the location and altitude (USCEAR, 2000). Outdoor air is mostly referred to as ambient air. The radon levels in outside air are quite low and usually considered as background but the Indoors are generally high. The concentration of radon in the outdoor air is linked up with the pressure in the atmosphere. When radon is released from the atmosphere, it quickly dilutes to a very low concentration and this is not harmful. The average concentration of radon outdoor varies from 5–15 Bq/m^3. Outdoor radon is highly influenced by moisture content of the ground (http://www.int.mediacentre/factsheets/ Fs291/en/).

Radon in water is partially soluble; Water is drawn into concrete by the capillary action of the pores in concrete or pushed in by hydrostatic pressure (seepage). The higher temperature and lower pressure indoors release the dissolved gas. Water in pits also releases radon. Water from underground wells and bore holes most often contains elevated amount of radon than in surface water such as the lakes and rivers. According to Ghana Statistical Service report in 1984, approximately 40.7 % of total population depends on the ground water supply in Ghana. The Ghanaian Environmental Protection Agency (EPA), recommended that all ground water or partial ground water be it domestic water supply be tested for radon under a proposed regulation, accordingly, every district should develop a well enhanced radon in water program to meet 4,000 pCi/L (https://www.epa.gov). These will help in achieving a standard for radon in drinking water. Water from this source is used in the home for cooking washing flushing of toilet for bathing and so on. Figure 2.1. depicts a picture of radon entry into homes WHO (2009)

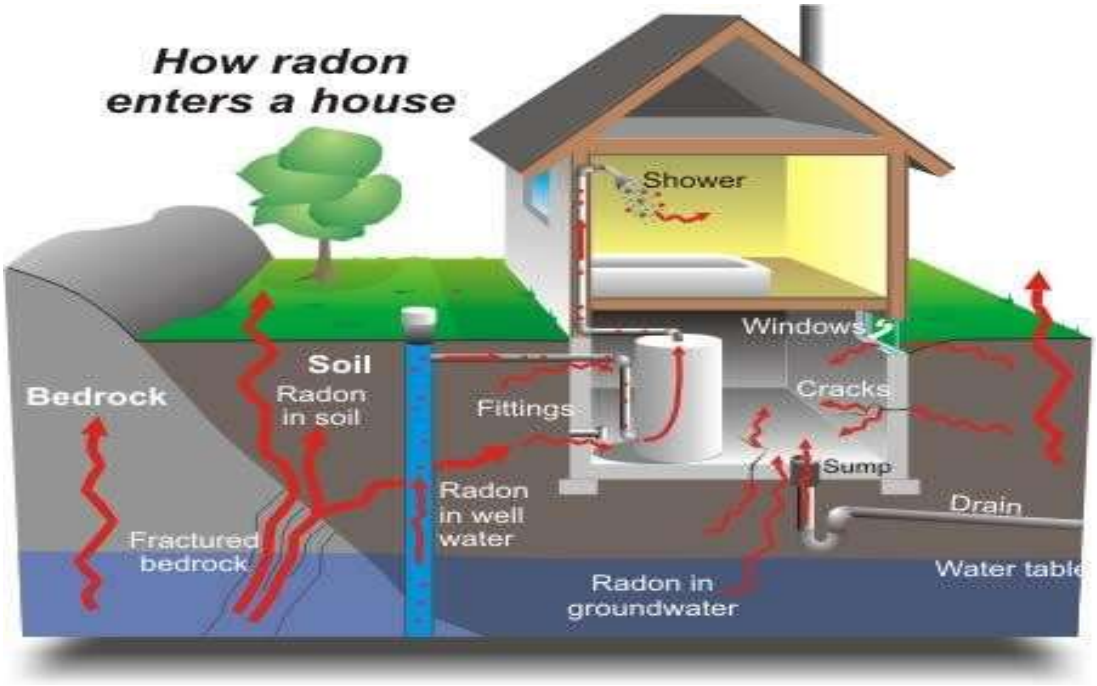


Figure 2.1: A picture depicting radon entry into homes WHO (2009)

2.1.2 Theory on Radon Emanation.

The process whereby radon gas travels from a solid medium to the gaseous medium is referred to as radon emanation. The whole mechanism by which the process occur is alpha recoil. Alpha recoil occurs when gas and water movement from both ends of the soil beneath and underground results in radon transport to the surface of the ground – this is caused by the mechanical movement of alpha recoil. Some radon atoms may divert from the path of particle injection, and this result into the radioactive decomposition of its parent atom radium – 226 the movement of radon atoms in between the spaces in the soil can be affected by the net movement of atom from a region of higher concentration to a region of lower concentration as a result of random motion of the atom and the heat transfer due to bulk movement of molecules within fluids such as gases and liquids, including molten rocks. When radon finally comes out of the pores then exhalation also takes place.

2.1.3 Exhalation of Radon

The efficiency at which radon is eventually released into the ambient air after its release into the pore space is what is termed exhalation. Just as the release of radon from water is also called evaporation. The pace, at which this procedure takes place, varies with the weather which is dependent on precipitation and pressure from the atmosphere. The release of soil radon gas into the ambient air is dependent on the levels of radon present in soil pore and available porosity. As radon is released a few meters above the surface of the ground, dispersion of the radon gas begins depending on the stability of the atmosphere which is dependent on the vertical temperature gradient, the turbulence, and force that comes with the wind which is dependent on its direction.

2.1.4 Diffusion

Radon is also pulled in by diffusion which is driven by the difference in radon concentrations indoors and in the soil. As with all gases, radon tries to equalize the indoor concentration as a result; its atoms easily penetrate through the pores in the concrete. The average concentration of radon in soil exceeds 1,000 pCi/L, while the average indoor concentration is only 1.2 pCi/L. The diffusion-flow through an intact concrete slab is several times higher than the pressure-driven adventives flow. Diffusion contributes up to 80 % of the radon level found in homes. This also explains why mitigation methods of pressurizing the basement do not work.

2.1.5 Soil to Radon Transport

Radon diffusion coefficient and the soil – air permeability is an essential soil related path that can be classified by radon transport. This can be determined in many ways which may cause mixed- up. It relates the gradient of the radon concentration in air –

filled pores to the flux density across the air – filled pore area. The "bulk" diffusion coefficient relates the same gradient to the flux density across the geometric (bulk) area. The pore volume is divided into air-filled and water-filled part (UNSCEAR Annex B, 2000). Microscopic fractures and fissures, called nanopores, and pits or opening caused by previous radioactive decays provides additional pathways for radon release. Particularly in sand-sized and larger grains, nanopores can increase the specific surface area of the grain, enhancing emanation by one or two orders of magnitude. (UNSCEAR Annex B, 2000). Soil moisture places an important role in the emanation of radon and its diffusion in soil, for several reasons. Soil moisture in the form of a thin film of water surrounding soil grains directly affect radon emanation by capturing the radon recoils from the soil matrix. The captures increase the likelihood that radon atoms will remain in the pore space instead of crossing the pore and imbedding themselves in adjacent soil grains. Decrease absorption increases the emanation factor at low water content. Once radon enters the pores space, its partition between the gas and liquid phase depends on the volume of water in the pore space and in the atmosphere.

2.1.6 Mitigation Strategies

Radon levels in home and workplaces can be improved by upgrading the ventilation structure in the dwelling or the workplace and prevent radon passage from the basement into living rooms or the office, installation of radon sump system in the basement, sealing floors and walls, installation of pressurization amongst others. Radon safety should be considered when new houses are built, particularly in high radon areas. In Europe and the United States of America, the inclusion of protective measures in new buildings has become a routine measure. In some countries it has

become a mandatory procedure. Most countries have adopted an indoor air radon concentration of 200–300 Bq/m^3 as a reference level above which mitigation measures should be taken. On September 22, 2009, the World Health Organization released a Comprehensive global initiative on radon that recommended a reference level of 100Bq/m^3 for indoor radon. To this effect, WHO recommends that countries implement National program to reduce the population's risk from exposure to the national average radon concentration, as well as reducing the risk for individuals exposed to high radon levels. Building codes should be implemented to reduce radon levels in homes under construction. A national reference level of 100 Bq/$m^3$is recommended by the WHO, however, if this level cannot be reached under the prevailing country-specific conditions, the reference level should not exceed 300 Bq/m^3

2.2 Health Impact of Radon

Large amount of radiation delivered to man is from nature, and a lot of them are found in the outdoor air which could be dangerous to the human body. Amongst them is radon, which contributes about 60% to human radiation exposure. This can pose some health implications to the general population, most importantly when it accumulates in a poorly ventilated residences and workplaces. According to the Office of the USA Surgeon General's 2009 report: Indoor radon gas is a serious health problem in the nation that can be addressed by individual action, unless people become aware of the danger radon poses, they will not act. Millions of homes are estimated to have elevated radon levels. Fortunately, the solution to this problem is straight-forward. Like the hazards from smoking, the health risks of radon can be reduced. The total average annual exposure to radiation, of about 2 of 3.6

millisievert per year is mainly accounted for by radon and its progenies. Radon report by the National Academy of Science (NAS) , Regarding the Health Effects of Exposure to Radon (the BEIR VI Report, published in 1999), admitted about 14% of the 164,100 lung cancer deaths in the United States each year are attributed to exposure to radon Correlating to approximately 15,000 to 22,000 people dying of lung cancer every year. 160 of these deaths have been found to be the presence of radon dissolved in drinking water and 700 deaths are also attributed to radon in the ambient atmosphere and the groups of the public exposed to this are miners. The average number of years of life expectancy lost per death from lung cancer is about fifteen. In a second NAS report published in 1999 on radon in drinking water, the NAS estimated that about 89% of the fatal cancers caused by radon in drinking water were due to lung cancer from inhalation of radon released to indoor air, and about 11 percent were due to stomach cancer from consuming water containing radon.

2.2.1 Estimation of Annual Effective Dose

Based on detrimental and epidemiological studies, the ICRP adopted conversion for radon exposures. The ICRP has not provided values of the doses per unit intake for radon and its decay products from application of the respiratory tract model because lung cancer has been observed and studied extensively in miners exposed to radon-222. As stated in ICRP Publication 65, a conversion from radon exposure to effective dose was obtained by a direct comparison of the detriment associated with a unit effective dose and a unit radon exposure. The detriment per unit effective dose is 7.3×10^{-5} per mSv for the general public based mainly on studies of A-bomb survivors (ICRP, 1993). The detriment per unit exposure to radon progeny is 8.0×10^{-5} per mJ h m^3 (1 mJ h m^{-3} = 0.282 WLM, where WLM is the exposure unit of Working Level Month commonly used in workplaces) (ICRP, 1993). In terms of

detriment, an exposure to radon progeny of 1 mJ h m^3 for members of the public (i.e. $8.0 \times 10^{-5}/7.3 \times 10^{-5} = 1.10$). The ICRP conversion from radon exposure to effective dose has nothing to do with any dosimetric parameters and does not rely on tissue or radiation weighting factors. This is not a dose in the sense of dosimetry. It is solely based on equality of detriments resulting from two totally different exposure scenarios. Assuming 7000 hours per year indoor (an occupancy factor of 80%) and an equilibrium factor of 0.4, then 1 Bq/ m^3 is equivalent to 1.56×10^{-2} mJ h m^{-3}. These recommendations confirmed that authorities should set a national reference level as low as reasonably achievable in the range of 100 – 300 Bq/m^3. Radon concentrations are compared to the reference level to help control radon in homes and most workplaces.

Direct measurements of the concentrations of all short-lived decay products of radon are difficult and limited. They are estimated from considerations of equilibrium (or disequilibrium) between radon and its decay products. An equilibrium factor F is defined as that which permits the exposure to be estimated from the measurement of the radon gas concentration.

The equilibrium equivalent radon concentration is directly proportional to the Potential Alpha Energy Concentration (PAEC) in the following manner:

1 Bq/m³ (EEC) = 5.56X 10^{-6} mJ/m³ (PAEC) = 0.27 mWL (Working Level)

The equilibrium factor (F) is defined as the ratio of the Equilibrium Equivalent radon Concentration (C_{EEC}) to the radon concentration (C_{Rn}).

$$F = \frac{C_{EEC}}{C_{Rn}} \quad \text{..... (2.1)}$$

With $C_{EEC} = 0.105\ C_{218Po} + 0.515\ C_{214Pb} + 0.380\ C_{214Bi}$ (2.2)

Where C_{218Po}, C_{214Pb} and C_{214Bi} are the concentrations of the short-lived decay products in air. In order to estimate the annual effective doses indoors, one has to take into account the conversion coefficient from absorbed dose in air to effective dose and the indoor occupancy factor. In the UNSCEAR 2000 Report, a value of 9.0 x 10^{-6} $mSvh^{-1}$ per Bq m^{3} was used for the conversion factor (effective dose received by adults per unit Rn- 222 activity per unit of air volume), 0.4 for the equilibrium factor of Rn-222 indoors and 0.8 for the indoor occupancy factor. Hence, the effective dose rate indoors in units of $mSvy^{-1}$, H_E is calculated by the following formula:

$$H_E\,(mSv/y) = C_{Rn} \times F \times T \times D \ldots\ldots\ldots\ldots\ldots\ldots (2.3)$$

Where C_{Rn} is the measured Rn-222 concentration (in Bq m^{-3}), F is the Rn-222 equilibrium factor indoors (0.4), T is the indoor occupancy time (0.8 × 24 h ×365 = 7008 h y^{-1}), and D is the dose conversion factor (9.0×10^{-6} mSv h^{-1} per Bq m-3).

2.2.2 Physical Dosimetry Using Radon

The United Nations Scientific Committee for the Effects of Atomic Radiation—UNSCEAR assessments on sources and effects of ionizing radiation are used as a basis for radiation protection programs and research in the scope of nuclear and radioactivity issues by international organizations, national regulatory bodies, and research institutions (UNSCEAR, 2000). Many publications have dealt with radon dose to the lung determined from physical dosimetry (Harley and Patermack, 1972; Harley et al., 1996; Porstendoefer, 2001; Marsh and Birchall, 2000; Marsh et al., 2001). There are absorbed dose, equivalent dose and effective dose. Literature values of absorbed doses to the lung vary from 5 to 71nGy per ($Bqhm^{-3}$) (UNSCEAR, 2000). The central value is estimated to be 9 nGy ($Bqhm^{-3}$) which represents the effective dose received by adults per unit Rn-222 activity per unit air volume. At a certain radon concentration C_{Rn} in Bqm^{-3}, the annual radon (absorbed) dose, D_{Rn} is usually expressed in the unit of mSv from the following relation.

$$D_{Rn}\,(mSv/y) = C_{Rn} \cdot D \cdot H \cdot F \cdot T \ldots\ldots\ldots\ldots\ldots (2.4)$$

Where D is the conversion factor used to assess radon dose for unit radon exposure. That is because of the physical difference between the radon concentration and radon dose. Also, two more factors; an occupancy factor, H, of 80% (home), and equilibrium factor, F, of 0.4 as used in ICRP publications, Table 2.2. Finally T is hours in a year = 8760 h/y. Now to calculate the annual equivalent dose and effective dose, one has to apply a tissue and radiation weighting factors according to ICRP, 1991. The equivalent dose is the radiation- weighted absorbed dose. The radiation weighting factor for alpha particles is 20 as recommended by ICRP, 1991. With the effective dose, a tissue weighting factor is applied. According to ICRP, the tissue weighting factor for lung is 0.12. With these two weighting factors, the radon

(absorbed) dose of 2.5mSv to the lung for one year exposure at 100 Bqm-3 becomes an annual effective dose of 6mSv.In terms of effective dose, for one year of radon exposure at 100Bqm^{-3}; the estimate from dosimetric approach is 6mSv, while the estimate from an epidemiological approach is 1.7mSv. The dosimetric estimate is thus 3.5 times higher than the epidemiological estimate. It is, however, apparent that the time spent by individuals in the home varies widely. The occupancy factor of 0.8 over estimates the excess lung cancer risk in the temperate regions but may be valid for the inhabitants of the climate zone. In the temperate regions, people spend most of their time in open air and only go indoors to sleep at night. In this present study, the occupancy factor that will be used for the annual radon dose calculation will be 40% (0.4).

