RISK ASSESSMENT OF RADON GAS CONCENTRATION FOR SOME SELECTED OFFICES ON KNUST CAMPUS, KUMASI

by

YAW ADDO, BEDIAKO, BSc(Hons)

A Thesis Submitted to the Department of Physics,

Kwame Nkrumah University of Science and Technology

in partial fulfillment of the requirements for the degree

of

MASTER OF SCIENCE

College of Science

November 26, 2013

Declaration

I hereby declare that this submission is my own work towards the M.Sc and that, to the best of my knowledge, it contains no material previously published by another person nor material which has been accepted for the award of any other degree of the University, except where due acknowledgement has been made in the text.

....	....	....
Student Name & ID	Signature	Date

Certified by:

....	....	....
Supervisor Name	Signature	Date

Certified by:

....	....	....
Head of Dept. Name	Signature	Date

Abstract

Radon (^{222}Rn) has been identified as an important factor that could result in a health hazard by studies all around the world. The health risks can be minimised by preventive measures where radon is highly concentrated as in some mines or homes or offices. A study in the buildup concentration of the inert gas, will give us a better understanding of its possible pathways through soil into the air surrounding an office where the radon releases can become hazardous. Measuring the radon concentrations on Campus, can help to deduce the radon flux to identify the problem areas for rehabilitation. An active method incorporating Trace level radon gas detection and continuous monitoring method was used in this study to determine the radon concentration of the selected offices. Concentrations ranging from 0.010 to 0.498 pCi/l were detected, with the head of Optometry and Visual Science recording the heighest concentration of o.498 pCi/l, while the head of Agricultural Engineering department office with the least concentration of 0.010 pCi/l. Although these concentrations are generally low as compared with the EPA guidelines of an action level of 4 pCi/l, but no amount of radiation is said to be safe.

Contents

List of Tables

List of Figures

List of Symbols and Acronyms

$BEIR\ (VI)$	sixth Committee on Biological Effects of Ionizing Radiation
BG	background
Bq/m^3	Becquerel per cubic metre
CPM/cpm	Count per minute
DES	Department of environmental science
$DISC$	Discriminater
DNA	Deoxyribonucleic acid
EPA	Environmental Protection Agency
GI	gastrointestinal
HPA	Health protection agency
HV	High Voltage
$IARC$	International Agency for Research on Cancer
$ICRP$	international commission on radiological protection
MeV	Mega electronvolts
NAS	National Academy of Science
NIH	National institutes of health
NRC	National Research Council
$NTDs$	Nuclear track detectors

$PADC$	poly-allyl diglycol carbonate
$PAEC$	Potential alpha-energy concentration
PMT	Photomultiplier Tube
Pa	Pascal
TEL	Trace level radon gas detector
$U.S$	United States
UK	United Kingdom
$UNSCEAR$	United Nations Scientific Committee on the Effects of Atomic Radiation
WHO	World Health Organisation
WL	Working Level
WLM	Working Level Month
λ	decay constant
mSv	milli sievert
pCi/l	picocuries per litre
rem	Roentgen equivalent man

Acknowledgments

My first and foremost appreciation goes to the Almighty God for His unending mercies and grace towards me throughout the duration of this work.

I would like to take this oppurtunity to also acknowledge the following people for their invaluable support while conducting the study as well as through the writing process:

Mr Eric K.T Addison, supervisor, for his guidance, mental and technical support as well as financial contribution and willingness to always help in the completion of this study,

The Heads of Departments of KNUST, who allowed me to carryout my research, for the kind support and assistance throughout the course of the study,

My parents, Mr and Mrs Anthony Nimoh, my family and friends for their support, love and encouragement throughout.

CHAPTER 1

INTRODUCTION

1.1 Background

In radiation epidemiology, much work had been carried out in the past on the health effects of external photon exposures. Yet, population exposures are generally complex, including both external and internal exposure due to ingestion or inhalation of radionuclide. Today, one of the main issues in radiation protection is the quantification of long term effects of exposure to different radiation types, in particular alpha-emitters, which the general public may inhale daily at low levels through domestic exposure to radon and to which various subgroups of workers are exposed during occupational life. Emission of radon from the subsurface is the main source of radon gas accumulation in residential buildings. The fraction of radon gas (^{222}Rn and ^{220}Rn) released from the soil particles accumulates in the soil gas phase and spreads through unsaturated pores and fractures. The transport is driven by differences in concentration (diffusion) and in total pressure (advection). During transport, radon attenuates by radioactive decay, for which reason radon entering buildings from the soil usually originates from the upper few meters of the soil. In addition, radon dissolves within water contained in the soil pores and it is adsorbed onto soil grains. The latter has been reported to significantly reduce radon migration fluxes in dry soils since vapor adsorption in these cases takes place directly on the grain surfaces. Inside buildings, ventilation and stack effects usually cause the air pressure to be lower than in the surrounding soil. This produces a pressure gradient across the foundation ranging from 2 to 10 Pascal (Pa), but it may be as high as 15 Pa during the warm weather seasons. As a result, advective air movement transports radon and other soil vapors adjacent to the building's substructure through the zone of influence with a flux highly exceeding what is achieved by diffusion alone. For a century, it has been known that some underground miners suffered from higher rates of lung cancer than the general population. In recent decades, a growing body of evidence has clinically linked lung cancers to exposure to high levels of radon and also to cigarette-smoking. The connection between radon and lung cancer in miners has raised concern that radon in homes might be carcinogen of lung cancer in the general population, although the radon levels in most homes are much lower than in most mines. The National Research Council study, which had been carried out by the sixth Committee on Biological Effects of Ionizing Radiation (BEIR VI), had used the most recent information available to estimate the risks posed by exposure to radon in homes. Air near the ground may contain radon in high concentrations, while the concentration of radon activity declines with increasing height above the ground. Human interventions in nature, particularly mining for ore, may result in locally higher radon concentrations. The determination of radon concentration in offices is of considerable importance. Due to health effects pose by radon and its daughters to the general public, it is necessary to determine the present trace levels of radon activity in our offices and homes. Radon is responsible for the majority of the public exposure to ionizing radiation. It is often the single largest contributor to an individual's background radiation dose, and is the most variable from location to location. Radon gas from natural sources can accumulate in buildings, especially in confined areas such as attics, and basements. It can also be found in some spring waters and hot springs. Epidemiological evidence shows a clear link between breathing high concentrations of radon and incidence of lung cancer. Therefore, radon is considered a significant contaminant that affects indoor air quality worldwide. But lack of statistical power prevented most of them from showing a significant risk. To deal with this problem, several joint analyses have been conducted in recent years. They report a significant lung cancer risk after domestic radon exposure (Darby et al. 2005; Krewski et al. 2005;). Scientists have used all of these data to assess the lung cancer risk associated with indoor radon. The principal risk assessments come from the United States, the United Kingdom, and Canada (BEIR 1999; Darby et al. 2005; Krewski et al. 2005). The aim of this study is to assess the risk associated with public radon exposure in offices in the Kwame Nkrumah University of Science and Technology (KNUST), Kumasi, Ghana. The analysis will consider the variability of public radon exposure in KNUST and allows the quantification of uncertainties related to each of the exposure response relations. According to the United States Environmental Protection Agency, (EPA) radon is the second most frequent cause of lung cancer, after cigarette smoking. Radon concentration is usually measured in the atmosphere, in Becquerel per cubic meter (Bqm^{-3}), the SI derived unit. It is often measured in picocuries per liter (pCi/L) in the USA, with 1 pCi/L equivalent to 37 Bqm^{-3}. In the mining industry, the exposition is traditionally measured in working level (WL), and the cumulative exposure in working level month (WLM). The element emanates naturally from the ground, and some building materials, all over the world, wherever traces of uranium or thorium can be found, and particularly in regions with soils containing granite or shale, which have a higher concentration of uranium. There is a great interest in the study of natural environmental radioactivity in soil and air because the population is exposed at different levels depending on the concentration of natural radioactive minerals in each region in the world. Naturally occurring radiation and environmental radioactivity has led to the performance of extensive surveys in many countries of the world. Such investigations can be useful for both the assessment of public dose rates and the performance of epidemiological studies.

However, continual improvements in mining methods, engineering and ventilation controls, and radiation protection (including the enforcement of lower limits for exposure to radon daughters) have improved working conditions greatly. Although there are some exceptions, in general, the migration of radon up from the soil contributes the largest percent of radon found in the average office. The radon contributed from building materials is typically very small. Department of environmental science(DES) recommends that the two predominant pathways should be evaluated and that initial action to reduce radon exposure should target the pathway that contributes the largest percentage of risk to occupants. It is important to note the radon exposure is highly variable such that a high measurement can be taken in one building and the one next to it could be low. Variations also occur between rooms in a building with the lowest level usually having the highest radon reading. Variation can even happen within a room with higher levels nearest high points of radon inflow such as cracks or sumps.

1.2 Radon Characteristics

Radon is a chemical element with symbol Rn and atomic number 86. It is a radioactive, colorless, odorless, tasteless noble gas, which comes from the natural decay of radium that is found in nearly all rocks and soils or occurring naturally as the decay product of uranium. It is one of the densest substances that remains a gas under normal conditions and is considered to be a health hazard due to its radioactivity. The most stable isotope, radon-222, and has a half-life of 3.825 days. The rate of radon seepage is variable, partly because the amounts of uranium in the soil vary considerably. Radon flows from the soil into outdoor air and also into the air in offices from the movement of gases in the soil beneath offices.

Outside air typically contains very low levels of radon, but it builds up to higher concentrations indoors when it is unable to disperse. Some underground mines, especially uranium mines, contain much higher levels of radon. Radon inhalation is the main source of exposure to radioactivity for most people throughout the world [National Research Council's (NRC) Committee on the Biological Effects of Ionizing Radiation (BEIR) 1999; National Council for Radiation Protection and Measurements 1984a, 1984b; U.S. Environmental Protection Agency (EPA) 2003; United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR) 2000]. Most inhaled radon is rapidly exhaled, but the inhaled decay products readily deposited in the lung epithelium irradiate sensitive cells in the airways and thereby enhance the risk of lung cancer. In 1988, the International Agency for Research on Cancer (IARC) declared radon to be carcinogenic for humans (lung cancer) and classified as a group one (1) carcinogen (IARC 1988), based on the results of experimental animal and epidemiological studies, in particular among uranium miners. In 1988, the available results came from studies of high exposure levels. Extrapolation of this risk to the general population, who are exposed to lower levels in residential settings, raised numerous questions. In recent years, the average annual exposure of uranium miners has fallen to levels similar to the concentrations inhaled in some offices, and discussion today focuses on the transposition of the risk from occupational to general populations. Several case-control studies of residential radon have tested the validity of this risk transposition in the past decade (Auvinen et al. 1996; Kreienbrock et al. 2001; Letourneau et al. 1994; Schoenberg et al. 1990),

1.2.1 Transport Throughout Soil

Emanation is the process by which radon is transported from a solid to a gas or liquid medium. After radon is produced at the soil particulate level from the radioactive decay of radium, it is released into small air or water containing pores between soil and rock particles. This transportation of radon throughout soil is primarily accomplished through alpha recoil and the mechanical flow of air and water throughout the soil. Alpha recoil is defined as the process by which an atom (radon) recoils in the opposite direction from the path of particle ejection following the radioactive decay of its parent atom. Transportation throughout soil and within these pores is also somewhat facilitated by diffusion and convection. The diffusion constants for radon in air and water, 10^{-2} cm^2 s^{-1} and 10^{-5} cm^2 s^{-1}, respectively, which indicate that diffusion of radon is a relatively slow process and the movement of radon is therefore not significantly affected by this mechanism. After radon is released into the pore spaces, the efficiency of its eventual release into ambient air, termed exhalation, is a function of the following: the soil porosity, the concentration of radon in the soil/gas pore, meteorological factors, including, precipitation and atmospheric pressure. Following the release into ambient air, the dispersion of radon is primarily determined by atmospheric stability, including vertical temperature gradients and direction of wind's force, and turbulence.

1.3 Transportation Into and Throughout Indoors

Under certain circumstances the concentration of radon in a building can be increased significantly over its normal outdoor level. Most buildings have a confined air space with limited air movement and only a slow exchange with outside air. Consequently the concentration of any particulates or gases released into the building atmosphere will tend to increase above the concentration normally found in outside air. Radon can enter a building in a number of ways and once inside, the concentration of its particulate progeny will increase as the radon decays. Therefore, high concentrations of radon located in soil gas within soils with high transport efficiency (i.e. loose, porous, dry soil) can lead to elevated radon concentrations in buildings. Because radon-222 is a gas, it can readily travel vertically throughout several meters of permeable soils before decaying. The major sources of radon-222 in indoor air are: soil gas emanations from soils and rock, off-gassing of waterborne radon-222 into indoor air (initial entry through utilities such as water or natural gas), building materials, outdoor air.

Radon entry through the most important path, radon released soil-gas emanations, occurs primarily by bulk flow of soil-gas driven by small pressure differences between the lower part of the house interior and the outdoors. The pressure variability is primarily due to differences in indoor versus outdoor temperature and the effects of wind. The radon gas percolates up through porous soils under the office or building and enters through gaps and cracks in the foundation or insulation and through transport by means of pipes, sumps, drains, walls or other openings. The primary limiting factors for radon-222 gas migration out of the soil and its subsequent accumulation in a dwelling are: its half-life of 3.825 days, the geochemical composition and geophysical properties of the soil under and around the house, the nature and type of the building foundation, the construction techniques implemented, the level above the ground, the dimensions of the rooms, the ventilation rate, meteorological and seasonal parameters, living and working conditions.