Table 2.2: Summary of estimated radon doses at different radon concentrations, assuming 7000 hours per year indoor (an occupancy factor of 80%) and an Equilibrium factor of 0.4

Radon Concentration Bq/m3	100	200	400	600	800
ICRP risk equivalent radon dose mSv	1.7	3.9	6.9	10	14
USCEAR recommended radon dose mSv	2.5	5	10	15	20
Radon effective dose	6	12	24	36	48
Radon equivalent dose to the lungs mSv/ (W_R=20)	50	100	200	300	400
Radon equivalent dose to the lungs(W_R=10)	25	50	100	150	200

2.3 Radon Measurement Techniques

In order to control and assess radiation exposure to the general population it is very important that quantitative measurement of radon product and its daughter are carried out. There are three accepted categories of measurement techniques. Grab Sampling belongs to one category, Continuous and Active Sampling belonging to other

category and then finally has the Integrative Sampling. Depending on the type of analysis and the particular area, as and when a particular instrument will be available for measurement at one location the kind of accuracy one want to achieve that the measurements related so that risk estimation can be done, and the cost involved one can choose any of the measurement technique for analysis

2.3.1 Grab Sampling

In this measurement results are gotten instantaneously either for radon itself or the radon daughters in air. The values gotten are on and off which is also caused by a number of factors. This technique is mostly used in industrial monitoring xiangzhong, (2003).

2.3.2 Continuous and active sampling

Continuous and Active sampling are measurements that are done repeatedly within a short times. The outcome is in series, which provide information on how the measurements was done and their levels of concentrations beside them and the results also changes throughout the measurements interval. This is preferred when a particular measures shows a problem often and the exact point where radon access inside needs to be investigated.

2.3.3 Integrative sampling

Integrative sampling Is the collection of data on radon levels The Integrating devices takes information at a specific period of times but takes care of the whole radiation process some somehow may take a long period of time, say several days and so on. The result from integrating devices is an estimate of the approximate average concentration through the environment interval. The choice and method used for the measurements depends on the particular information required, the type of radon

survey and cost of apparatus involved, (Seitz, 1949).

2.4 Radon Measurement in Air

2.4.1 Alpha-Particle Scintillation Counter

Scintillation cells also known as Lucas cell is used for measuring concentrations of radon in air often called grab sample or continuous samples was introduce back in the olden days. The inner walls of the Scintillation cell has it surface coated with a zinc sulphide but one end of the cell is covered but with a window that allows one to see through and this allow the cell to be joined to a photomultiplier tube. in this technique when a radon gas is release into a cell, so when the radon gas which can breakdown to emits alpha particles hit the surface coating which is zinc sulphide a flash of light is indicated which is made possible by the photomultiplier tube and then it is converted into an electric signal. About 70 to 80% is the real efficiency of the cell, but the background rates in typical Lucas cells are low, about 0.1 or 0.2 counts per minute (cpm). Zapta-Garcia, Llauradó, Rauret, (2009)

2.4.2 Internal Ionization Chamber Counter

Alpha particles as a result of the breakdown of radon and its progenies which could be grabbed or continuous samples can be identify in ionization chambers. In these counters, an electrical signal is generated without the intermediary of scintillation counting. This counter is used either to count electrical pulses from individual decomposition events or to take measurements of the currents coming from the integrated effect of all decays. Usually scintillation counters are preferred to the ionization chambers since they are cost intensive to construct scintillation counters Hine, Brownell, (Eds.). (2013).

2.4.3 Two-Filter Method

Usually, the two filter method can be used in the Measurement of radon and radon daughter concentrations which in a way could be grab samples or continuous samples. For this method, air is passed through the filter where daughter products are removed. Then the air is passed through a long decomposition chamber, where daughter products are allowed to regenerate in and are placed on a second filter. The filters are counted differently to determine the concentration of radon (from the second filter) and daughter products (from the first filter). Grab samples and continuous samples are used for the measurement.

2.5 Residential Monitoring of Radon and Testing Device

Radon cannot be seen, however one can find out the presence of radon in home. Testing is easy and only takes few days to months depending on the kind of test you are undertaken. Two methods come up general over the years in testing for radon in homes, short-term testing and long-term testing.

2.5.1 Short -Term Testing

The fastest often used is the short-term test. Depending on the type of device used, Short-term tests remain in homes for two days to 90. Some of the detectors used for short- term indoor radon testing are: Charcoal canister, Alpha track detectors (ATDs), electrets ion chamber, continuous monitors and charcoal liquid scintillation detectors.

2.5.2 Long-term Testing

Long term test remain in homes for more than 90-days. ATDs and electrets ion chamber detectors are commonly used for this type of testing. Some of the detectors that are used for residential radon monitoring are listed below.

2.5.3 Charcoal Canister and Liquid Scintillation Detectors

Activated Charcoal detectors (ACDs) are passive devices deployed for 1-7 days to measure indoor radon. The principle of detection is radon adsorption on the active sites of the activated carbon. After sampling, the detector is sealed and the radon decay products equilibrate with the collected radon. After a 3-hour waiting period, the collectors can be directly gamma counted, or analytically prepared for liquid scintillation counting techniques. In the gamma counting method, the charcoal canisters or bags contain 25-90 g of activated carbon. In the alpha counting method, 20 ml liquid scintillation vials containing 2-3 g of activated carbon are used. The canisters can be open-faced or equipped with a diffusion barrier to extend the measurement period to 7 days.

2.5.4 Solid State Nuclear Track detectors (Alpha Track detector, ATD)

An ATD is a small piece of specially produced plastic substrate enclosed within a filter-covered diffusion chamber that excludes the entry of radon decay products. The plastic is generally a polyallyl diglycol carbonate (PADC or CR-39), cellulose nitrate (LR-115), or polycarbonate (Makrofol) material. When alpha particles are generate by radon or radon decay products in proximity to the detecting material, they can strike the detecting material, producing microscopic areas of damage called latent alpha tracks. Chemical or electro-chemical etching of the plastic detector material enlarges the size of the alpha tracks, making them observable by light microscopy so that they can be counted either manually or by an automated counting device. The number of tracks per unit surface area, after subtracting background counts, is directly proportional to the integrated radon concentration in Bqh/m^3. A conversion factor obtained by controlled exposures at a calibration facility allows conversion from track density to radon concentration.

2.5.5 Electret-Ion Chamber Counter (EIC)

EICs are passive devices that function as integrating detectors for measuring the average radon gas concentration during the measurement period. The electret serves both as the source of an electric field and as a sensor in the ion chamber. Radon gas, but not decay products, enters the chamber by passive diffusion through a filtered inlet. Radiation emitted by radon and its decay products formed inside the chamber ionizes the air within the chamber volume. The negative ions are collected by the positive electret located at the bottom of the chamber. The discharge of the electrets over a known time interval is a measure of time-integrated ionization during the interval. This in turn is related to the radon concentration. The electret discharge in volts is measured using a non-contact battery operated electret reader. This value, in conjunction with a duration and calibration factor, yield the radon concentration in desired unite.

Figure 2.2: Radon gas measurement devices and their characteristics

2.5.6 Solid State Nuclear Track Detectors (SSNTDs)

The detecting media most often used in the field of SSNTDs applications fall in two distinct categories. In the first category are polymeric or plastic detectors. These are most widely used not only for radiation monitoring and measurement, e.g. in health physics/radiation protection, or in environmental research and applications such as

measuring radon levels in dwellings or in the field, but also in many other fields involving nuclear physics and radioactivity. The second category of detectors is natural mineral crystals (and glasses) that have, imprinted within them, a record of their radiation (and thermal) history over the aeons. These find their greatest application in fields such as geology, planetary sciences (especially lunar and meteoritic samples), oil exploration, etc. Some of these minerals (e.g. sheets of mica) can, of course, also be used as custom-made detectors of heavy-ion or induced-fission bombardment. They can, for instance, be used inside reactor cores—since, by and large, they do not record neutron-recoils, and can withstand high temperatures and gamma-ray exposures (both of which properties are generally lacking in plastic detectors). One of the most commonly used nuclear track detectors is the CR-39 detector, which was discovered by Cartwright et al. and is based on polyallyl diglycol carbonate. Another most commonly used nuclear track material is cellulose nitrate. The most well-known detector in this group is being sold under the commercial name LR 115. Other kinds of detectors are also in use, such as the Microfilm detector which is based on polycarbonate. Some natural materials that show the track effect, such as apatite, mica, olivine, etc. are used for fission or fossil track studies. General properties of some of the most widely used plastic track detectors are listed.

Examples of Some Solid State Nuclear Track Detectors and Their General Etching Conditions

Table 2.3: Useful Characteristics of Some plastic Detectors

Category	Detector Material	General etching conditions	Lightest detectable particle	Critical Angle Q_C
Minerals /crystals	Olivine Zircon Quartz Mica	KOH Soln.,160^{o}C,6 Min, 10% HF ,23^{O}C ,30 sec 85% H_3PO_4 ,500^{o}C ,1 min KOH Soln..,210^{o}C ,10 min 48 % HF ,23^{o}C,3 Sec -40-min	Fe Ca Ar(100MeV) Ne(20MeV)	 4^o 30
Glasses	Sodalime glass Phosphate glass	48 % HF, 23^{o}C, 3 Sec. 48 % HF, 23^{o}C, 3Sec	Ne(20MeV) F (20MeV)	~50^o 1-5
Plastics	Polycarbonate Plastics (lexan,makrafol,mila) Cellulose Nitrate (Daicell, LR-115,CA-80-15) Allyldidlycol Polycarbonate (CR-39)	6 N NaOH, 60^{O}C, 60 min 3-6 N NaOH, 50^o, 4O min 6 N NaOH,70^o, 1-4 hrs	He(0.3MeV) H (0.5MeV) H(1.0 MeV)	~2-3^o ~4-8^o ~10^o

Table 2.4: Formation of the Latent Tracks

materials	composition	Trade name	Density(gcm^{-3})	Refractive index
cellulose nitrate	$C_6H_8O_9N_2$	CH 85[1]	1.52	
		CA 8015[1]	1.52	1.51
		LR 115[1]		
		Daicel[2]	1.42-1.45	1.505
		DNC[3]	1.4	1.5
Bisphenol-A Polycarbonate	$C_{16}H_{14}O_3$	Makrofol[4]	1.29	
		Lexan[5]		
Allydiglycol Carbonate	$C_{12}H_{18}O_7$	Cr39[6]	1.32	1.45
		TASTRAK[8]		

[1]Kodak Pathe
[2]dai Nippon Co, Japan
Cellulose nitrate produced in Russia
Bayer AG Germany
General electric Co., USA
American Acrylics:USA: Homalite,USA:Baryotrack,Japan:Pershore,UK
[7]MOM (Hungrian Optical Works), Hungary
[8]Track Analysis systems ltd, UK

2.5.7 Advantages of SSNTDs

The SSNTDs are very sensitive, pose no great handling problems and are not fogged by exposure to light or affected by moderate degree of heating. Due to their durability and simplicity, they are particularly valuable for remote use, such as in high altitude balloon exposure to cosmic rays and their robustness enable them to be used in personnel dosimetry. The reasons for its widespread use include the basic simplicity of its methodology and the low cost of its materials. Other important factors include the small geometry of the detectors, and their ability in certain cases to preserve their track record for almost infinite lengths of time (indeed, mineral grains in geological and planetary materials less than a millimeter across can, by suitable treatment, be made to reveal the billions of years old record of their radiation history).

2.6 Formation of the Latent Tracks

There are no universally accepted models for the formation of latent tracks in dielectric solids. In polymers, two processes are believed to determine the formation of a latent track:

Defect creation and (2) Defect relaxation; these are briefly outlined below.

The defect creation process can be subdivided into the following steps:

a. The primary interaction between the passing particles and the atoms of the medium which takes place over a very short time (of the order of 10^{-17}s for 1 MeV α-particles).
b. The electronic collision cascade process, which spreads out from the particle trajectory: it leaves behind a positively charged plasma zone, and produces chemically activated molecules outside this zone. The process lasts approximately 3 orders of magnitude longer than the primary interaction

(i.e.10^{-14}s).

c. The atomic collision cascade is the next process, which occurs owing to the Coulomb explosion of the remaining charged plasma. The process takes place within a timescale of 10^{-12}s.

The defect relaxation can be subdivided into two processes:

i. Aggregation of the atomic defects within the depolymerized zone (track core) into an extended defect over a timescale of about 10^{-10}s

ii. Relaxation of molecular defects via secondary reactions of chemically activated species in the partly depolymerized zone (track halo). This process occurs on a timescale of~1s.

The track core, ˜10nm in diameter, corresponds to the range of the atomic collision cascade. In this zone the molecular weight is drastically reduced. The track core is surrounded by a track halo, 100–1000nm in diameter, corresponding to the electronic collision cascade, with modified chemical properties.

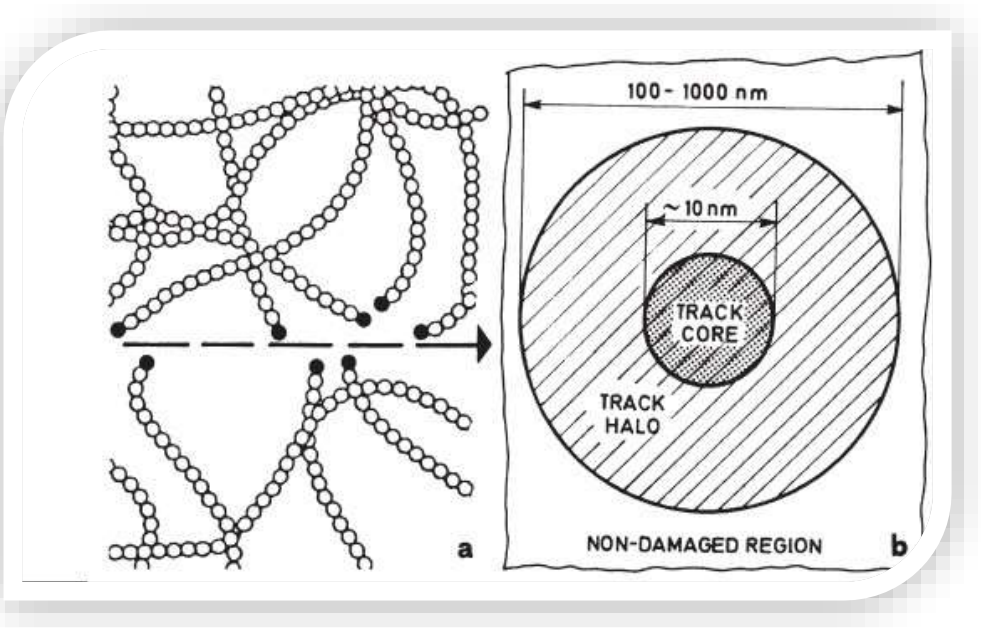


Figure 2.3:(a) Axial and (b) radial sections through a particle track in polymer (not drawn to scale). Chain breaks allow preferential etching at lower damage density (Illic, 1990).

2.6.1 Models of Track Formation

Universally, there are no accepted models for the formation of tracks in dielectric solids. There are six proposed track formation models. These are linear energy transfer, ion explosion spike and primary ionization cloud, secondary electron damage, restricted energy loss, primary and secondary ionization model and radio-chemical mechanism of damage.

2.6.2 Limitation of the Linear Energy Transfer (LET) Model

Initially, the LET (i.e., the overall energy loss per unit path length of the charged particles, (dE/dx) was considered relevant parameter for track formation (Fleischer et al., 1965a). However, it was soon realized that experimental data was inconsistent with dE/dx criterion. For example, it was shown (Fleischer et al., 1967b) that relativistic iron nuclei do not produce tracks in Nixon-Baldwin cellulose nitrate, though tracks were predicted by the dE/dx criterion. This is because the entire energy

loss does not contribute to the track formation. That portion transferred to high – energy δ rays may create damage too far from the track core to be effective. This limitation became apparent with relativistic ions because of the fraction of energy which goes into high energy δ rays increase with the energy of the heavy particle.