1.3.1 Physical Factors Affecting the Dose

Progeny that are attached to dust particles (the attached fraction) deposit much more efficiently than free or unattached progeny; of the attached progeny, only those adhering to the smallest particles are likely to reach the alveoli. The amount and deposition of inhaled radon decay products vary with the flow rate in each airway segment and is dependent on the fol-

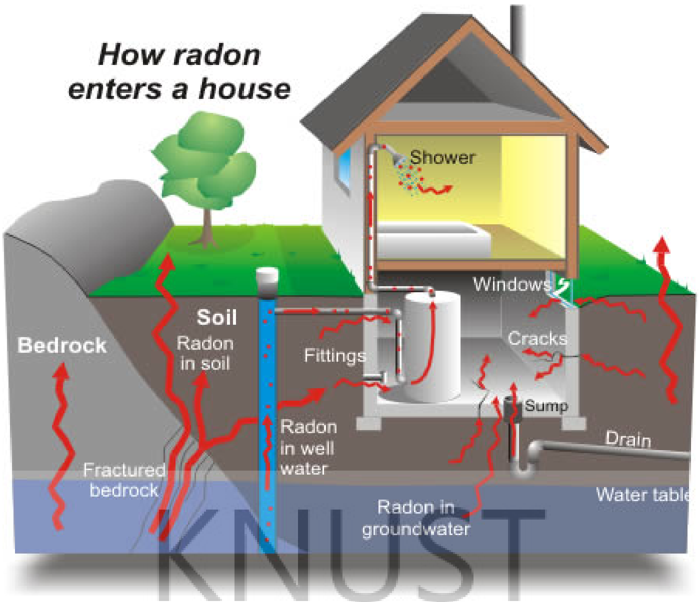

Figure 1.1: Radon entry path into offices

lowing factors. Radon concentration in air and duration of exposure, Equilibrium between Radon gas and solid progeny, Airborne particulate level, Aerosol size distribution

1.3.2 Biological Factors Affecting the Dose

There are a lot of factors that the amount of radon dose any individual receive depends on, some of these are:

1.3.2.1 Breathing Pattern

The proportion of oral to nasal breathing will affect the number of particles reaching the airways. Oral breathing deposits more of the larger particles in the nasopharyngeal region. Regardless of the breathing pattern, the smaller the particle, the deeper it penetrates into the lung and the more likely it is to deposit there.

1.3.2.2 Architecture of the Lungs

Sizes and branching pattern of the airways affect deposition; these patterns may differ between children and adults and between males and females. Preferential deposition of larger particles occurs at all branch points because of inertial impaction.

1.3.2.3 Biologic Characteristics of the Lungs

The radiation dose occurs in those areas where mucociliary action is either absent or ineffective in removing the particles. Particles moving with the mucous flow cause essentially no radiation dose to tissue because of the short range of alpha particles in fluids. Bronchial morphology, Lung tidal volume. Deposition increases with increased tidal volume, Oral vs. nasal inhalation route, Clearance rate from the lungs are other factors that affect the dose.

It is possible, therefore, that two environments with the same radon measurement might cause different deposition patterns and, therefore, deliver different doses of alpha radiation to a person's lungs. Likewise, two persons in the same environment might receive differing doses of alpha radiation to the target cells in the upper portion of their lungs because of differing breathing patterns and pulmonary architecture. Long lived radon progeny (lead-210, bismuth-210, and polonium-210) contribute little to the dose because they are eventually removed by the mucous and cilia in gastrointestinal(GI) tract before they can decay.

1.4 Risk Assessment

1.4.1 Radon Prevalence and Public Health Impact

Natural sources contribute significant quantities of radiation toward the total radiation exposure that humans receive as background radiation as shown in figure 1.2. The majority of this natural radiation is harmless to humans in the ambient environment. However, radon, a large component of the natural radiation that humans are exposed to (greater than 60%), can pose a threat to the public health when radon gas accumulates in poorly ventilated residential and occupational settings. According to the Office of the Surgeon General: 'Indoor radon gas is

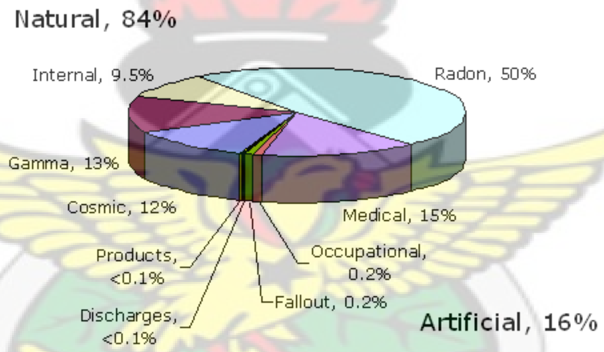

Figure 1.2: Annual Dose due to natural radiation sources

a serious health problem that can be addressed by individual action. Unless people become aware of the danger radon poses, they will not act. Radon, although not always publicized as a tremendous public health concern, but it is ranked highly among other preventable causes of death, including drunk driving, drowning, and fires. Additionally, the death risk to the average person from radon gas at office is 1,000 times higher than the risk from any other carcinogen or toxin regulated by the united state food and drug administration(FDA) or EPA. For these reasons, research must be conducted to evaluate certain subgroups that have elevated risks and technology must be developed and implemented in order to limit exposure to dangerous levels of radon and its harmful progeny.

1.4.2 Risk Estimates

For a lifetime exposure, the EPA recommends guideline of 4 pCi/L. The EPA estimates that the risk of developing lung cancer is 1 to 5%, depending on whether a person is a nonsmoker, former smoker, or smoker. The overall risk of radon exposure is related not only to its average level in the office, but also to the occupants and their lifestyles.

1.4.3 Factors that Influence the Risk of Lung Cancer from Radon Exposure

There are a lot of factors that contribute to the level of radon that an individual is exposed to, some of these factors include: age, duration of exposure, time since initiation of exposure, cigarette smoking, other carcinogenic exposures, gender, physical condition, Geographic location Certain characteristics of the residence and environmental factors will play a role in determining the indoor radon concentrations. The highest radon levels are typically found in the lowest level of the house. If well water is the major source of radon, upper floors can be affected more than lower floors because of dissolution of radon from the water. Radon levels are elevated in colder climates (winter) rather than in more mild temperatures (summer and spring). The risk of lung cancer associated with lifetime inhalation of radon in air at a concentration of 1 Bqm^{-3} was estimated on the basis of studies of underground miners. The values were based on risk projections from three follow-up studies: BEIR IV (National Research Council 1988). These three reports used data from 4 to 11 cohorts of underground miners in seven countries and developed risk projections of 1.0×10^{-4}, 1.2×10^{-4}, and 1.3×10^{-4} per unit concentration in air (1 Bq m^{-3}), respectively. The three values were for a mixed population of smokers and nonsmokers. The risk of lung cancer (discussed in two reports of the National Research Council and one of the National Institutes of Health) posed by lifetime exposure to radon (^{222} Rn) in water at 1 Bq m^{-3} was calculated to be 1.3×10^{-8}. As already stated, an increase in the number of radiation particles that pass through the human body correlates to an increase in the chance of developing cancer. Therefore, the risk to people is proportional to the length of exposure and the radon concentration in air (linear, no-threshold hypothesis). However, the radon risk begins to level off for extremely high concentrations, like for miners, because more lung cells are killed off by the radiation (rather than becoming cancerous) and some radiation is wasted on the already killed cells (the "inverse exposure-rate effect"). But at lower concentrations, like in residences, every emitted particle will have an impact.

1.4.4 Workers at Risk

There are a number of occupations that have the potential for high ^{222}Rn progeny exposure, some of these are: Mine workers(uranium, hard rock, and vanadium), Workers remediating radioactive contaminated sites, Workers at underground nuclear waste repositories, Radon mitigation contractors and testers Employees of natural caves, Phosphate fertilizer plant workers, Oil refinery workers, Utility tunnel workers, Subway tunnel workers, Construction excavators, Power plant workers, including geothermal power and coal, Employees of radon health mines, Employees of radon balneotherapy spas, Water plant operators Fish hatchery attendants, Employees who come in contact with technologically enhanced sources of naturally occurring radioactive materials, Incidental exposure in almost any occupation from local geologic ^{222}Rn sources

1.4.5 Risk for Women and Men

The effect of radon exposure on lung cancer risk in women might be different from that in men because of differing lung dosimetry or other factors related to gender. Women have displayed lower rates of lung cancer incidence than males, even after stratifying the analysis to control for smoking history. In 1999, the National Academy of Sciences calculated the lifetime risks of exposure to Radon-222 at home for each Bq m^{-3} (0.007 pCi/L) in air:

1.4.6 Risk for Children and Elderly

Data on the effects of radiation in children is rather limited; however, several studies have showed that children are more susceptible to radon exposure than adults. Children have different lung architecture and breathing patterns, resulting in a somewhat larger dose of radiation to the respiratory tract. Children also have longer latency periods in which to develop cancer. Hofmann reported that the radon dose was strongly dependent on age, with a maximum value reached at about the age of 6 years. Despite these findings, no conclusive data exists on whether children are at greater risk than adults from radon. Because of the latency time for cancer to develop and the cumulative nature of radon risk through time, there is very little possibility that someone could get lung cancer from radon before age 35, although exposures before that age contribute to the risk at later ages. The relative risk from domestic radon exposure is also higher for children because they spend more time at home and/or the basement. On average, children spend 70% more time in the house than adults. It has been hypothesized that decreased efficiency in DNA repair mechanisms is a function of age. Therefore, as a person gets older, their DNA becomes more unstable and abnormalities persist through the cell cycling process because of a lack of repair capabilities. For this reason, alpha particle exposure at later life stages can have greater potential for causing genomic changes. However, individuals of this age are probably too old to die of the associated tumor progression (cancer endpoints take many years [usually >15] to manifest themselves).

1.4.7 Risk for Individuals with Preexisting Respiratory Conditions

Populations that may be more susceptible to the respiratory effects of radon and radon progeny are people who have chronic respiratory diseases, including asthma, emphysema, and fibrosis. People with chronic respiratory disease often have reduced expiration efficiency and increased residual volume (i.e., greater than normal amounts of air left in the lungs after normal expiration). Therefore, radon and its progeny would be resident in the lungs for longer periods of time, increasing the risk of damage to the lung tissue. Additionally, persons who have existing lung lesions may be more susceptible to the tumor-causing effects of radon.

1.4.8 Ionizing Radiation

Matter is composed of atoms. Some atoms are unstable. As unstable atoms change and become more stable, by giving off invisible energy waves or particles called radiation. There are different types of radiation, some more energetic than others. One type of radiation, non-ionizing radiation, has enough energy to move atoms but not enough to alter them chemically, like microwaves, radio waves and visible light. Ionizing radiation is capable of removing electrons from atoms and damaging living cells and affecting the DNA of those cells. From here on ionizing radiation will be referred to simply as radiation. In Ghana, we measure radiation doses in units called gray(Gy). Under the metric system, effective dose is measured in units called sieverts(Sv). In this document millisievet(mSv) are used when talking about effective dose.

1.4.9 Ionizing Radiation Consists of Alpha, Beta Particles and Gamma ray

Alpha radiation is simply helium nuclei, that is, each particle consists of two protons and two neutrons. Because the nuclei have no electrons, they have a +2 charge (figure 1.3). Because of its mass, alpha radiation will not penetrate healthy skin or even a piece of paper. However, if alpha radiation enters the mouth or nose, it may cause cancers in lungs or other organs. Beta radiation consists of electrons. They have negative charges. Because they are

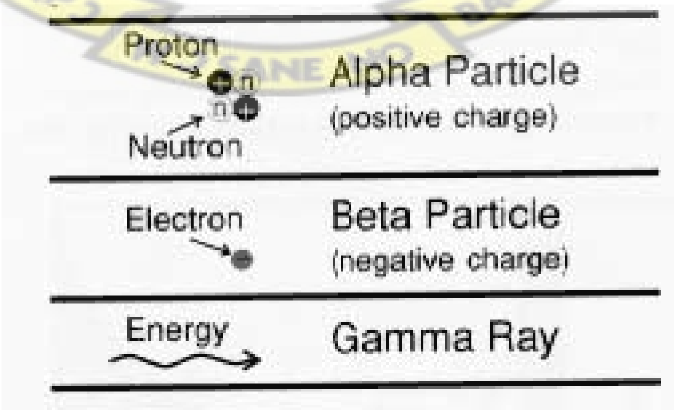

Figure 1.3: Radioactive particles

energetic and have no rest mass, they can be more of a potential health threat than alpha radiation. Beta radiation may penetrate 1-2 cm of human flesh, but may be stopped by a few millimeters of aluminum or glass. Gamma radiation consists of photons (figure 1.3), Gamma rays are extremely energetic and potentially dangerous. Gamma radiation readily passes through the human body and can only be attenuated with lead or concrete (figure 1.4). Most atoms are electrically neutral; they have the same number of positively charged protons in their nucleus as negatively charged electrons orbiting the nucleus. However, when ionizing radiation passes through a material, it can transfer some of its energy to an electron; this 'knocks' the electron out of its orbit. The free negative electron leaves behind a positively charged ion. This process is called ionization.

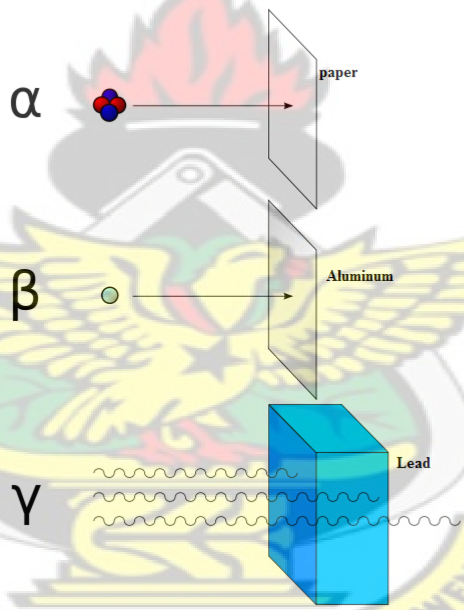

Figure 1.4: Penetration of radioactive particles

1.4.10 Specific Genetic Damage Caused by Radon

Most of the epithelial cellular damage is not from radon gas itself, which is removed from the lungs by exhalation, but from radon's short-lived decay products (half-life measured in minutes or less). When inhaled, these decay products may be deposited in the airways of the lungs and subsequently emit alpha particles as they decay further. The total amount of energy emitted by the progeny is several hundred times that produced in the initial decay of radon. The increased risk of lung cancer from radon primarily results from these alpha particles irradiating lung tissues. When an alpha particle passes through a cell nucleus, DNA is likely to be damaged. More specifically, available data indicates that alpha particle penetration of the cell nucleus may cause genomic changes typically in the form of point mutations and transformations. Since alpha particles are more massive and more highly charged than other types of ionizing radiation, they are more damaging to the living tissue. As previously described, alpha radiation travels only extremely short distances in the body. Therefore, alpha radiation from decay of radon progeny in the lungs cannot reach cells in any other organs, so it is likely that lung cancer is the only major and likely cancer hazard posed by radon. By breaking the electron bonds that hold molecules together, radiation can