2.6.3 Ion Explosion Spike and Primary Ionization Model

Based on the observation that tracks are not formed in metals, Fleischer et al, (1965a) proposed the ion explosion model. This model suggests that initially the ionization and δ-ray generation by the track forming particle create a narrow cylinder of matter with a net positive charge. The mutual Coulomb repulsion of the ions then causes an explosive ejection of these ions from the trajectory of the particle, thus producing a preferential path for the chemical etchant. In this model, only the "primary ionization, that along the primary track core, is relevant and not the secondary ionizations produced by δ rays that occur in regions remote from the track core Fleischer et al, (1969). According to this model tracks will not be formed in metals, since conduction electrons will replace those ejected by the ionizing particle before the ion explosion spike occurs. Although the ion explosion model provides a comparatively satisfactory explanation of track formation in inorganic detectors, its validity for organic polymers is doubtful. The very high sensitivity of these detectors cannot be explained simply on that basis.

2.6.4 Restricted Energy Loss (REL) Model

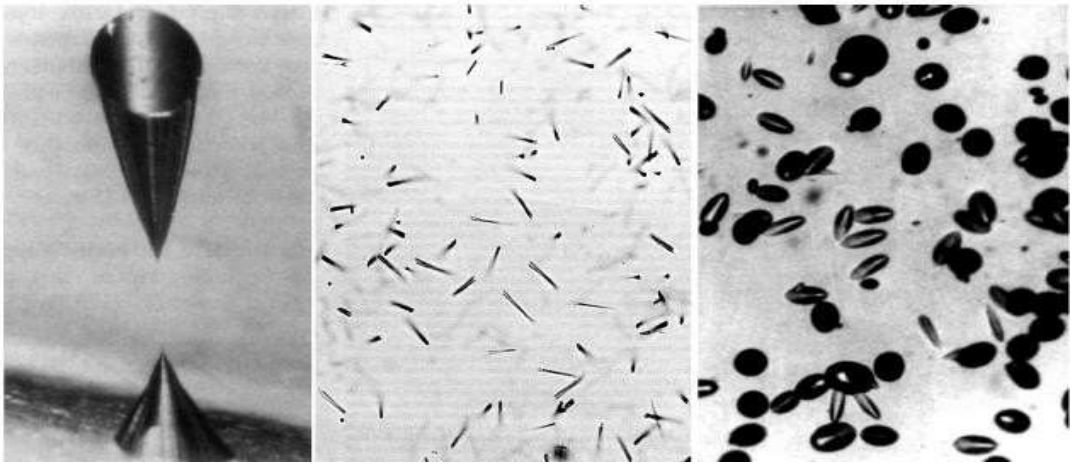
Using the quantity energy- restricted dE/dx first proposed by the ICRP (1963), Benton, (1970) postulated that only that part of the energy loss which goes into moderately low energy δ rays was important for track formation. This restricted energy loss model (REL model), although it has its own limitations (Fleischer et al.,

1975), can be applied easily and agrees with most experimental data.

2.7 Etching Mechanisms (Track Revelation)

Etching is the process of subjecting the exposed detectors to an etchant (that is a polymer degrader rather than a solvent) for latent track to be visible under optical microscope. The speed at which the dissolved plastic material is removed from the remaining plastic sheet is called the etching rate. For a track detector there are two kinds of etching rate. These are bulk or material etching rate V_B (μmh^{-1}) for the undamaged material and the track etching rate V_T (μmh^{-1}) at which the etching solution proceeds along the latent track. A track will obviously be enlarged by etching only if the rate of etching along the track, $V_{T,}$ exceeds the rate at which the surface is etched, V_B. The track etching rate depends strongly on the energy loss of the ion. The two forms of etching are chemical and electrochemical etching.

The surface of the polymer will be removed with a bulk etch rate V_B. As a result of the passage of a highly ionizing particle in a polymer (LR-115 type II), a chemically reactive damage trail may be produced, characterized by different etching rate known as the track etch rate V_T. The volume around the latent track will be attacked preferentially, so that the trail of heavily charged particles and nuclear particles become visible as cylindrical or cone-shaped hole of ~ 1- 30 μm length as shown



(A) (B) (C)

Figure 2.4: (A) Etched track of cosmic ray (Argon) ion that penetrates an Apollo electrophoresis device made of Lexan (B) Etched spontaneous-fission tracks (238U) in Durango apatite (C) Etched neutron-induced fission tracks (235U) in obsidian glass

2.7.1 Chemical Etching

Chemical etching is usually done in a thermostatically controlled bath. For plastics, the frequently used etchant is the aqueous solution of NaOH (or KOH) with concentrations ranging from a molarity of 1- 12 (~ 6 M being frequently used). The temperature usually used ranges from ~ 40 ^{o}C to 70 ^{o}C. Sometimes ethyl alcohol is added to the etchant to increase sensitivity and speeding of etching. A large beaker is usually placed inside the temperature controlled bath, and it is this beaker which contains the etching solution. Several detectors that are to be etched simultaneously are suspended by means of strings or wires making sure that they do not touch each other. The beaker is covered to reduce evaporation. According to different properties of etched tracks, the detectors can be classified. They are thin detectors where majority of etched tracks are etched through holes and thick detectors where the residual foil thickness is greater than the etched-track depth. This is indicated in the diagram below

(a) Represents the thin detector and

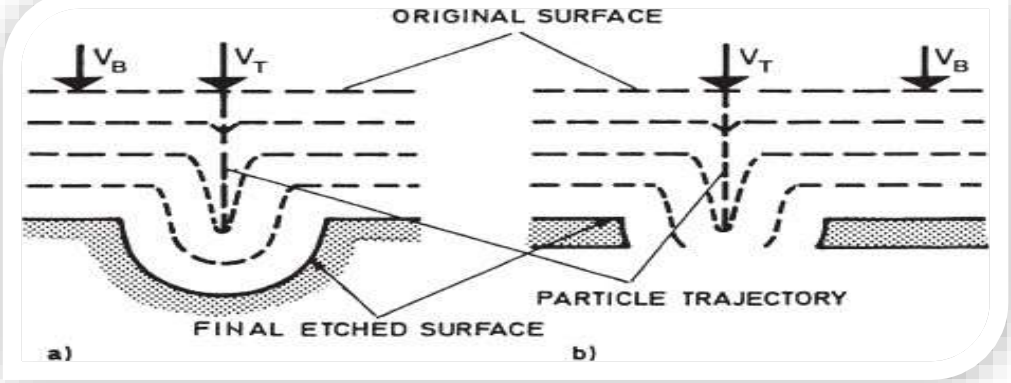


Figure 2.5: Simple schematic diagram of thin and thick detector (Enge 1980, L'Annunziata, 1998 and Kase et al., 1985).

(b) Represents the thick detector

Table 2.5: summarizes some useful etchants for Solid State Nuclear Track Detectors.

MATERIALS	ETCHANT
Polycarbonate plastics	Aqueous NaOH solution; typically 1-12M.Temprature: 40-70^{0}C alternatively, PEW' solution:15G KOH+45g H_2O + 40g C_2H_5OH,Temprature: 40-70^{0}C
Cellulose nitrate plastics	NaOH:1-12.Temprature 40- 70^{0}C
CR 39 plastic Polyalyldiglycol (carbonate)	NaOH , KOH solution, 1-12M.Temprature 40-70^{0}C
Orthopyroxenes and Clinopyroxenes	6g NaOH+4g H_2O,Boiling under flux
Mica	48% HF. Temprature 20-25^{0}C
Glasses	1-48% HF, Temprature 20-25^{0}C
Feldspars	1g NaOH + 2g H_2O. Boiling under flux
Apatite, Whitlockite$^+$	0.1-5%HNO_3- Temprature: 20-25^{0}C
Ziron	11.5gKOH+8g NaOH (eutectic).temprature:200-220^{0}C
Olivine	1ml H_3PO_4 +1g oxalic acid +40g disodium salt of EDTA + 100g H_2O; NaOH added to bring pH to 8.0(the WN solution).boiling under flux
Sphene	1HF:2HNO3:6H2O,Temprature 20^{0}C

In the figure below, there is an angle θ_c for each medium and a given heavy ion such that by the time that the etchant travels a distance V_B t vertically into the body of the detector, it reaches the end of the range of the particle proceeding along that ''dip angle'' θ_c at the same instant, i.e. $\frac{V_B t}{V_T t} = Sin\,\theta_c$. Only tracks making dip angles with the detector surface, such that $\theta > \theta_c$, will thus leave observable track openings. The half cone angle of all such etch pits is also $\theta_c = Sin^{-1}\left(\frac{V_B}{V_t}\right)$ (Durranni, 1997).

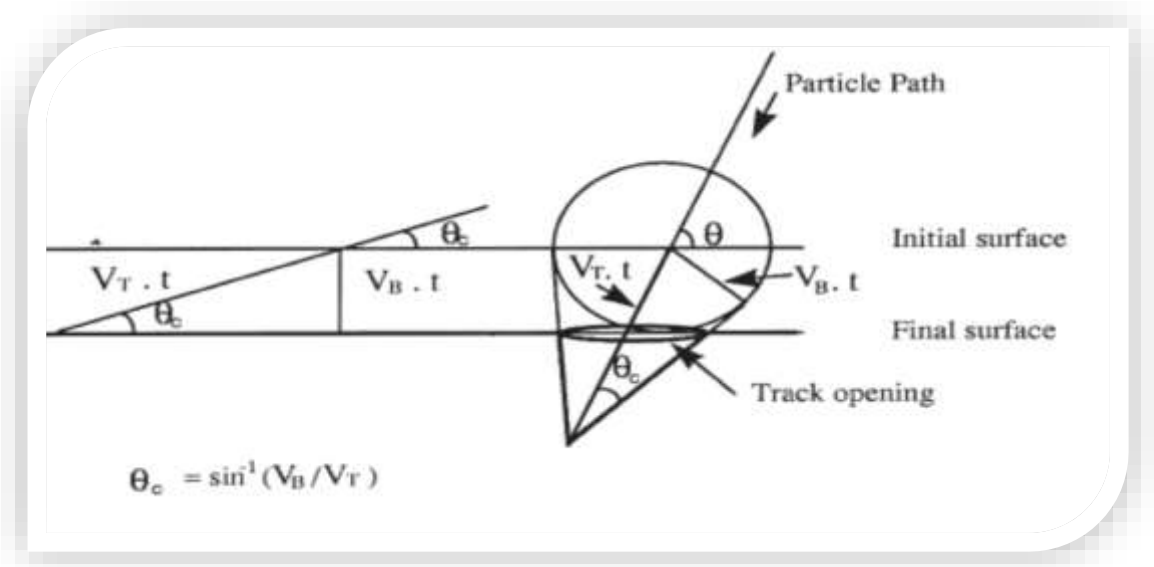


Figure 2.6: The theory of etching

2.7.2 Electrochemical Etching

Electrochemical etching (ECE) is helpful to enlarge the tracks to ease counting when the track density is not too high (i.e. is less than ~ 10^3 tracks cm^{-2}). It enlarges the chemically etched tracks a hundred fold or so. The principle of the ECE method is to apply a high –frequency (several KHz) electric field (~ 30- 50 $KVcm^{-1}$) across two component of an etching cell, filled with a conducting etchable solution example NaOH and separated by a plastic detector containing etchable tracks on its surface. After a period of chemical pre-etching, which produce sharp tipped tracks, the electric field at the tip builds up to a value equaling the breakdown limit of the dielectric medium (i.e. the plastic detector). At this point, treeing takes place resulting in large Lichtenberg- type surrounding the track-tip

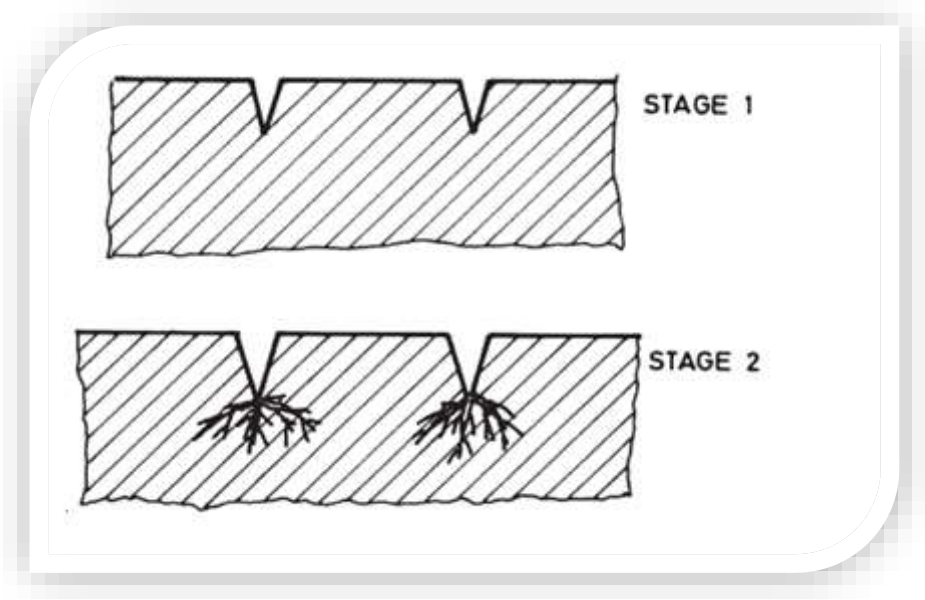


Figure 2.7: The formation of electrochemical spot. Stage 1: formation of track pits due to pre-etching process. Stage 2: treeing at the tip of the track pit due to electrical breakdown of the dielectric medium (L'Annunziata, 1998).

2.8 Track Counting and Evaluation

The evaluation of SSNTD for track diameter and track density is done by various methods. Some of the methods are manual or ocular counting; spark counting and analysis with image analyzers.

2.8.1 Manual or ocular counting

The transparent property of all practical track detector material makes the use of optical transmission microscopes applicable in track evaluation. This is the easiest and most preferred counting tool. The difference in refractive index between the tracks detector material and air gives subsurface track a high contrast, when proper magnification is used. Tracks vary in shape and size. It depends on the particle to be detected, its energy, and angle of entrance in relation to the detector surface, the detector material and the etching conditions. The optical microscope consists of a moving stage, and two eyepieces (which ranges between ~ 8 X and 16 X). The choice of objectives employed depends on the track density, etch-point size and the degree

resolution required. The objective mostly used for counting purposes are 20 (or 25) X and 40 (or 45) X. If pit size needs to be measured, then 63 X or 95 (or 100) X should to be used. Oil-immersion objectives are required for better resolution, but dry objectives are easier to use. Most tracks range in length from less than 1 μm to perhaps 10 or 15 μm, therefore the microscope must have an overall magnification in the range of 100 X to 1000 X. The most common magnification for fission fragments track counting are 200 X and 400 X. Practically, the track density is obtained by placing a glass disk with a scribed square, circle, or other reference marking of a known image area in the microscope eyepiece. The number of tracks within the pattern divided by the pattern area yields the track density. Here, a number of locations of fields on the sample may have to be counted to reduce the statistical uncertainty for a particular measurement. To attain accuracy, it is necessary to develop a consistent convention for treating tracks that touch or lay across the reticule border. That is if they are all counted, the track density is overestimated, while if they are ignored, underestimation occurs. Other information which can be obtained by an optical microscope other than track density is track size and orientation. For such measurements the use of microscope with vernier stage and focus controls can facilitate such measurements, although they are very tedious. For convenience, one can attach a television camera to the microscope so that the image can be projected on a video monitor for easy counting and reduce eye strain (L'Annunziata, 1998, and Eghan et al., 2007).

2.8.2 Spark counting technique

A spark counter is a semi-automatic device used to count low track densities (10^2-10^3 cm^{-2}) examples are those encountered in radon monitoring and personnel neutron

dosimeter. There are different types of electronic circuits for spark counters by different manufactures. Plastic detectors foil mainly LR-115 Type II containing etched through-holes produced by etching of the film exposed to alpha particles is placed on the electrode, and covered by another plastic foil ~ 100 μm thick support backing, which is thinly aluminized on the lower face to offer a conducting path. When the switch is closed and a high voltage is applied, the potential across the capacitor is raised. Voltage then appears across the electrode and hence across the etched detector. Eventually, a discharge takes place between the anode and the cathode across an etched track. Spark jumps through different holes in the detector

Foil in random sequence but only once per through-hole. The sparks are counted by scalar through a discriminator. After each spark, the capacitor needs to recharge by the applied voltage to provide sufficient potential for the next spark. When a detector has been sparked counted, the replica tracks on the foil can be counted with ease using a low magnification optical system such as microfiche reader. This is necessary where a film has been damaged. The counts obtained are used to calculate the track density based on the area of the electrode used and finally the concentration of the heavy charged particles which interacts with solid state detectors is calculated. (L'Annunziata, 1998).