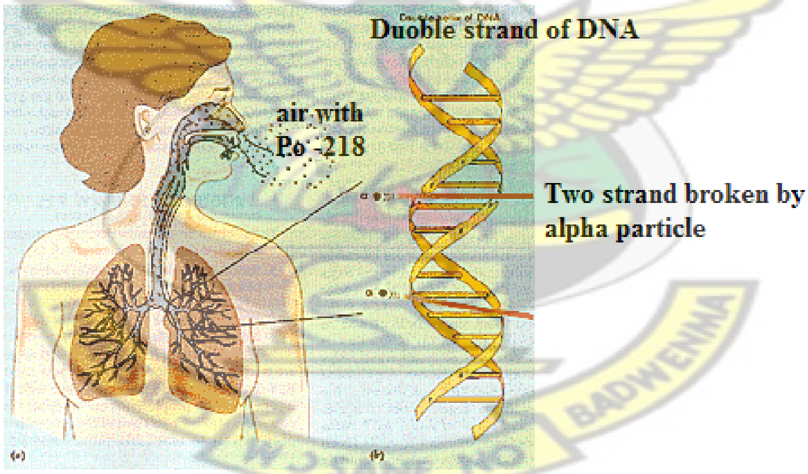

Figure 1.5: Effect of inhaled Alpha particles

damage human DNA, the inherited compound that controls the structure and function of cells. Radiation may damage DNA directly by displacing electrons from the DNA molecule, or indirectly by changing the structure of other molecules in the cell, which may then interact with the DNA. The latter mechanism will be described in more detail later. When one of these events occurs, a cell can be destroyed quickly or its growth or function may be altered through a change (mutation) that may not be evident for several years. At low radiation doses, however, the possibility of such a change causing a clinically significant illness or other problem is believed to be remote.

1.4.11 Possible Teratogenic Effects Caused by Radon Exposure

Alpha particle exposure through early life stages may have profound effects on the health and survivability of an embryo or fetus. If dissolved in a mother's blood stream in the uncharged phase, radon can pass through the placenta and into the developing child. If the developing child is only in the embryo phase, and a radon particle forms a progeny and deposits anywhere, emitting alpha radiation, the formation of DNA lesions will most likely kill it. At such an early point in human development, the presence of inheritable DNA adducts or lesions causes too much genomic instability to allow for a throughput organism. On the other hand, if the developing child is in the fetal stages, most of the bodily development has already occurred. In this case, a radon particle passing into the fetus would likely move to lipid portions of the unborn child, namely the brain and other organs. Since brain development is most crucial in this phase, ionizing radiation at this point might not kill the organisms but may cause severe inhibition in brain development leading to mental retardation after birth. Exposure of radon to a developed child after the first year of birth, when the brain is less lipid-like and the blood-brain-barrier is fully formed, follows the same pathways as for adults. Exposure to children, however, means they have a much longer time than adults to allow for the progression of DNA lesions to form their toxic endpoints.

1.5 Assessment of Radon Concentration

The most direct way to assess the risks posed by radon in homes and offices is to measure radon exposures among people who have lung cancer and compare them with exposures among people who have not developed lung cancer. Several such studies have been completed, and several are under way. The studies have not produced a definitive answer, primarily because the risk is likely to be very small at the low exposure encountered from most homes and because it is difficult to estimate radon exposures that people have received over their lifetimes. In addition, it is clear that far more lung cancers are caused by smoking than are caused by radon. However, continual improvements in mining methods, engineering and ventilation controls, and radiation protection (including the enforcement of lower limits for exposure to radon daughters) have improved working conditions greatly. The improvements which have been achieved suggest that uranium or thorium can be mined and processed safely, without undue risk to workers or to the public. However, meticulous care should always be taken to ensure safe working conditions for the workers, and efforts should always be directed to betterment. It needs to be emphasized that any country undertaking active exploration, or mining and milling of radioactive ores, should be aware of the radiation hazards involved in such operations, and should also know of regulatory and radiation control measures, if they are not to repeat past mistakes in the development of the uranium industries in developed countries.

1.6 Safe Working Levels

Radiation occurs naturally both underground and on the surface, this background radiation averaging about 2.5 mSv per year. The International Commission on Radiological Protection (ICRP) has recommended an Action Level of 5 mSv, above which action should be taken to reduce the radon concentration. The Ionizing Radiation Regulations 1985 require employers to restrict the extent to which their employees and other persons are exposed to ionizing radiations. The ICRP recommend a maximum annual dose limit of 50 mSv for people at work in an area exposed to radiation, with lower levels of 5 mSv for other persons. Areas where exposure is likely to exceed a certain level are designated as Supervised Areas and regular radon monitoring must be carried out. Areas with greater exposure levels are designated as Controlled Areas and personal radon monitoring is required.

1.7 Stochastic Health Effects

Stochastic effects are associated with long-term, low-level (chronic) exposure to radiation. ("Stochastic" refers to the likelihood that something will happen.) Increased levels of exposure make these health effects more likely to occur, but do not influence the type or severity of the effect. Cancer is considered by most people the primary health effect from radiation exposure. Simply put, cancer is the uncontrolled growth of cells. Ordinarily, natural processes control the rate at which cells grow and replace themselves. They also control the body's processes for repairing or replacing damaged tissue. Damage occurring at the cellular or molecular level, can disrupt the control processes, permitting the uncontrolled growth of cells–cancer. This is why ionizing radiation's ability to break chemical bonds in atoms and molecules makes it such a potent carcinogen. Other stochastic effects also occur. Radiation can cause changes in DNA, the "blueprints" that ensure cell repair and replacement produces a perfect copy of the original cell. Changes in DNA are called mutations. Sometimes the body fails to repair these mutations or even creates mutations during repair. The mutations can be teratogenic or genetic. Teratogenic mutations are caused by exposure of the fetus in the uterus and affect only the individual who was exposed. Genetic mutations are passed on to offspring.

1.8 Non-stochastic Health Effects

Non-stochastic effects appear in cases of exposure to high levels of radiation, and become more severe as the exposure increases. Short-term, high-level exposure is referred to as 'acute' exposure. Many non-cancerous health effects of radiation are non-stochastic. Unlike cancer, health effects from 'acute' exposure to radiation usually appear quickly. Acute health effects include burns and radiation sickness. Radiation sickness is also called 'radiation poisoning.' It can cause premature aging or even death. If the dose is fatal, death usually occurs within two months. The symptoms of radiation sickness include: nausea, weakness, hair loss, skin burns or diminished organ function. Medical patients receiving radiation treatments often experience acute effects, because they are receiving relatively high "bursts" of radiation during treatment.

1.9 Introduction to Radon Detection

The decay products of radon (radon progeny) are a well recognized cause of lung cancer in miners working underground. When radon was found to be ubiquitous indoor air pollutant, however, it raised a more widespread alarm for public health. To develop appropriate public policy for indoor radon, decision makers need a characterization of the risk of radon exposure across the range of exposures people actually receive. There are several measuring devices to measure radon levels. These include alpha track detectors, activated charcoal adsorption devices and the AlphaGUARD monitor. The alpha track detector is constructed in such a way that a thin piece of plastic or film is mounted on the inside of the detector. The detector allows for radon to diffuse into the device via a filtered covered opening. The purpose of the filter is to keep dust and radon decay products out. Another function of it is for structural support for the detector housing. Radon eventually decays in the detector and the emitted alpha particles hit the film and the radiation damage causes a track on the film. The immediate radon decay products may also give off an alpha particle on decay, and hence, leave a track on the plastic. Diffusion barriers are usually constructed to measure the thoron and radon track density separately. The films are then placed in a caustic solution, which enhance the tracks left on the plastic and these tracks can then be counted via an automated system. The number of tracks on the film would give an indication of the radon concentration, provided a few conversion factors are used from the calibration process [EPA92]. A drawback to using track detectors arises when measuring high radon concentrations that cause a high density of tracks per unit area on the film [Ger04]. Activated charcoal devices, as the name suggest, utilizes granular-activated carbon to analyze the radon potential. The charcoal is usually kept in containers with a diameter of about 10 cm to 2.5 cm [Geo84]. The top of the canister is covered with a screen for radon to diffuse into the canister and get adsorbed by the charcoal.

After the exposure period, the container is sealed and the charcoal is analyzed by using a HPGe gamma ray detector to detect the radon decay products [Ger04]. Correction factors also need to be used to calculate the final radon level [EPA92]. The charcoal canisters are usually used for short-term measurements, i.e. from 24 hours to about 7 days. There are a few drawbacks to using charcoal devices, but the most prominent one is the saturation of charcoal due to water adsorption [Ger04].

1.10 Health Effects and Risk

The primary risk pathway from exposure to radon gas is through inhalation of radon-laden air in a home, office and any structure where ventilation is a factor. Studies indicate that high levels of radon gas in the air increase the risk of lung cancer. An additional health risk is associated with the ingestion of the radon that remains dissolved in the water and is consumed. On average, this latter risk is substantially lower than that associated with inhalation. The risk from radon in water is relatively high when compared to other drinking water contaminants. Radon flows from the soil into outdoor air and also into the air in homes and offices from the movement of gases in the soil. Outside air typically contains very low levels of radon, but it builds up to higher concentrations indoors when it is unable to disperse. Some underground mines, especially uranium mines, contain much higher levels of radon. Although radon is chemically inert and electrically uncharged, it is radioactive, which means that radon atoms in the air can spontaneously decay, or change to other atoms. When the resulting atoms, called radon progeny, are formed, they are electrically charged and can attach themselves to tiny dust particles in indoor air. These dust particles can easily be inhaled into the lung and can adhere to the lining of the lung. The deposited atoms decay, or change, by emitting a type of radiation called alpha radiation, which has the potential to damage cells in the lung. Alpha radiations can disrupt DNA of these lung cells. This DNA damage has the potential to be one step in a chain of events that can lead to cancer. Alpha radiations travel only extremely short distances in the body, thus cannot reach cells in any other organs, so it is likely that lung cancer is the only potentially important cancer hazard posed by radon in indoor air. The connection between radon and lung cancer in miners has raised concern that radon in homes, offices and working environment might be causing lung cancer in the general population, although the radon levels in most homes are much lower than in most mines.

1.11 Statement of the Problem

It is of great importance to assess the exposure to ^{222}Rn and its progeny in dwellings, especially houses, offices, and schools, for the purposes of quality control.There is a considerable evidence to show that excessive radon levels in some mines cause lung cancer in miners (BEIR 1999), and that the increase in lung cancer follows a linear relation with the increasing radon level. The international commission on radiological protection (ICRP) has concluded that excessive radon levels are a health hazard (ICRP 1993) in homes and workplaces. In a recent study by Darby et al (2005), it was shown that modest risk from radon extends down to 100 Bqm^{-3} in domestic housing in line with the linear no-threshold theory. In 1990 the UK national radiological protection board now health protection agency (HPA) proposed an action level of 200Bqm^{-3} for domestic properties and 100 Bqm^{-3} for domestic indoor radon in the UK. In order to limit the risk of cancers ICRP 93 specify a 1.0 mSv annual dose for members of the public, 6 mSv for radiation workers and 20 mSv for classified workers who are required to have annual health checks. In accordance with current knowledge of radiation health risks, the Health Physics Society recommends against quantitative estimation of health risk below an individual dose of 0.05 Sv in one year, or a lifetime dose of 0.1 Sv in addition to background radiation. Risk estimation in this dose range should be strictly qualitative accentuating a range of hypothetical health outcomes with an emphasis on the likely possibility of zero adverse health effects. The current philosophy of radiation protection is based on the assumption that any radiation dose, no matter how small, may result in human health effects, such as cancer and hereditary genetic damage. There is substantial and convincing scientific evidence for health risks at high dose. Below 0.1 Sv (which includes occupational and environmental exposures) risks of health effects are either too small to be observed or are non-existent. Exposure to radon, a process known as radiation Hormesis, has been suggested to mitigate auto-immune diseases such as arthritis. Hormesis is the stimulation of any system by low doses of any agent (Luckey, 1980a). Large and small doses of most agents elicit opposite responses. A dose that elicits a response which separates positive from negative effects is the threshold dose. Radon is considered the second leading cause of lung cancer and leading environmental cause of cancer mortality. Most models of residential radon exposure are based on studies of miners, and direct estimates of the risks posed to home owners would be more desirable. In effect, radon concentration with its transport process and the health hazards in our homes and offices must be studied in order to put preventive measures in place to minimize the effects it poses to workers, the public and the environment.