2.8.3 Image analyzers

Many automatic systems for track evaluation are currently available on the market and others have been developed by various research laboratories by upgrading the conventional optical microscope operation with additional hardware, this is done to avoid manual counting of large number of samples especially, if many fields must be

counted on each sample. Here the image is provided by an optical on scanning electronic instruments capable of transmitting an image to a video system. The background can be reduced with the shape discrimination properties, it can be established that the tracks have length to-width ratio in a certain range and that dimension also has limits that can be specified to avoid counting artifacts that have dimensions different from the set criteria. With advanced systems, simultaneous measurements are made of track size parameters and grey levels inside the tracks of a single track. A typical example of the modern processor system is seen in figure 2.10.The main components of such a system are optical microscope equipped with auto Focus and an X-Y moving stage, a CCD video camera, a digitizer and a personal computer. The image of the detector surface is obtained by conventional optical microscope and transmitted by the CCD camera to the computer. The general principle is, as the video signal sweeps, a track or other object results in change of signal level. The degree of change is related to the contrast of the object. The important information required by the system is obtained from duration of the changed signal level, position of related changes in an adjacent video sweeps (related to particle size and shape) and magnitude of signal level change (contrast). The amount of information obtained depends on the complexity of information processing unit and is ultimately reflected in system cost. The X-Y stage is capable of moving over large areas (30 cm × 10 cm) in steps of about 1 μm. The detector foil can be usually scanned at a rate of up to four frames per second. The magnification used is specifically 0.5 μm/pixel, giving a resolution of 0.2 μm by interpolation along a line of pixels. Due to their speed, automatic system are not only used for routine work but they are now contributing to the possibility of more advanced research work in field such as high-energy heavy-ion interaction, exotic decays, cosmic ray and monopole

investigations (L'Annunziata, 1998). A typical example of a modern processor system is shown in figure 2.10.

Figure 2.8: A current v-600 perfection scanner

2.9 Exposure Uncertainties

In the exposure of detectors, uncertainties occur are not due to the measurement techniques only, but also the method used to estimate personal exposure. Actually no personal dosimeters are used, but environment measurements and occupancy factors are utilized to obtain personnel exposure, especially for long periods of time. A tentative study to compare personal monitoring with environmental monitoring has recently been published [Litt et al., 1990], but it refers to an exposure of few days. The summary of uncertainties in exposure includes

2.9.1 Sampling location

Radon detectors are fixed in room of the individual houses, but the most preferred place in the house is the bedroom where most of the time is spent in sleeping, This introduces a bias in those cases where the radon concentration varies appreciably from one room to the other, as it could happen in multistory dwellings, where significant variations could exist between the upper floors and ground.

2.9.2 Occupancy factor

In practice the occupancy factor is very difficult to measure. Personal judgment is often the only way for its estimation, especially in case of long periods. This factor differs among persons, as it is strictly linked with age, occupation, state of health, etc. Also, the occupancy factor could differ significantly during weekends and holidays. However, when averaged over the general population, it is relatively constant. It still depends on climate, being usually higher in cold climate countries. Most authorities for a first approximation assume an occupancy factor of 0.8, being made up of about 0.6 at home and 0.2 in other indoor situations [ICRP, 1993; UNSCEAR, 1993].

2.9.3 Retrospective assessment

In case–control epidemiological studies retrospective assessment of exposure is required in case-control epidemiological studies. Usually this assessment is made measuring at present the radon concentration in all dwellings used in the period under study. This procedure could introduce a high bias, that can be tentatively limited if a strict protocol for case and control selection is used. According to Samuelsson (1988), other experimental techniques for retrospective assessment of radon exposure based on the build-up of polonium- 210 on glass surfaces in dwellings is under

development. A similar approach is also now under development in which the buildup of ^{210}Po in porous materials (volume trap) in dwellings is measured as an aid to retrospective assessment of radon exposure.

2.9.4 Measurement Period

In order to get a correct estimation of the mean concentration of radon it is always essential to consider a one year integrated measurements thou results could vary, say from a year to a year, which is most likely to be caused by a powerful climatic changes Ramola et al., (2015), in the absence of occupants measurements of radon concentration using the dosimeters still continuous which may end up introducing some bias in the results in the home especially when there is a significant drift with respect to the period of the day when persons are at home or at work. Example monitoring carried out in Radon Laboratory of Colorado, United States of America Department of Energy (DOE) for 5 year duration in 40 residences showed a mean coefficient of variation of approximately 22%.

2.9.5 Measurement technique

For long term radon measurements passive track dosimeters are usually utilized for alpha radiation release and a result of the breakdown of radon and it daughters. The total uncertainty which comes up from reproducibility and calibration mostly varies from 10% to 30% (one standard deviation), depending on the actual radon concentration and other factors.

2.9.6 Research done on Radon in Ghana

Modern residences are constructed with materials which may aid radon exhalation, glasses used for windows remain closed in the absence of occupants throughout the day and this prevents exchange of air between indoor and outdoor. Soil gas transported by pressure induced convective flows or diffusion may find its way into a dwelling through fractures in concrete slabs, pores and fractures in concrete blocks, mortar joins, loose fitting pipe entries and water in rooms amongst others. These are all factors contributing to indoor radon concentration. The potential long term hazards associated with indoor radon calls for concern. In most countries including Ghana the health issues from radon-222 is affiliated mainly with the release of radon indoor (UNSCEAR, 2000)

In Ghana there have been studies carried out on the indoor and outdoor radon measurements in the environment by Oppon et al., (1990) in the Dome Kwabenya constituency. Andam and Amoo (2007) at Tarkwa and Prestea Goldfields, Quashie et al., (2011) at Kassena Nankana Area of the Upper East Region of Ghana Akwasi and Asumadu-Sakyi et al., (2012) around faulted areas in Accra, and Nsiah Akoto et al., (2013). In all, SSNTDs were used.

CHAPTER 3

METHODOLOGY

3.1 STUDY LOCATION

Ga East is one of the highly populated municipalities in Ghana. It is located in the northern part of Accra which is among the eight largest cities in Ghana (Ghana Statistical Service 2013). It is one of the sixteen districts in the Greater Accra region and covers a land area of about 96 sq. /km. Based on the topography, geology, climate and ease of accessibility the municipality was selected for studies. Dome Afghanistan, Achimota- ABC and Achimota-Mile7 were chosen because of the previous works done in Dome which indicate that radon levels are high. The closeness from the various sites to the laboratory, Ghana Atomic Energy Commission was also considered. According to the Ghana Statistical Service, population census in 2013 the municipality has an estimated population of 114, 745 and lies between latitude of: 55”44” 10.19 North and Longitude of 0” 11” 2.5 0”East, with an average elevation of 190 feet and 58 meters at sea level.

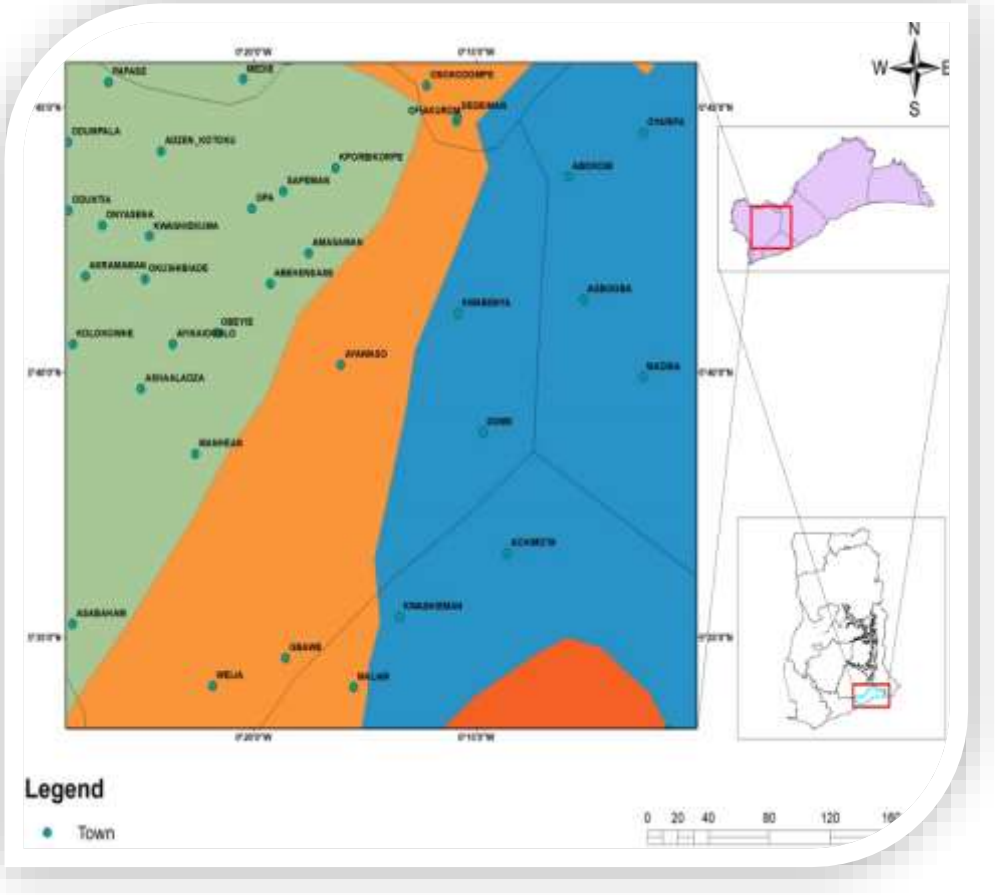


Figure 3.1: Map showing the sampling sites

3.1.1 Types of Dwellings and Materials Used

Generally building materials contributes significantly to radon gas indoor. For most of the houses which was selected for the study, the building materials used in their construction was mainly cement, sand and stone. Almost all the houses in the study areas are modern or sand Crete structures, the ventilation systems are fairly poor. Each house has about three to four rooms. Most of the ceilings in the dwellings are made of plywood and plastic T and J. A number of the dwellings was roofed with corrugated sheets and are at a height of about 2.5 m-4 m from the ground. A nunber of the houses that was selected for the study were not furnished thus they were not painted. The spaces on the floor of the selected dwellings are approximately 4 x 3 m^2 .At least each house has two windows and are mainly the modern sliding windows

and the conventional louvered blade type with a door. About 70% of the population have floor tiles, 20% have cemented floors and 10 out of 100 uses concrete floor with carpet. Even though there were a number of storey buildings as well, ranging from first to third floors, only the ground floor was selected for studies.

Figure 3.2: Showing some dwellings in the Dome and its environs that were selected for monitoring.

3.2 Geology of Ga East Municipal (Ghana)

The Geology of the country falls within the Precambrain Guinea Shield of West Africa. The main Precambrian rock units existing in the country are the metamorphosed and folded Birimian, Tarkwanian, Dahomeyan Formation, the Togo Formation and the Buem Formations. About two-thirds of Ghana is dominated by Paleoproterozoic Birimian rocks consisting of five evenly spaced volcanic belts trending northeast- southwest. The intervening basins between the volcanic belts are filled by sediments. The remaining one-third is made up of post-Birimian rocks (Amedoful et al., 2008; Kesse., 1985). Ga East municipal is made up of the Togo and the Dahomeyan Formations.

3.2.1 The Togo Formation

These are rocks forming the Akwapim range of hills trending northeast wards from the coast West of Accra through Kpong, Anum into the Republic of Togo. The rocks mostly found in the Togo are phyllites, schists and quartzite. Yet in some places unaltered shale and sandstone are common. Phyllonite has been found in many excavation pits along the Togo and Dahomeyan Formation.

3.3 Methodology

The passive technique has been utilized for the indoor radon levels monitoring in dwellings in Dome, ABC and Mille 7 in the Greater Accra Region. Based on LR-115(type II) track detection technique which has been known over the years to be, highly sensitive to alpha radiations, its ruggedness, it long term integrated read-out, in terms of cost is less expensive compared to the other detectors and above all it simple and always available. The measured track density was then translated into the amount of radon in each dwelling.

3.3.1 Materials used in Indoor Radon Measurement

The following materials were used for the measurement of indoor radon concentration; Cellulose Nitrate LR 115 type II (SSNTDs, cardboard paper, glue, scissors and marker.

During the preparation of etchant, the following were used; NaOH pallet, beakers, 1 Litre volumetric flask, magnetic stirrer, weighing balance ceramic and hot plate.

Materials used for tracks revelation included, thermostatic controlled etching bath, etching bowl detectors and beakers. Track Counting was done using V-600 perfection scanner and LR115 type II detectors. Tracks evaluation was done using image j computer software and Microsoft (javanoboard image processing programmer).

3.3.2 Sampling

Indoor radon concentration was studied in sixty (60) homes and a total of hundred and twenty (120) detectors were used. The random method of sampling was utilized for the selection of the houses, so that there were no significant Changes in the construction and its operation. Each house has three to four rooms. The ceilings of the houses are mostly made of plywood and plastic T and J and roofed with corrugated sheets that are at a height of about 2.5 m – 4 m from the ground. There were a number of story buildings as well, but only three were considered in this work and the measurement was done in their basement. The floor spaces of the rooms are approximately 4×3 m^2 with two windows mainly sliding and louvered bade type and a door.

3.3.3 Measurement of Indoor Radon

The Solid State Nuclear Track Detectors sensitive to alpha particles were utilized in this investigation. Cellulose nitrate LR- 115 Type II alpha particle detectors with a thickness of 13 µm on a 100 µm polycarbonate backing were used. The choice of LR-115 Type II alpha detector was preferred to the LR- 115 Type I because it is strippable; it's sensitive and can be analyzed easily by a scanner and Image j computer software. The dimensions of Type II plastic detectors that is the length and breadth is about (3.0 cm × 2.5 cm) respectively, this is then positioned in the Centre of a specially designed cardboard measuring (11 cm× 12 cm), with the aid of cello tape. It was hanged on the walls about 1.5 meters from the floor in the dwellers bedroom. The 1.5 meters was assumed to be an average respiratory level. The upper surface which remains highly sensitive was freely revealed or exposed so that it was able to take records of the alpha- particles which is been release because of the decomposition of radon in the room in Dome, ABC and MIL7 of the locality. One hundred (120) LR-115 type II plastic detectors were fixed in the bedrooms of the inhabitants. In each house, a total of two detectors were fixed in individuals bedrooms at a height of about 3m above the floor with the help of a masking tape. The exposure time used for all houses was from July 2017 to September 2017 representing the rainy season and then from October 2017 to January 2018 as the drying season.

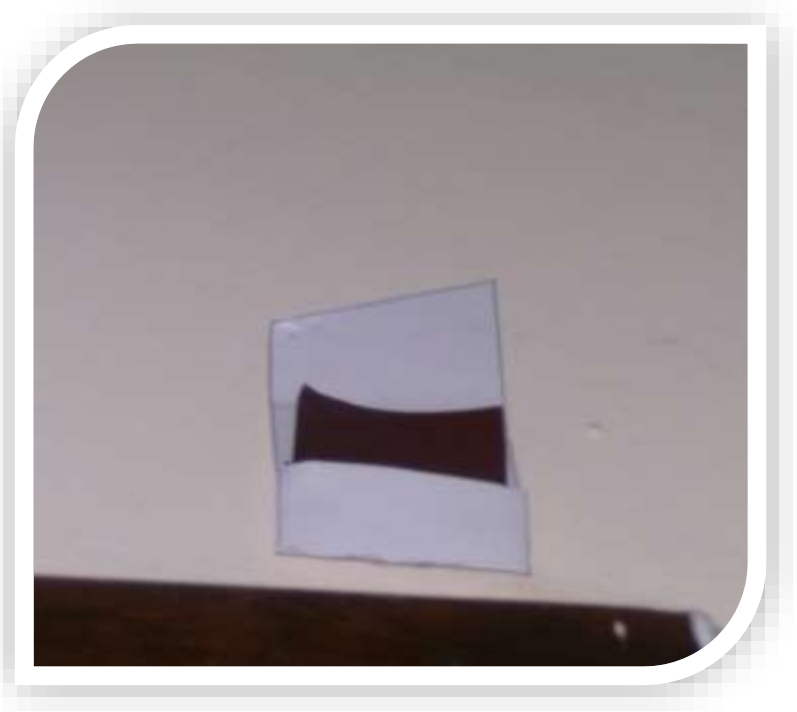


Figure 3.3: Special envelope designed with SSNTD fixed in the middle

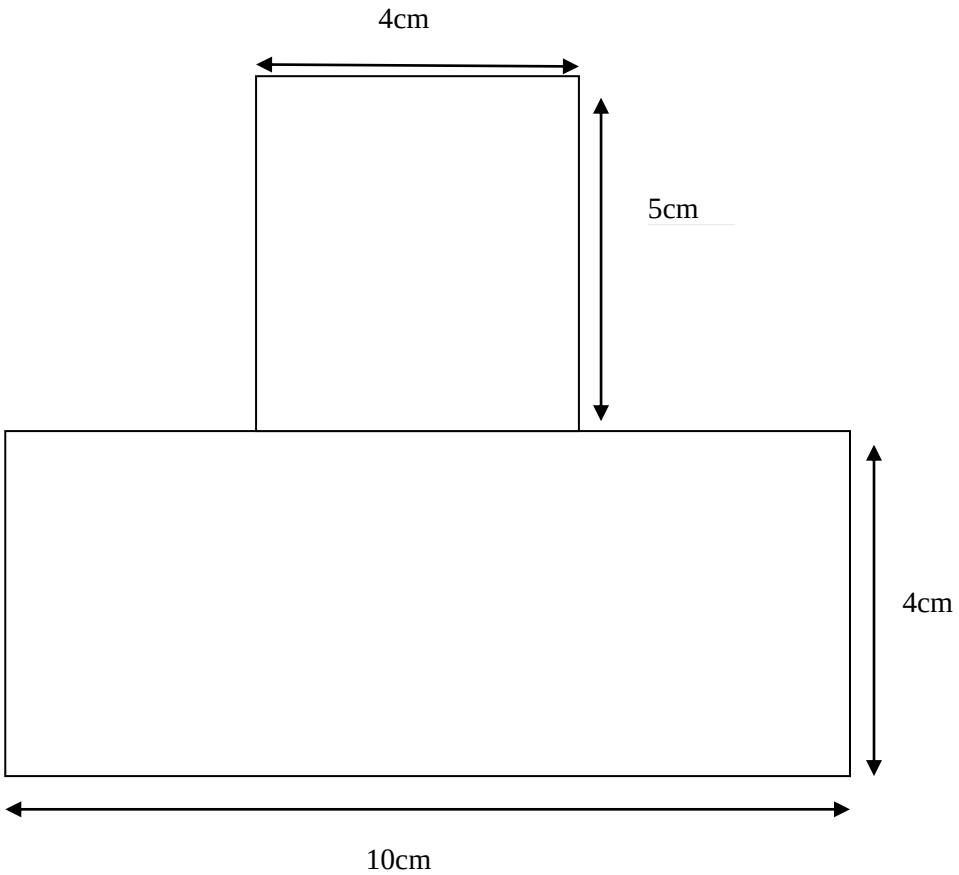


Figure 3.4: Typical outline of the especially design envelop

3.4 Materials used in Soil Radon Measurements

1. Cutlass, Cellulose Nitrate LR 115 type II (SSNTDs), Meter rule, wooden corks, masking tape, PVC pipes and Aluminum Roofing sheet

3.4.1 Soil Radon Measurement

The radon concentration levels in Soil were monitored in fifteen (15) randomly selected houses. A total of sixty (60) detectors were used, The Setup system was made up of polyvinyl chloride pipes with a length of 250 cm and 45 cm as base and a cork made of wood to hold the detector and fixed in a way that it covers one side of the pipe. The cellulose nitrate plastic strippable detector having the size 2 X 2 cm^2 is supported with a paper cellotape attached to the wooden cork and well label to avoid mixing of the detectors

With the aid of a pickaxe, cutlass, and garden fork, the soil was dug to a depth of 75 cm and the soil apparatus setup was placed in the dug pits. These was done in the immediate radon environ where the indoor radon sampling was done, as shown in figure 3.8. They were carefully covered with an aluminum roofing sheet and sand to create a normal soil environment for 14 days. The detectors were replaced with another set of fifteen (15) after two week's period. Four (4) samplings were carried out. Two measurements in the rainy season and two in the dry season was done. After each set of sampling the detectors were removed, and kept for analysis at the Nuclear Track Detection Laboratory of the National Nuclear Research Institute (NNRI), Ghana Atomic Energy Commission (GAEC).

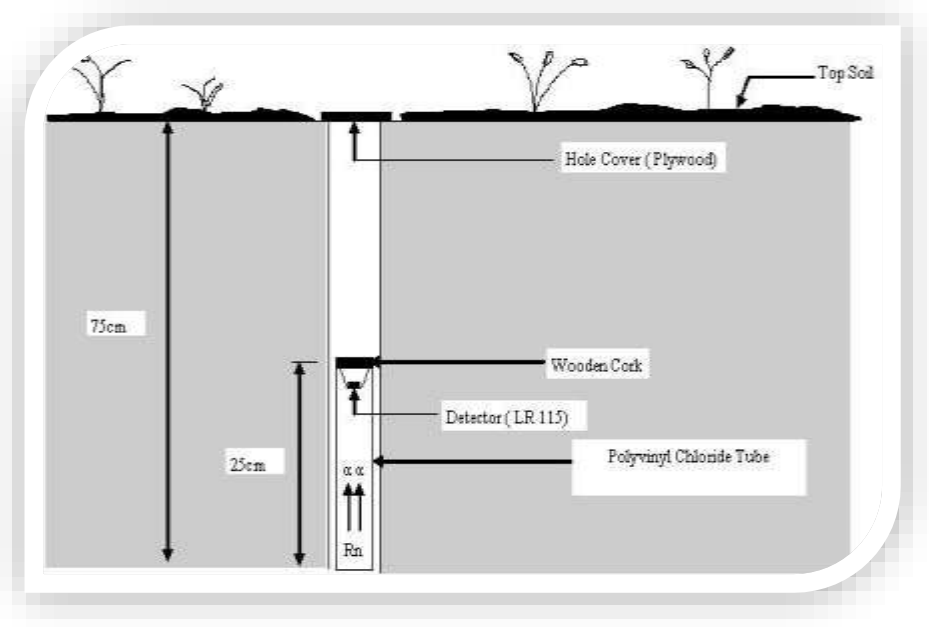


Figure 3.5: A typical set up of soil radon measurement.

3.5 Analysis of Detectors

3.5.1 Etchant Solution (2.5m NaOH Solution)

About 100 grams of sodium hydroxide pellet was weighed in a beaker with an electronic weighing balance in the weighing room at the Alpha Spectrometry Laboratory, Radiation Protection Institute Ghana Atomic Energy Commission (GAEC). About 100 cm^3 of distilled water was used to dissolve the pellet completely with the help of a 4 by 4 ceramic hotplate and magnetic stirrer. The solution was transferred into a 1 L volumetric flask. The beaker was rinsed thoroughly and the water that was used to rinse the beaker was added to the solution in the volumetric flask. In other to make a 1 Litre marked solution, it was topped up with distilled water.

3.5.2 Etching Procedure (Track Revelation)

After the 2 weeks and then 3 months of exposure, the detectors were removed and sent to the Nuclear Track Detection (NTD) Laboratory, National Nuclear Research

Institute (NNRI), Ghana Atomic Energy Commission (GAEC). At the laboratory, they were treated with 2.5M analytical grade sodium hydroxide (NaOH) etching solution, contained in beakers of different sizes. The beakers with its contents were immersed in a water bath. The detectors were hanged on copper wire and were chemically etched by suspending them in the etchant solution at a temperature of 60+1 ºC. The beakers were covered with lids to reduce evaporation which may result in formation of concentrates on the detectors. It was expected that considering the rightly prepared etchant solution, the set temperature and time frame, the maximum number of the tracks as a result of interaction with alpha particles Type II detectors were enlarged. The procedure went on till all the detectors were etched after one and half hour. The detectors were removed, placed in cold water to stop the etching process and was again rinsed with distilled water so that the strippable surface can be removed easily. The detectors were air dried and was read for the image j software analysis

3.6 Track Counting

3.6.1 Scanner Image Acquisition

Getting the image of the tracks created in the detector was done using a commercial scanner (Epson Perfection V600) having 4800`x9600-dpi resolution and 48-bit for colour and 16-bit for grey gives the highest depth An essential characteristic of the Epson Perfection V600 scanner is its two-lighting system. The films are inserted between two rigid transparent sheets on the scanner surface. This setup gives a meaningful consistent brighten of the films, decreases bubbles formation. The negative acquisition of film image is done using 24-bit colour deep and 4800-dpi resolution. This was preferred because it produces an image that allows discerning

appropriate tracks without getting lots of memory. A square area (1x1) cm^2 within the revealing surface of the film is obtained.

3.7 Data Analysis and Results

For image processing and analysis, Image j (Image Processing and Analysis in Java), a free digital image-processing software developed by the National Institutes of Health of the United States of America.

3.7.1 Calculations

Calculation for the Track Density and Radon Concentration:

Track Density

The term used for the average number of counts per unite area of an electrode is

$$\textbf{Track density} = \frac{\textbf{Average number of count}}{\textbf{area of electrode}} \text{.........}\textbf{Eqn (1)}$$

The area of the viewed field was obtained from the diameter (d) of the circular shape of the electrode using the expression

$$\textbf{Area} = \frac{\pi(d)2}{4} \text{...}\textbf{Eqn (2)}$$

Where d=0.8 cm

Convection, the area of the electrode =0.5027

Concentration of indoor radon gas in Bqm^{-3} was calculated using the

Formula: After the track density (ρ), the corresponding radon concentrations of the detector were also determined using the relations in (Eqn 3 and Eqn 4).

$$\textbf{Conc.} = \frac{\textbf{track density } (\rho)}{\textbf{calibration factor}(\varepsilon) \times \textbf{Exposure time}(\mathbf{T})} \text{...............} \text{ (Eqn3)}$$

$$\textbf{Radon Conc. } (C_{Rn}) = \frac{(\textbf{track density}(\rho) - \textbf{background density}(\rho\beta))}{(\textbf{calibration factor}(\varepsilon) \times \textbf{Exposure time}(T)} \quad \text{(Eqn4)}$$

Or

$$\textbf{Radon Conc. } (C_{Rn}) = \frac{\rho - \rho\beta}{\varepsilon XT}\ \textbf{KBq/m}^3\textbf{/hrs} \quad \text{(Eqn5)}$$

Where

$\mathcal{E}$: Calibration factor =1($Tracks \cdot m^3/cm^2 kBq \cdot h$) of the LR-115 (Type II)

T (hrs): Exposure time in hours =336 hrs (14 days) thus measurements of radon in soil.

T: Exposure time = 2160 hrs (90 days) for indoor passive monitoring

Background density(ρB) = Average count on unexposed part of the detector.

3.7.2 Calculations of Annual Absorbed Dose

Annual Absorbed dose (D_T) = $C_{Rn} \times D \times H \times F \times T$ (mSv/y)……. (Eqn5)

Where:

D = Dose conversion factor (9×10^{-6} mSv/hr per Bq/m^3)

H = Indoor occupancy factor (0.4)

F = Indoor radon equilibrium factor (0.4)

T = Number of hours in a year (24 hrs×365 days=8760 hrs/y).

CHAPTER 4

RESULTS AND DISCUSSION

Results of the indoor and soil radon measurement carried out seasonally in three localities (Afghanistan, Achimota-Mile7 and ABC) are presented in Sections 4.1 and 4.2 for the rainy and dry seasons respectively. In each locality, 20 houses were selected for the study. Thus in all, 60 dwellings were monitored. In each location, five soil measurements were carried at a depth of 75 cm. Tables (4.1. to 4.1.6) contain the values of the soil and indoor radon measurements for the three localities. The soil radon and indoor radon measurements were done in order to have an idea on the amount of radon that is able to diffuse from ground into dwellings and also give an idea of the difference between the outdoor and indoor radon concentrations. This difference would help in evaluating the factors contributing to the indoor radon concentration. As stated earlier, the factors that might be contributing to indoor radon are soil radon gas exhalation, diffusion and transporting into dwelling, ventilation and the building materials. The rainy season spanned from June, 2017 to September, 2017 and the dry season spanned from October, 2017 to January, 2018. The distances between the houses were approximately half kilometer apart. The track densities found on the LR115 detectors after exposure to radon-222 both soil and indoor, were calculated using the average number of tracks per unit area. The track densities found on the processed detectors were converted into radon concentrations in Bqm^{-3} and the corresponding doses calculated

4.1 RAINY SEASON

4.1.1 Soil and Indoor Radon Measurements in the three Localities.

Table 4.1 shows the results of the soil radon concentration measured at 75 cm depth in five locations at the Afghanistan locality. These results are far higher than that obtained for the indoor radon concentrations shown in Table 4.1.1. The foundation depth of one storey building is often three feet which is almost equivalent to 75 cm, the depth at which the soil radon measurement was done. It was therefore expected that an appreciable amount of radon-222 gas measured at 75 cm depth would be transported from the ground by pressure induced convective flows or diffusion into the dwelling through fractures that might be in the concrete slabs, the outdoor pores and fractures in the concrete blocks. However, the indoor concentrations measured in all the seasons seemed to be far lower than the soil measurements at 75 cm depth. This suggested that there might be only few entry routes through which the radon gas passes into the dwellings. The concrete floor and blocks of the dwellings seemed to provide shielding and prevent radon diffusion from the ground and outdoor air into the dwellings. Similar trends were observed from Tables 4.1.3 through to 4.1.6 and these are the results of Achimota Mile-7 and Achimota ABC.

The annual effective dose (AED) in the dwellings for Afghanistan in the rainy season ranges from4.8 mSv/y to 20.2 mSv/y and that of Achimota Mile 7 and ABC ranged from 3.23 to 13.9 mSv/y and 3.5 to 10.74 mSv/y respectively. According to ICRP Publication 115 (2010) statement on radon, the upper value for radon reference level of 300 Bq/m^3 corresponds to an AED of 17 mSv/y. Thus the three localities are generally found within the ICRP (2010) limit; however, dwelling AF H17 recorded indoor radon concentration of 334.10 Bq/m^3

With a corresponding AED of 20 mSv/y. This is relatively higher than the ICRP limit.

Generally, the closing of window during the rainy season and the other factors could have accounted for the high indoor radon concentration in this season.

Table 4.1: Soil Radon Concentration and Housing Codes, in Afghanistan.

Dwelling codes	AF H1	AF H4	AF H7	AF H8	AF H10	MEAN
KBq/m^3	1.02	0.78	0.46	0.37	0.98	0.7 ±02

Table 4.2: Indoor Radon Concentration and Its Annual and Effective Dose Afghanistan

Dwelling Codes No	**Indoor Radon Conc. Bq/m^3**	**Annual Dose (mSv/y)**	**Annual Effective Dose (mSv /y)**
AF H1	240.38	6.06	14.55
AF H2	243.65	6.15	14.75
AF H3	173.82	4.39	10.52
AF H4	140.30	3.60	8.49
AF H5	176.45	4.45	10.68
AF H6	282.58	7.13	17.11
AF H7	89.74	2.26	5.43
AF H8	189.35	4.78	11.46
AF H9	105.10	2.65	6.36
AF H10	176.65	4.46	10.69
AF H11	158.21	3.99	9.58
AF H12	105.10	2.65	6.36
AF H13	99.21	2.50	6.01
AF H14	256.07	6.46	15.50
AF H15	97.22	2.45	5.89
AF H16	79.39	2.00	4.81
AF H17	334.10	8.43	20.23
AF H18	183.53	4.63	11.11
AF H19	90.53	2.28	5.48
AF H20	87.43	2.21	5.29
MEAN	**165.1±74.0**	**4.2±1.9**	**9.1 ± 4.4**

Table 4.3: Soil Radon Concentration and Housing Codes, Mile7.