1.12 Objectives

The specific objective is to assess the potential radon exposure to maximally exposed workers on KNUST campus. The second specific objective is to assess the potential radon exposures to office workers who may be stationed in nearby office or support facilities. The thesis work aims at the following objectives

1. To study radon levels in offices of KNUST, and determine the associated occupational and public exposures.
2. To deepen the understanding of the general public concerning the effects of radon gas
3. Assessment and quantitative measurement on epidemiological studies to be allowed.
4. Predict lung cancer risk in these areas by using a cancer model based on cellular radiation effect.
5. To assess lung cancer risk due to radon exposure for the population

1.13 Relevance and Justifications

Radon is a radioactive and chemically inert gas found in soils and rocks containing radium and uranium. Radium can migrate from the ground and accumulate in buildings. The decay products of radon emit alpha particles and it effect may lead to lung cancer when inhaled. Studies of underground miners have shown that radon exposure is a risk factor for lung cancer (Lubin et al.1994; 1995). Since the 1500s, it has been recognized that underground miners in the Erz Mountains of Eastern Europe are susceptible to high mortality from respiratory disease. In the late 1800s and early 1900s, it was shown that these deaths were due to lung cancer. The finding of high levels of radon in these mines led to the hypothesis that it was responsible for inducing cancer(EPA 2003). Radon is a pollutant of indoor air believed to have the potential to cause cancer through inhalation. In addition, radon in water can contribute to the indoor air inhalation risk when it comes out of solution. This occurs particularly as a result of heating, spraying, or agitation of water (for example, taking a shower). The exposure pathways are therefore identified as: Inhalation of radon progeny, Inhalation of radon gas, and Ingestion of radon gas. The sources of radon into buildings can then be assessed as: (1)Soil gas derived, (2)Ambient air derived, and (3)Water derived. Sources 1 and 2 involve risks through both inhalation pathways while the water source includes all three pathways. The occurrence of radiological hazards may pose serious health implications to workers, the public and the environment, the most direct way to assess the risks posed by radon in homes is to measure radon exposures among people, therefore the concentration of radon in offices and homes must be assessed or verify the extent of any abnormality and prevention and mitigation measures undertaken where appropriate. Risk estimates are quantitatively assessed for the general population (useful for public health planning or multiple-occupants buildings) and presented both numerically and graphically. For single dwellings, individuals may customize their risk estimates based on their smoking histories

1.14 Scope and Definition

The purpose of this research is to assess the effect of Radon in working place within the KNUST community. This research work is intended to cover some heads of departments offices. At each site, data on radon concentration will be collected for analysis of natural radioactivity and subsequent assessment of occupational and public exposures. Measurements were made using a radon measurement system, comprising a radiation monitor type Pylon AB-5, and a trace level radon gas detector (TEL), which are available at the nuclear Physics laboratory, Departments of Physics, Kwame Nkrumah University of Science and Technology, Kumasi

1.15 Structure of the Thesis Work

The Thesis work has seven (6) chapters with each chapter addressing a main heading. Chapter one introduces the subject matter, outlining the background of the research, objectives of the research, justification of the objectives of the research, location and accessibility of the research area, Chapter two gives the theory which Shows the features and particulars of radon, Chapter three gives literature review which shows the work that has been done on radon. Chapter four outlines the methodology of the research, it also deals with the materials or equipments used for the acquisition of data . Chapter five deal with the results and discussion. Chapter six draws conclusions from the research and makes recommendations for future works to be embarked on.

CHAPTER 2

THEORETICAL BACKGROUND

2.1 Radioactive Decay Processes

2.1.1 The Radioactive Decay Law

Radioactive nuclide decay statistically by processes like alpha or beta decay and gamma emissions. A radioactive element will not release all particles at once. The decay process is statistical in nature, early researchers came to the realization that it was impossible to predict when a specific atom would disintegrate to form another. This led to the following deductions. If there exist a number, N of radioactive nuclei at a certain time t, and no new nuclei are being formed in that sample, then the decay (dN) in the sample in a certain time (dt), would be proportional to the total number of nuclei N in the following way

$$\frac{dN}{dt} = -\lambda N \tag{2.1}$$

where λ is called the decay constant of a specific radioactive species Equation (2.1) can be rewritten as

$$\lambda = \frac{dN/dt}{N} \tag{2.2}$$

The above equation explains the nature of λ, which is the probability per unit time for the decay of an atom. The value of λ differs for each nuclide. The solution of equation (2.2) is called the exponential law of radioactive decay. It is $N(t) = N_o e^{-\lambda t}$ where N_o is the original number of nuclei present at time $t = 0$. The above number of nuclei will slowly decay in some cases and faster in other species, but there will be a statistical time ($t_{1/2)}$ after which half of the number of nuclei would have decayed. To get $(t_{1/2}), N = N_o/2$ is substituted in equation above to give

$$t_{1/2} = N_o e^{-\lambda t} \tag{2.3}$$

$t_{1/2} = \frac{ln2}{\lambda}$ which is also called the half-life of a species. Typical examples of half-lives are that of radon and radium which are 3.825 days and 1600 years respectively as indicated in Figure 2.1 in the lower part of the boxes. The activity of a species is expressed in the SI unit Bq (Becquerel), so named after Henri Becquerel that is defined as 1 disintegration per second. The historical unit that was used is the curie, abbreviated Ci, which is 3.70×10^{10} decays per second and 1Ci was originally the activity of 1 gram of radium.

2.1.1.1 Alpha Decay

Decay by alpha emission occurs naturally in heavy nuclei in the radioactive series. In the early 20th century, Rutherford's work on α- particle scattering led to the realization that the atom consisted of largely empty space while the nucleus is a relatively large mass in the centre of the atom. He also concluded from his experiments with alpha particles entering a thin-walled chamber, that α- particles were in fact helium nuclei [Kra88]. The α- emission takes place, because the nucleus gains binding energy from a decrease in the mass of the system. Since the alpha particle is very stable and a relatively tightly bound structure and its mass is relatively small compared to the remaining parts of the nucleus, it is favored to be emitted from the system together with the release of kinetic energy. The emission of α-particles in these cases is spontaneous and can be stated in the following way

$$ {}^{A}_{Z}X \longrightarrow {}^{A-4}_{Z-2}Y + \alpha $$

where A is the mass number of the nuclear species, Z is the atomic number of the species and N is the number of neutrons. N is not usually indicated in the equation, but could readily be obtained by A-Z. X is the initial decaying nucleus, whereas Y is the final state, and an alpha particle is emitted. Alpha emission is evident in the ^{238}U nucleus and as an example can be written as

$$ {}^{238}_{92}U \longrightarrow {}^{234}_{90}Th + \alpha $$

The final species is thorium-234 accompanied with the release of kinetic energy. In Figure 2.1, these energies are indicated in parenthesis in the sketch for that specific alpha decay.

2.1.1.2 Beta Decay

Beta decay occurs when a nucleus decays and gives off a beta particle; which can be an electron or a positron. In the case of electron emission, it is referred to as beta minus decay and in the case of a positron, beta plus decay. Those are the two most basic processes of β decay. In the β^{+} decay process, a proton is converted to a neutron through the weak nuclear force and what comes out is a β^{+} particle and a neutrino (see equation 2.4). In β^{-} decay however, a neutron is converted to a proton through the same weak nuclear force, and the result is a β^{-} particle as well as an antineutrino (see equation 2.4). Beta decay in the nucleus changes the Z as well as N. This can be represented with the following equation

$$ {}^{A}_{Z}X \longrightarrow {}^{A}_{Z\mp1}Y + \beta $$

The process of beta decay leaves the mass number unchanged. Here follows the basic processes [Kra88]

$$ \begin{aligned} p &\longrightarrow n + e^{+} + \nu(\beta^{+}) \\ n &\longrightarrow p + e^{-} + \bar{\nu}(\beta^{-}) \\ p + e^{-} &\longrightarrow n(\varepsilon) \end{aligned} \tag{2.4} $$

Equation 2.4 depicts the scenario where an orbital electron is captured. The additional particles in the equation are called the neutrino and the antineutrino respectively. A beta decay is depicted in Figure 2.1 when ^{214}Pb decays to ^{214}Bi.