Dwelling Codes	M7 H2	M7 H4	M7 H7	M7 H9	M7 H6	MEAN
KBq/m^3	0.84	0.64	1.19	0..98	0.77	0.89 ± O.2

Table 4.4: Indoor Radon Concentration and Its Annual and Effective Dose Mile7

Dwelling Codes	**Radon Conc. Bq/m^3**	**Annual Dose (mSv/y)**	**Annual Effective Dose (mSv/y)**
M7 H1	53.91	1.36	3.26
M7 H2	121.27	3.10	7.34
M7 H3	215.94	5.45	13.07
M7 H4	90.93	2.29	5.50
M7 H5	92.84	2.34	5.62
M7 H6	100.80	2.54	6.10
M7 H7	137.99	3.48	8.36
M7 H8	74.21	1.87	4.49
M7 H9	126.60	3.19	7.67
M7 H10	72.94	1.84	4.42
M7 H11	53.35	1.35	3.23
M7 H12	78.11	1.97	4.73
M7 H13	173.82	4.39	10.52
M7 H14	176.69	4.46	10.70
M7 H15	86.23	2.18	5.22
M7 H16	92.60	2.34	5.61
M7 H17	132.10	3.33	7.99
M7 H18	229.23	6.40	13.88
M7 H19	87.43	2.21	5.29
M7 H20	77.24	1.95	4.68
MEAN	**115.9 ± 48.2**	**2.9 ±1.4**	**7.0 ± 2.9**

Table 4.5: Soil Radon Concentration and Housing Codes, ABC

Dwelling codes	ABC H1	ABC H3	ABC H6	ABC H9	ABC H10	**MEAN**
KBq/m^3	1.23	1.11	1.08	1.39	1.52	1.3 ± 0.8

Table 4.6: Indoor Radon Concentration and Its Annual and Effective Dose ABC

Dwelling codes	**Radon Conc./m^3**	**Annual Dose (mSv/y)**	**Annual Effective Dose (mSv/y)**
ABC H1	158.21	3.99	9.58
ABC H2	85.76	2.16	5.19
ABC H3	172.15	4.34	10.42
ABC H4	177.40	4.48	10.74
ABC H5	116.10	2.93	7.03
ABC H6	121.82	3.07	7.38
ABC H7	75.80	1.91	4.59
ABC H8	80.18	2.02	4.85
ABC H9	88.94	2.24	5.39
ABC H10	60.28	1.52	3.65
ABC H11	146.51	3.70	8.87
ABC H12	75.72	1.91	4.58
ABC H13	151.44	3.82	9.17
ABC H14	158.85	4.01	9.62
ABC H15	98.42	2.48	5.96
ABC H16	85.83	2.17	5.21
ABC H17	64.34	1.62	3.89
ABC H18	57.89	1.46	3.50
ABC H19	78.83	1.99	4.77
MEAN	**119.3 ± 37.1**	**2.7±1.0**	**7.2 ± 2.2**

4.2 DRY SEASON

Measurement of both soil and indoor radon concentrations were done under the same conditions as that of the rainy season. Table 4.2 shows the results of the soil radon concentration measured in five localities. These results are extremely higher than that obtained for the indoor radon concentrations, as shown in Table4.2.1 through to 4.2.6. Similarly, as observed in the rainy season, the low indoor radon concentration values in the dwellings suggest that the entry routes of radon into the dwellings may be few. The concrete floor and blocks of the dwellings seemed to provide shielding and prevent radon diffusion from the ground and outdoor into the dwellings. Similar trends were observed in Tables 4.2.3 through to tables 4.2.6 and which are the results of Achimota Mile-7 and Achimota ABC.

The dry season in dwellings for Afghanistan recorded an annual absorb and effective dose ranges from 1.08 to 3.13mSv/y and 2,6 to 7.5mSv/y, that of Achimota Mile 7 and ABC ranged from 1.17 to 2.81mSv/y and 2.9 to 7.1 mSv/y then 1.20 to 2.15 and 2.8 to 5.6 respectively. According to ICRP Publication 115 (2010) statement on radon, the upper value for radon reference level of 300 Bq/m^{-3} corresponds to an AED of 17mSv/y. Thus the three localities are generally, below the ICRP (2010) limit; however, dwelling AF H6 recorded the highest indoor radon concentration of 124 Bq/m^{-3} with a corresponding AED of 7.5 mSv/y. But this is relatively lower than the ICRP limit. Generally the dry season is seems to have recorded lower indoor radon concentration compare to the rainy season. Regular opening of windows and other means of providing air exchanges in the rooms during the dry season could have accounted for the low levels of indoor radon concentrations.

Table 4.7: Soil Radon Concentrations and Dwelling Codes in Afghanistan

Dwelling	AF H1	AF H7	AF H11	AF.H20	AF H13	MEAN
KB/q/m^3	1.50	3.55	2.76	1.43	2.10	49.0 ± 18.

Tables 4.8. Indoor radon concentration and its annual and effective dose Afghanistan.

Dwelling Codes	**Radon Conc./m^3**	**Annual Dose(mSv/y)**	**Annual Effective Dose**
AF H1	74.53	1.72	3.24
AF H2	84.32	2.13	5.11
AF H3	76.20	1.92	4.61
AF H4	101.92	2.57	6.17
AF H5	60.36	1.52	3.65
AF H6	124.05	3.13	7.51
AF H7	57.09	1.44	3.46
AF H8	76.28	1.92	4.61
AF H9	100.17	2.53	6.07
AF H10	64.73	1.63	3.92
AF H11	57.81	1.46	3.50
AF H12	93.88	2.37	5.68
AF H13	110.68	2.79	6.70
AF H14	75.01	1.89	4.54
AF H15	45.94	1.16	2.78
AF H16	84.40	2.13	5.11
AF H17	42.76	1.08	2.59
AF H18	67.12	1.69	4.06
AF H19	85.12	2.15	5.15
AF H20	75.72	1.91	4.58
MEAN	**77.1 ± 21.0**	**1.95 ± 0.5**	**4.7 ± 1.3**

Table 4.9: Soil Radon Concentrations and it Dwelling Codes in Achimota Mile7

Dwelling codes	MI7 H2	MI7 H16	M7 H20	M7 11	M7 H4	MEAN
KBq/m^3	2.48	2.35	2.60	1.64	4.08	2.6±0.9

Table 4.10: Indoor Radon Concentrations and it Annual and Effective Dose Achimota Mile7

Dwelling Codes	**Indoor Radon Conc./m^3**	**Annual Dose (mSv/y)**	**Annual Effective Dose(mSv/y)**
M7 H1	117.21	2.96	7.10
M7 H2	78.27	1.97	4.74
M7 H3	85.83	2.17	5.20
M7 H4	76.04	1.99	4.60
M7 H5	77.95	1.97	4.72
M7 H6	69.03	1.74	4.18
M7 H7	64.49	1.63	3.91
M7 H8	77.08	1.94	4.67
M7 H9	63.62	1.60	3.85
M7 H10	74.45	1.88	4.50
M7 H11	93.32	2.35	5.65
M7 H12	62.90	1.59	3.81
M7 H13	73.02	1.84	4.42
M7 H14	63.94	1.61	3.87
M7 H15	46.34	1.17	2.81
M7 H16	56.45	1.42	3.42
M7 H17	71.50	1.80	4.33
M7 H18	66.88	1.69	4.05
M7 H19	71.18	1.79	4.31
M7 H20	60.36	1.52	3.65
MEAN	**73.1 ± 13.2**	**1.8 ±0.4**	**4.4 ± 0.9**

Table 4.11: Soil Radon Concentration and it Dwelling Codes in Achimota ABC

Dwelling Codes	ABC H10	ABC H6	ABC H14	ABC H20	ABC H3	MEAN
kBq/m^3	2.15	3.46	4.23	3.38	1.50	2.9 ± 1

Table 4.12: Indoor Radon Concentration and it Annual and Effective Dose in Achimota ABC

Dwelling Codes	**Radon Conc. Bq/m^3**	**Annual Dose (mSv/y)**	**Annual Effective Dose(mSv/y)**
ABC H1	59.64	1.50	3.61
ABC H2	74.77	1.89	4.52
ABC H3	69.19	1.75	4.19
ABC H4	51.04	1.29	3.09
ABC H5	65.93	1.66	3.99
ABC H6	56.77	1.43	3.44
ABC H7	85.28	2.15	5.16
ABC H8	61.39	1.55	3.71
ABC H9	68.64	1.73	4.16
ABC H10	72.69	1.83	4.40
ABC H11	47.62	1.20	2.88
ABC H12	76.28	1.92	4.62
ABC H13	66.08	1.68	4.00
ABC H14	69.11	1.74	4.18
ABC H15	75.88	1.91	4.59
ABC H16	50.32	1.27	3.05
ABC H17	75.96	1.92	4.59
ABC H18	67.44	1.70	4.08
ABC H19	72.38	1.83	4.38
ABC H20	55.49	1.40	3.36
MEAN	**66.1±10.1**	**1.7 ±0.3**	**4.0 ±0.6**

4.3 Overview of the two seasons

Indoor radon concentrations for the rainy season show relatively high values than that for the dry season. This was expected as the sliding windows used for the dwellings are not opened during the rainy season. This might have resulted in the accumulation of radon gas in the rooms. Ventilation therefore plays a major role in reducing indoor radon concentration.

Otoo (2016) worked extensively on building materials. The radon concentrations measured for the building materials (tiles, cement, sand, and cement block, sand Crete) ranged From 17 to 43 Bq/m^3. Similar building materials were used for the dwellings under study. Table 4.3.1 below presents a summary of the range of indoor radon concentrations recorded during the two seasons and the range of values obtained by Otoo et al., (2016) for the building materials. Comparison of the lower and upper limit values of the indoor radon concentrations obtained in the two seasons with that of the same building materials shows that the building materials have relatively low radon concentrations. As mentioned earlier, other factors such as the routes of entry seemed to be minimal. Reduction of the indoor radon concentration to further lower levels could be successfully achieved through good ventilation system.

Table 4.13: Range of indoor radon concentration during rainy and dry season

Locality	Rainy Season Bq/m^3	Dry Season/Bqm^3	Building materials Bqm^{-3} (Otoo et al., (2016)
Dome Afghanistan	79 – 334	42 – 124	
Achimota Mile7	53 – 229	46 – 117	**17-43**
Achimota ABC	**60 – 177**	**50 – 85**	

4.4 Range of indoor radon concentration during rainy and dry seasons

Dwelling AF H17 in the Dome Afghanistan locality recorded the highest indoor radon concentration in the study area. Indoor radon concentration of 334.10 Bqm^{-3} with a corresponding annual effective Dose of 20.2 mSv/y was recorded. This relatively high value could be attributed to the position of this building and size of the room. This dwelling is surrounded by a cluster of room and therefore was no window; the door to this dwelling was the only opening for air exchange resulting in an elevated level of indoor radon in the dwelling.

4.5 Comparism of the Current Studies, to Previous Studies in Dome.

Oppon et al., 1998 measure indoor radon concentration in both sand Crete and adobe houses at Dome village and found a mean indoor radon concentrations of 91 Bq/m3. Nsiah-Akoto et al., (2010) measured radon at a different location in Dome and found a mean indoor radon concentration of 466 Bqm^{-3}. It was expected that the radon

concentration in Dome Afghanistan will vary from one location to the other in Dome. The Average indoor radon levels for the current study in Dome-Afghanistan is 121.1 Bqm^{-3}

Achimota-mile7 had 94.5Bq/m3/and Achimota ABC had 92.75 Bqm^{-3}

Comparatively, the current study in Dome indicates that mean indoor radon concentration deviates significantly from the mean indoor radon concentration in 2010, the result seem to be closer to the mean indoor radon concentration obtained in 1989.

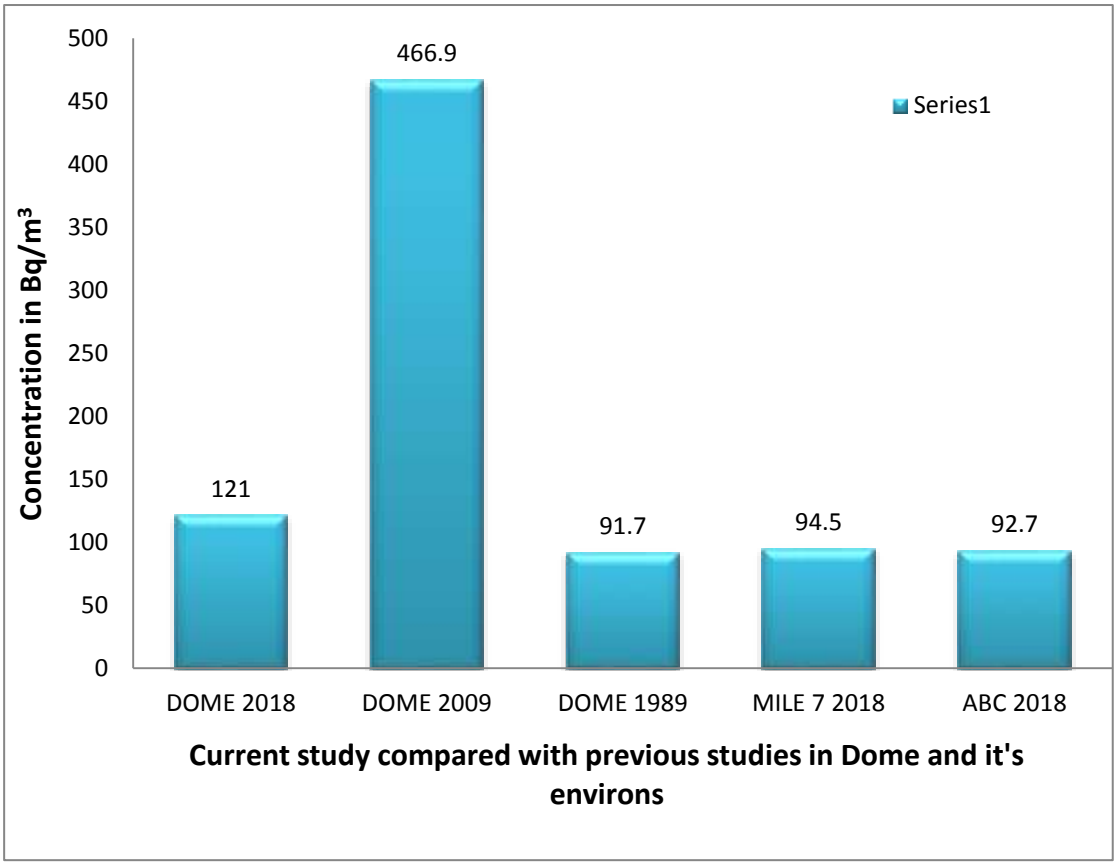


Figure 4.1: Indoor radon concentrations current study compared to previous studies in Dome

4.6 CORRELATION ANALYSIS

4.6.1 Indoor Radon Verse Soil Radon Concentrations in the Rainy Season

In the analysis of soil radon concentration and indoor radon concentrations in the rainy season, a linear correlation graph was used. This graph gave an R-Squared value of 0.0032; the value indicated a weak negative correlation between soil radon concentration and indoor radon in the rainy season.

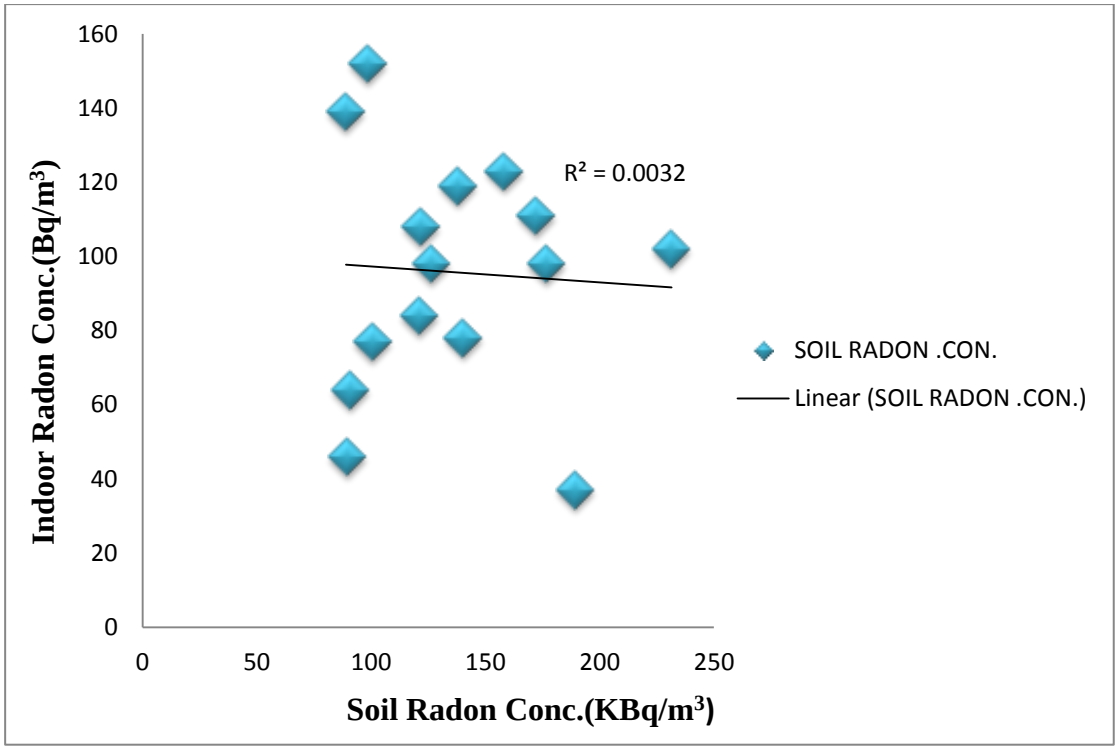


Figure 4.2: Linear Correlations between Indoor Radon Concentrations against Soil Radon Concentration during the Rainy Season.

4.6.2 Indoor radon verses soil radon in the dry season.

A linear correlation graph is used. The graph obtained an R-squared value of 0.0021. This value clearly indicates a weak negative correlation between soil radon and indoor radon in the dry season, which is represented on the x and y axis respectively this implies that the indoor radon concentration do not depend largely on the soil radon gas.

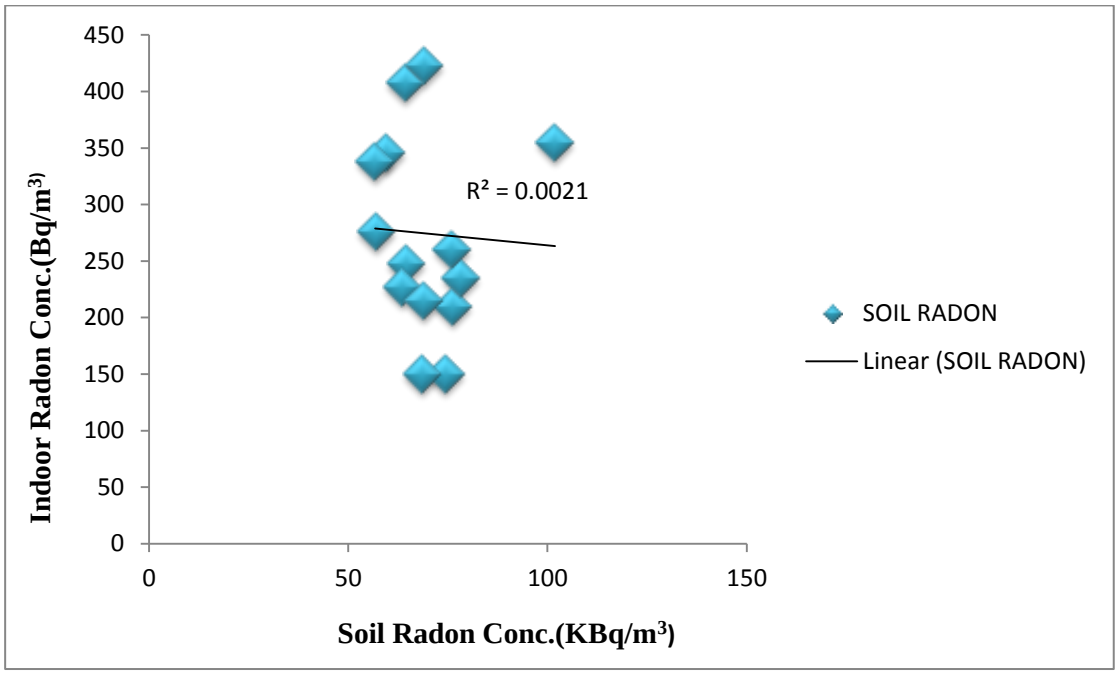


Figure 4.3: linear correlations between indoor radon concentrations against soil radon concentration during the dry season.

CHAPTER 5

CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

Seasonal assessment on indoor and soil radon has been conducted in Dome and its environs, Greater Accra region of Ghana. The duration for the survey was 90 days for indoor and 28 days for soil. The rainy season spanned from June to September 2017, and the dry season spanned from October to January 2018. A total of 60 houses were monitored, 180 detectors were used for the measurement. One hundred and twenty detectors were used for indoor radon and 60 for soil radon measurements. Significant seasonal variations were observed in the radon concentrations of the dwellings studied. The rainy season recorded high indoor radon concentrations compared to the dry season in all the dwellings. The high concentrations in the rainy season might be attributed to the infrequent opening of the slide glass windows to allow exchange of air. It was possible that if louvers were used for the windows it would have been easier to open during the rainy season and that could have allowed free exchange of air and hence the reduction in the indoor radon concentrations. It was expected that the indoor radon in Dome –Afghanistan will be higher than indoor radon values obtained in Dome-2010 (Nsiah-Akoto, etal.,2010), but indoor radon reduced significantly between 2018 and 2009, but rather close to the radon concentration in 1989. It was also expected that an appreciable amount of radon-222 gas measured at 75cm depth would be transported from the ground by pressure induced convective flows or diffusion into the dwelling through fractures that might be in the concrete floor, the outdoor pores and fractures in the concrete blocks.

However, the indoor concentrations measured in all the seasons seemed to be far lower than the soil measurements at the 75 cm depth. The soil radon gas that was

measured in the dry season was higher than the measurements in the rainy season. This was attributed to the high moisture content of soil during the rainy season, which slowed down radon exhalation, diffusion and transportation. The lower moisture content in the dry season increased radon exhalation from the soil. This suggested that there might be only few entry routes through which the radon gas passes into the dwellings. The concrete floor and blocks of the dwellings seemed to have provided shielding and prevented high radon diffusion from the ground and outdoor into the dwellings.

A linear correlation analysis on the influence of soil radon concentration on indoor radon concentration in rainy and dry seasons, gave and an R-squared value of 0.0032 and 0.0021 indicating a weak negative correlation between soil radon concentration and indoor radon concentrations. This implies indoor radon concentration; do not depend on soil radon.

The dwellings in the study areas recorded a mean indoor concentration of 121 Bq/m^3 for Afghanistan, 94.5 Bq/m^3 for Achimota Mile 7 and Achimota ABC had 92.7 Bq/m^3 .All the dwelling in the study area has a mean indoor radon above the worlds average indoor radon level of 40 Bq/m^3 (USCEAR 2004). Dwelling AF H17 in the Dome Afghanistan recorded the highest indoor radon concentration of 334.10 Bq/m^3,with a corresponding annual and effective dose of 8.43 and 20.2 mSv/y and this was recorded in the rainy season. This room is surrounded by a number of rooms with no windows, only the door serves as the opening for exchange of air. This seemed to have accounted for the high radon level. Ventilation is therefore a key factor affecting indoor radon concentration in the study area. This study will be added to the existing data on radon in dwellings and also increase knowledge in radon.

5.2 RECOMMENDATIONS

The Following Recommendations Are Provided**;**

a) Detail studies on radon monitoring should be conducted by the Radiation Protection Institute, Ghana atomic Energy Commission and the Nuclear Regulatory Authority (NRA) on dwellings with sliding glass windows so that appropriate recommendations could be made to the District Assemblies through the Ministry of Local Government for the necessary steps to be taken to include piping systems at the design stages of buildings (as a building code). These piping systems provide automatic air exchanges in dwellings irrespective of whether the windows are opened or not.

b) An authentic radon map can only be realized in Ghana only if continuous monitoring is done with a proper records keeping.

c) Similar studies should be conducted in the study area to comprehend the relationship amongst indoor and soil radon fixations and altitude variables and pH.

d) Detailed studies on indoor radon should be conducted in painted buildings and those that are not painted.

REFERENCES

Ameyibor, K., Wiredu, M.B. (1999). GAST Chemistry. Unimax Macmillan. London

Amoah, P., Andam, A.B., Amponsah, E.K. and Nsiah–Akoto, I. (2012). Variation of Radon Gas Emanation with Altitude in Some Parts of Greater Accra

Andam A.A.E, Amankwah E.A., Addison E.C.K, Nani E.K. (2007). Radon Measurements in Ghana: Health Risk Assessment at the Lake Bosomtwi Basin. *Ghana J Science*. 9:85-93

Aniagyei H.M and Kyere A.W.K. Monitoring of Natural Background Radiations in Some Ghanaian Homes. Paper Presented at the International Conference on High Levels of Natural Radiation, 3-7 November 1990.Ramsar, Islamic Republic of Iran.

Asumadu-Sakyi, A. B., Fletcher, J. J., Oppon, O. C., Quashie, F. K., Wordson, D. A., Adjei, C. A., ... & Amponsah, P. (2011). Preliminary studies on geological fault location using solid state nuclear track detection. Research Journal of Environmental and Earth Sciences, 3(1), 24-31.

Ansre, C. Y. (2015). *Dose assessment of radon levels in the South-Dayi district of the Volta Region, Ghana* (Doctoral dissertation, University of Ghana).

Appleton, J. D. (2007). Radon: sources, health risks, and hazard mapping. *AMBIO: A Journal of the Human Environment*, *36*(1), 85-90.

Bhagwat, A. M. (1993). *Solid state nuclear track detection: theory and applications* (No. ISRP-K-TD--2). Indian Society for Radiation Physics.

Bhagwat,A. M. (1993). ”Solid State Nuclear Track Detector: Theory and Application”. India Society for Radiation Physics, Kalpakkam Chapter.

Cember, H. introduction to Health physics 3 edition GRAW-hill, New York (2000) Ciotoli, G.Lombardi, S. Annunziatellis, A., 2007.Geostatisticalanalysis of soil gas data in a high seismic Inter montane basin the Fucino plain, Central Italy

Cothern, C. R. (1987). Estimating the health risks of radon in drinking

Darby, S.C., Whitley, E. and Howe, G.R. (1995). Radon and Cancers Other Than Cancer in underground miners: a collaborative analysis of 11 studies. Journal of the National Cancer Institute, 87 (5), 378-384-. Journal-American Water Works Association, 79 (4), 153-

158.

Darby, S., Hill, D., Auvinen, A., Barros-Dios, J. M., Baysson, H., Bochicchio, F & Heid, I. (2005). Radon in homes and risk of lung cancer: collaborative analysis of individual data from 13 European case-control studies. Bmj, 330(7485), 223.

Darko E. O., Tetteh G. K. and Akaho E. H. K. Occupational radiation exposure to norms in a goldmine. *Rad. Prot. Dosim., 114(4): 538–545, (2005).*

Darko E.O., Nguelem E.J.M., Ndontchueng M.M., Schandorf C., Akiti T.T., Muhulo A.P. and Dogbey R.O.G. Assessment of Natural Radioactivity Level in Groundwater from Selected Areas in Accra Metropolis, *Research Journal of Environmental and Earth Sciences, 5(2): 85-93, (2013).*

Download radonfactsheet.downloardon27/07/2018 at11.00am

Duggal, V., Mehra, R., & Rani, A. (2015). An investigation of factors influencing Indoor radon concentrations in dwellings of Northern Rajasthan, India. Journal of the

Durrani, S. A. (1997). *Radon measurements by etched track detectors: applications in radiation protection, earth sciences and the environment*. World Scientific.

Eghan, M. J., Buah-Bassuah, P. K., & Oppon, O. C. (2007). Track analysis of laser-illuminated etched track detectors using an opto-digital imaging system. *Measurement Science and Technology*, *18*(11), 3651.Enge, W. (1980). Introduction to plastic nuclear track detectors. *Nuclear tracks*, *4*(4), 283-308.

Fahiminia, M., Fard, R. F., Ardani, R., Naddafi, K., Hassanvand, M. S., & Mohammadbeigi, A. (2016). Indoor radon measurements in residential dwellings in Qom, Iran. International journal of radiation research, 14(4), 331-9.

Fox, G. A., & Kendall, B. E. (2002). Demographic stochasticity and the variance reduction effect. Ecology, 83(7), 1928-1934.

Geological Society of India, 86(2), 173-180.

Ghana District Assemblies, 2012. *http://www.ghanadistrictassemblies.com*

Ghana Statistical Service, 2013. Population and Housing Census Final Report.

Gilmore G. & Hemingway J. D. Practical Gamma Spectrometry, John Wiley and Sons, NY, NY. (1995). Harb S., Salahel Din K. and Abbady

Harley N. H., and Pasternak B. S. (1972). Alpha Absorption Measurements Applied to Lung Dose from Radon Daughters. *Health Phys*. 23: 771-782

Hewitt, C. N., & Kelly, M. (1990). Environmental radon: A brief review. Environmentaltechnology,11(4),387-392.

https://certmapper.cr.usgs.gov/data/PubArchives/radon/georadon/3.html

https://do1.org/10.1029/j2070i002p00471

ICRP (1987). Lung cancer from indoor exposure to radon daughters. ICRP Publication 50, Annals of the ICRP, l7 (1).

ICRP. Protection against ^{222}Rn at home and at work, International Commission on Radiological Protection, ICRP publication 65, Pergamon Press, Oxford, (1993).

J.K. Gbadago, A. Faanhof, E.O. Darko, C. Schandorf, and M.A. Addo (2010).Contributions of natural radionuclides in the domestic water of two critical gold mining communities in Ghana. *Water Qual Expo Health Dec 2011*.

Kandall, G. A. (2002). Classroom capsules: Euler's theorem for generalized quadrilaterals. *The College Mathematics Journal*, *33*(5), 403.

Kansaana, C., Aba, A. B., Addision, E. K. T., Darko, E. O., Adukpo, O. K., & Faanu, A. (2012). Measurement of radon activity in soil samples of some selected towns across the Lake Bosumtwi basin, Ghana. *Radiation Protection and Environment*, *35*(2), 84.

Kase, K.R., Bjärngard, B.E., Attix, F.H. (1985). The Dosimetry of Ionizing Radiation, Etch track detectors in Radiation Dosimetry: Academic Press. London. 3:323-419.

Kendall, G.M., and Smith T.J. (2002). Doses to organs and tissues from radon and its decay products. *Journal of Radiological Protection, 22*(4): 389-406.

Kendall, G.M., Green, B.M.R., Miles, J.C.H., Dixon, D.W., 2005. The Development of the UK Radon Program. *J. Radiol. Prot*. 25:475–492.

Kesse, G.O., (1985). The mineral and rock resources of Ghana. The republic of Ghana – Geography, physiography, geology and geohydrology. A.A. Balkema/Rotterdam/Boston. P 9-42

Knoll F. Griffin. Radiation Detection and Measurement, 3rd ed., John Wiley & Sons, Inc. New York, USA, (1999).

L'Annunziata, M.E., (1998). Handbook of Radioactivity Analysis. Academic Press (Harcourt), London, U.K (eds.) p 179-237

Lawrie W.C., Desmond J.A., Spence D. ´Determination of radium-226 in environmental and personal monitoring samples´. *Applied Radiation and Isotopes, 53: 133 -137(2000).*

Lappenbusch, W. L., & Cothern, C. R. (1985). Regulatory development of the interim and revised regulations for radioactivity in drinking water--past and present issues and problems. Health physics, 48(5), 535-551.

Ludin F. E, Wagnor J.K and Archer V.E, (1971).Radon Daughter Exposure and RespiratoryCancer: Quantitative and Temporal Aspects. Environmental Health. 21:35-43

Magalhaes, M.H., Amaral, E.C.S., Sachett, I., Rochedo, E.R.R., 2003. Radon-222 in Brazil: an outline of indoor and outdoor measurements. *J. Environ. Radioact.* 67:131–143.

Mahmoud I. Abbas. Validation of analytical formulae for the efficiency calibration of gamma detectors used in laboratory and in-situ measurements, Applied Radiation and Isotopes ,64:1661–1664, (2006).

Mehra, R., Badhan, K., Kansal, S., & Sonkawade, R. G. (2011). Assessment of seasonal indoor radon concentration in dwellings of Western Haryana. Radiation Measurements,46(12), 1803-1806.

National Academy of Sciences. (1980). Effects on population Exposure to Low levels of Ionizing Radiation. BEIR III Report. Government Printing Office, Washington DC.

Ramola, R. C., Negi, M. S., & Choubey, V. M. (2005). Radon and thoron monitoring in the environment of Kumaun Himalayas: survey and outcomes. *Journal of environmental radioactivity*, *79*(1), 85-92.

Report. Health Effects of Exposure to Radon. National Academy Press, Washington DC.

National Research Council. (1999). Biological Effects of Ionizing Radiation. BEIRVI 2 Report. Health Effects of Exposure to Radon. National Academy Press, Washington DC

Nazaroff, W. W., & Nero Jr, A. V. (1988). Radon and its decay products in indoor air.

Nsiah- Akoto I., Fletcher J. J., Oppon O.C. and Andam A.B. (2011). Indoor Radon Levels and the Associated Effective Dose Rate Determination at Dome in the Greater Accra Region of Ghana. Research Journal of Environmental and Earth Sciences, 3(2): 124-130.

Obed, R. I., Ademola, A. K., Vascotto, M., & Giannini, G. (2011). Radon measurements by nuclear track detectors in secondary schools in Oke-Ogun region, Nigeria. Journal of environmental radioactivity, 102(11), 1012-1017.

Oppon O.C., Otoo, F., Adukpo, O. K., Darko, E. O., Emi-Reynolds, G., Awudu, A. R., Ahiamadjie, H., & Gyampo, O. (2011). Assessment of natural radioactive materials in building materials used along the coast of Central Region of Ghana. *Research Journal of Environmental and Earth Sciences*, *3*(3), 261-268.

Quashie, F.K., Fletcher, J. J., Oppon, O. C., Asumadu-Sakyi, A. B., Wordson, D. A. and Adjei, C. A. (2010). Preliminary Studies on Indoor Radon Measurements in Some Adobe Houses in the Kassena Nankana Area of the Upper East Region of Ghana. Research Journal of USEPA.

Radon mitigation research. United States Environmental Protection Agency Washington: September, (1999).

Vine, J. D., & Tourtelot, E. B. (1970). Geochemistry of black shale deposits; a summary report. *Economic Geology*, *65*(3), 253-272 Wen, T., Du, J., Ji, T., Wang, X., & Deng, B. (2014).

Use of 222Rn to trace submarine groundwater discharge in a tidal period along the coast of Xiangshan, Zhejiang, China. *Journal of Radioanalytical and Nuclear Chemistry*, *299*(1), 53-60.

World Health Organization (2009), WHO Handbook on Indoor Radon. A Public Health Perspective. WHO Press, Switzerland www.khanacademy.org/science/in-in-class-12th-physics-india/nuclei/in-in-nuclearphysics/a/radioactive-decay-types-article

Young, D. A. (1958). Etching of radiation damage in lithium fluoride. *Nature* 182:375–377

Zunic, Z. S., Carpentieri, C., Stojanovska, Z., Antignani, S., Veselinovic, N., Tollefsen, T., &

Bossew, P. (2013). Some results of a radon survey in 207 Serbian schools. *Romanian Journal of Physics*, *58*(S), S320-S327.

APPENDIXES

Appendix A

Analysis for Track Counting

1. Open the Image J Software interface
2. From the file menu select Import, under Import select Image sequence
3. A document folder will open. Select the folder that contains your saved images and select one image.
4. The sequence option dialog box will open after selection. Under the sequence dialog box select the following options:

Number of mages: 10

Starting image: 1

Increment: 1

Scale images: 100%

Do not select sort names numerically

Then Click OK

1. The images selected will appear in a dialog box. Check to see if all images appeared by using the control arrows.
2. From the image J window, Select plugin then filters and then accurate Gaussian blur
3. A dialogue box will appear. Select Sigma Radius - 2.0, then click OK
4. A dialogue will appear, select yes to Process all images
5. From the image J window, select Process – FFT – Band pass Filter From the Band pass filter dialog box:
    - " Filter large is structures down to 40 pixel in

the Band pass filter dialog box:’’

- “ Filter small structures up to 3 pixels’’
- “Suppress stripes : None’’
- “Tolerance of direction 5%’’
- Then neatly, select:
- Select auto scale after filter
- Saturate image when auto scaling
- Process entire stack.

Then click OK

Wait a while for the image to be processed

1. From Image J dialogue box select Image – color – split channels(it brings out 3 colors blue – green – red; choose green and close the rest)
2. From Plug-in on Image J window select Macros – Run.

APPENDIX B

Radon Concentration, annual dose and the annual effective dose to inhabitants at Afghanistan during the rainy season

AF: Rainy.	RadonConc. Bq/m^3	Annual DoseD_{Rn} ($mSvy^{-1}$)	Annual Effective Dose ($mSv\ y^{-1}$)
AF H1	240.38	6.06	14.55
AF H2	243.65	6.15	14.75
AF H3	173.82	4.39	10.52
AF H4	140.30	3.60	8.49
AF H5	176.45	4.45	10.68
AF H6	282.58	7.13	17.11
AF H7	89.74	2.26	5.43
AF H8	189.35	4.78	11.46
AF H9	105.10	2.65	6.36
AF H10	176.65	4.46	10.69
AF H11	158.21	3.99	9.58
AF H12	105.10	2.65	6.36
AF H13	99.21	2.50	6.01
AF H14	256.07	6.46	15.50
AF H15	97.22	2.45	5.89
AF H16	79.39	2.00	4.81
AF H17	334.10	8.43	20.23
AF H18	183.53	4.63	11.11
AF H19	90.53	2.28	5.48
AF H20	87.43	2.21	5.29

APPENDIX: C

Radon Concentration, annual dose and the annual effective dose to inhabitants at Achimota-Mile7 during the rainy season

M7 Rainy.	concentration Bq/m^3	Annual Dose D_{Rn} ($mSvy^{-1}$)	Annual Effective Dose E ($mSv\ y^{-1}$)
M7 H1	53.91	1.36	3.26
M7 H2	121.27	3.10	7.34
M7 H3	215.94	5.45	13.07
M7 H4	90.93	2.29	5.50
M7 H5	92.84	2.34	5.62
M7 H6	100.80	2.54	6.10
M7 H7	137.99	3.48	8.36
M7 H8	74.21	1.87	4.49
M7 H9	126.60	3.19	7.67
M7 H10	72.94	1.84	4.42
M7 H11	53.35	1.35	3.23
M7 H12	78.11	1.97	4.73
M7 H13	173.82	4.39	10.52
M7 H14	176.69	4.46	10.70
M7 H15	86.23	2.18	5.22
M7 H16	92.60	2.34	5.61
M7 H17	132.10	3.33	7.99
M7 H18	229.23	6.40	13.88
M7 H19	87.43	2.21	5.29
M7 H20	77.24	1.95	4.68

APPENDIX: D

Radon Concentration, annual dose and the annual effective dose to inhabitants at Achimota-ABC during the rainy season

ABC Rainy	Radon Conc. Bq/m^3	Annual DoseD_{RN} (mSvy^{-1})	Annual Effective DoseE (mSv y^{-1})
ABC H1	158.21	3.99	9.58
ABC H2	85.76	2.16	5.19
ABC H3	172.15	4.34	10.42
ABC H4	177.40	4.48	10.74
ABC H5	116.10	2.93	7.03
ABC H6	121.82	3.07	7.38
ABC H7	75.80	1.91	4.59
ABC H8	80.18	2.02	4.85
ABC H9	88.94	2.24	5.39
ABC H10	60.28	1.52	3.65
ABC H11	146.51	3.70	8.87
ABC H12	75.72	1.91	4.58
ABC H13	151.44	3.82	9.17
ABC H14	158.85	4.01	9.62
ABC H15	98.42	2.48	5.96
ABC H16	85.83	2.17	5.21
ABC H17	64.34	1.62	3.89
ABC H18	57.89	1.46	3.50
ABC H19	78.83	1.99	4.77
ABC H20	66.01	1.67	3.99

APPENDIX E

Radon Concentration annual dose and the annual effective dose to inhabitants at Dome-Afghanistan during the dry season

AF: Dry	concentration Bq/m^3	Annual Dose D_{Rn} (mSvy^{-1})	Effective Dose (mSv y^{-1})
AF H1	74.53	1.72	
AF H2	84.32	2.13	5.11
AF H3	76.20	1.92	4.61
AF H4	101.92	2.57	6.17
AF H5	60.36	1.52	3.65
AF H6	124.05	3.13	7.51
AF H7	57.09	1.44	3.46
AF H8	76.28	1.92	4.61
AF H9	100.17	2.53	6.07
AF H10	64.73	1.63	3.92
AF H11	57.81	1.46	3.50
AF H12	93.88	2.37	5.68
AF H13	110.68	2.79	6.70
AF H14	75.01	1.89	4.54
AF H15	45.94	1.16	2.78
AF H16	84.40	2.13	5.11
AF H17	42.76	1.08	2.59
AF H18	67.12	1.69	4.06
AF H19	85.12	2.15	5.15
AF H20	75.72	1.91	4.58

APPENDIX: F

Radon Concentration, annual dose and the annual effective dose to inhabitants at Achimota-mile7 during the dry season

M7 Dry	Radon Conc. Bq/m^3	Annual Dose D_{Rn} ($mSvy^{-1}$)	Annual Effective Dose E ($mSv\ y^{-1}$)
M7 H1	117.21	2.96	7.10
M7 H2	78.27	1.97	4.74
M7 H3	85.83	2.17	5.20
M7 H4	76.04	1.99	4.60
M7 H5	77.95	1.97	4.72
M7 H6	69.03	1.74	4.18
M7 H7	64.49	1.63	3.91
M7 H8	77.08	1.94	4.67
M7 H9	63.62	1.60	3.85
M7 H10	74.45	1.88	4.50
M7 H11	93.32	2.35	5.65
M7 H12	62.90	1.59	3.81
M7 H13	73.02	1.84	4.42
M7 H14	63.94	1.61	3.87
M7 H15	46.34	1.17	2.81
M7 H16	56.45	1.42	3.42
M7 H17	71.50	1.80	4.33
M7 H18	66.88	1.69	4.05
M7 H19	71.18	1.79	4.31
M7 H20	60.36	1.52	3.65

APPENDIX: G

Radon Concentration annual dose and the annual effective dose to inhabitants at Achimota-ABC during the dry season

ABC Dry	Radon conc Bq/m^3	Annual Dose D_{Rn} (mSvy^{-1})	Annual Effective Dose E (mSv y^{-1})
ABC H1	59.64	1.50	3.61
ABC H2	74.77	1.89	4.52
ABC H3	69.19	1.75	4.19
ABC H4	51.04	1.29	3.09
ABC H5	65.93	1.66	3.99
ABC H6	56.77	1.43	3.44
ABC H7	85.28	2.15	5.16
ABC H8	61.39	1.55	3.71
ABC H9	68.64	1.73	4.16
ABC H10	72.69	1.83	4.40
ABC H11	47.62	1.20	2.88
ABC H12	76.28	1.92	4.62
ABC H13	66.08	1.68	4.00
ABC H14	69.11	1.74	4.18
ABC H15	75.88	1.91	4.59
ABC H16	50.32	1.27	3.05
ABC H17	75.96	1.92	4.59
ABC H18	67.44	1.70	4.08
ABC H19	72.38	1.83	4.38
ABC H20	55.49	1.40	3.36

APPENDIX: H

1st detector results for soil radon concentration against the dwelling codes during the dry season

Dwelling. Codes	Detector/ Counrts	Soil Radon Conc.KBq/m^3	Radon Conc. Bq/m^3
AF H1	24342	1.94	1935.648
AF H7	45221	3.60	3598.107
AF H11	34910	2.78	2777.109
AF H13	28162	2.24	2239.809
MI7 H2	43219	3.44	3438.701
MI7 H16	11902	0.95	945.131
M7 H20	12412	0.99	985.739
M7 H4	39104	3.11	3111.050
M7 H18	34562	2.75	2749.400
ABC H3	43219	3.44	3438.701
ABC H10	19731	1.57	1568.504
ABC H6	82713	6.58	6583.352
ABC H14	53156	4.23	4229.920
ABC H20	26468	2.10	2104.927

APPENDIX I

2st detector results for soil radon concentration against the Dwelling codes during the dry season

Dwelling .Codes	Detector/ Counrts	Soil Radon Conc. KBq/m^3
AF S.R.D.2	13329	1.06
AF H7	44013	3.50
AF H11	32100	2.55
AF H13	25221	2.01
MI7 H2	19253	1.53
MI7 H16	47281	3.76
M7 H20	53984	4.30
M7 H4	63422	5.05
M7 H18	22530	1.79
ABC H3	10994	0.87
ABC H10	67329	5.36
ABC H6	23821	1.89
ABC H14	31972	2.54
ABC H20	11503	0.91
AF H4	45221	3.60

APPENDIX: J

The average of the 1st and 2nd result for soil radon concentration against their indoor radon concentration in the dry season.

Dwelling Codes	Indoor Conc. Bq/m^3	Soil Radon KBq/m^3
AF H1	74.53	150
AF H7	101.92	355
AF H11	57.09	276
AF H13	76.28	210
MI7 H2	64.73	248
MI7 H16	78.27	235
M7 H20	76.04	260
M7 H4	64.49	408
M7 H18	63.62	227
ABC H3	69.03	215
ABC H10	59.64	346
ABC H6	69.19	423
ABC H14	56.77	338
ABC H20	68.63	150

APPENDIX: K

1st detector results for soil radon concentration against the houses numbers during the rainy season

Dwelling Codes	Detector/ Counrts	Soil Radon Conc. KBq/m^3
AF H.S.R.R1	9151	0.73
AF H7	8958	0.71
AF H11	2198	0.17
AF H13	1985	0.16
MI7 H2	14564	1.16
MI7 H16	18957	1.51
M7 H20	26895	2.14
M7 H4	36601	2.91
M7 H18	15391	1.22
ABC H3	8212	0.65
ABC H10	8154	0.65
ABC H6	9093	0.72
ABC H14	9284	0.74
ABC H20	10928	0.87
AF H4	13799	1.10

APPENDIX : L

2nd detector results for soil radon concentration against the Dwelling codes during the rainy season

Dwelling Codes	Detector/ Counts	Soil Radon Conc. KBq/m^3
AF H.S.R.R2	7421	0.59
AF H7	1266	0.10
AF H11	7294	0.58
AF H13	5335	0.42
ABC H2	7811	0.62
ABC H16	17382	1.38
ABC H20	17669	1.40
ABC H14	18623	1.48
ABC H18	9296	0.74
M7 H3	11321	0.90
M7 H10	22923	1.82
M7 H6	18743	1.49
M7 H20	17724	1.41
M7 H4	24038	1.91
M7 H18	24365	1.94

APPENDIX M

The average of the 1st and 2nd result for soil radon concentration against their indoor radon concentration in the rainy season

Dwelling Codes	Indoor. Conc. Bq/m^3	Soil Radon Conc.(KBq/m^3)
AF H1	231.44	102
AF H4	140.3	78
AF H7	89.74	46
AF H8	189.35	37
AF H10	176.69	98
M7 H2	121.27	84
M7 H4	90.93	64
M7 H7	137.98	119
M7 H9	126.6	98
M7 H6	100.8	77
AB H1	158.21	123
AB H3	172.15	111
AB H6	121.8	108
AB H9	88.94	139
AB H10	98.72	152