2.1.2 Uranium Decay Series

Radon is formed in the ^{238} U decay series and this chain of events is depicted in Figure 2.1. It undergoes a series of 14 decays to ultimately form a stable nucleus, that of ^{206} Pb. The radon formed in the series is the only radioactive gas in the series and has the longest half-life (3.825 days) relative to its decay products up to the long-lived ^{210} Pb. Since the radon in this instance is contained in a porous material like soil, the time is long enough for the radon gas that is closer to the surface of the soil to be transported there and exhaled to the surrounding atmosphere [Ner88]. The distance it is transported to reach the surface is widely debated and ranges from 1 m for some soils [Ner88] to about 1.6-1.9 meters [Sog87]. One other point to notice in the ^{238} U series, is the radionuclides that radon decays to. These have relatively short half-lives and are chemically active. They can attach to airborne particles [God02] like dust

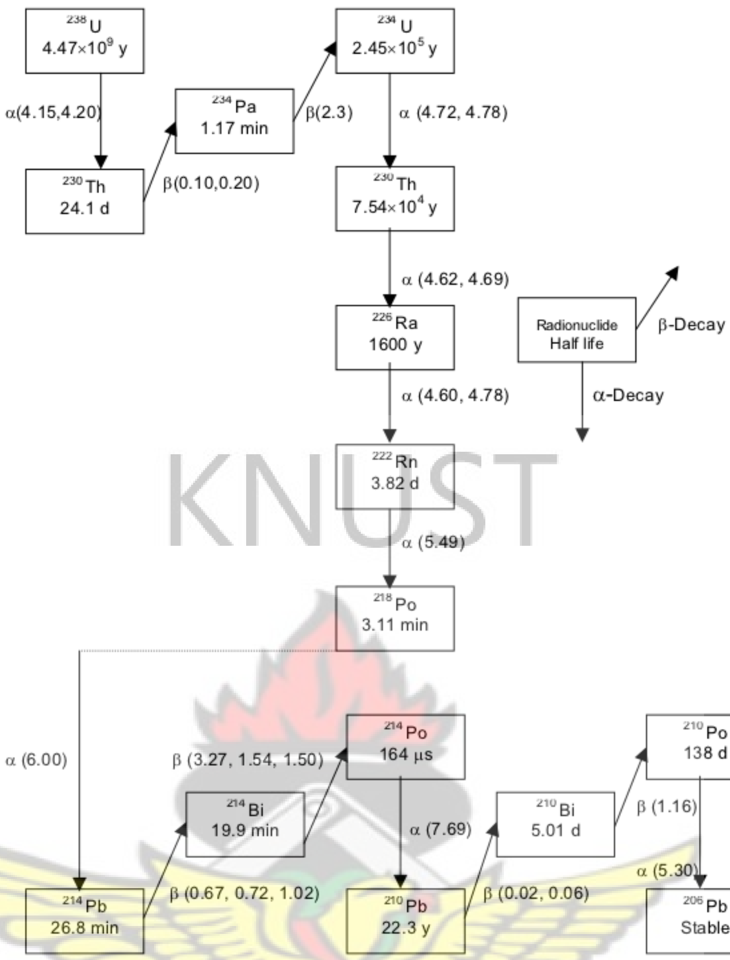

Figure 2.1: Schematic representation of the ^{238}U decay series, including ^{222}Rn as well as its decay products. As the legend suggests, arrows pointing downwards, indicate alpha decay whereas the diagonal arrows indicate beta decay. Alpha and beta energies are given in brackets in MeV

and indoor surfaces and respiratory tracts [Jam88]. From figure 2.1, it is evident that most of the decay products, decay through alpha emission and in some cases by beta emission. The energies noted in the figure 2.1 are in MeV, and the most significant contributors to the lung dose through alpha emission, are radionuclides like ^{218}Po and ^{214}Po with alpha energies of 6.00 and 7.69 Mev respectively. The vertical arrows pointing downwards represent alpha decay whereas the diagonal arrows upwards indicate beta decays. The decay products of ^{222} Rn in air also have an activity concentration contribution. This is correlated to the potential alpha-energy concentration (PAEC), which gives the overall activity concentrations of the decay products. The PAEC in turn depends on the concentrations of the 3 decay products

Nuclide	Energy(MeV)	Range(μm)
^{222} Rn	5.49	41
^{218} Po	6.00	48
^{214} Po	7.69	71
^{220} Rn	6.29	52

Table 2.1: Ranges in tissue of alpha particles from radon and its decay products

following radon [Ner88]. The PAEC was introduced in the 1950's in the unit; working level (WL) to implicate safety standards whereby radon decay-product concentrations could be measured in uranium mines. The working level could be expressed in terms of the potential alpha energy as a combination of the radon decay products that amount to $1WL = 2.08 \times 10^{-5}$J m^{-3}.

One working level corresponds to radon in equilibrium with its decay products with a radon activity concentration of 3700 Bqm^{-3} [Ald94]. The decay products carry with them the PAEC and can attach themselves to airborne particles. The potential risk of developing lung cancer from the decay products listed in Table 2.1 is enhanced through the deposition of it on the sensitive cells in the lungs. The table is listed to show the thickness of the epitheliums in the lung, that plays a role in the understanding of the absorbed dose by those cells [Jam88].

2.1.3 Radiometric Parameters and Units

The activity of a radionuclide is defined as the number of decays or nuclear transformations per unit time. The unit of activity is the Becquerel (Bq). One Bq is equivalent to one decay per second. The activity concentrations of radon and its decay products are expressed as a ratio of activity to volume, i.e., in Bqm^{-3}. The working level (WL) is an alternative unit of activity concentration that is used primarily in mining. Cumulative exposure can thus be expressed in either of two units: Bqm^{-3} or working level months (WLM). One WLM corresponds to a month's exposure to an activity concentration of one WL; it is defined as 1 WL multiplied by 170 hours (the working time in one month).

2.1.4 Measurement of Exposure

Radon concentrations can be measured inexpensively by means of a passive measuring device or an electronic apparatus with an immediate readout. Either way, the most important consideration is that the measurement should be carried out in the proper expert manner, with quality assurance. Because the values fluctuate considerably over time, short-term measurements provide little useful information.

2.1.5 Units of Measurement

There are several units of measurement when dealing with radiation.

1. Becquerel - 1 Becquerel (Bq) is equivalent to 1 atomic disintegration per second.
2. Millisievert - 1 Millisievert (mSv) is a concentration of 20 Bq of radiation per cubic metre of air.
3. Working Level - 1 Working Level (WL) is any combination of the short lived decay products of ^{222}Radon in a cubic metre of air that will result in the ultimate emission by them of 1.3×10^8 MeV of alpha energy.
4. Working Level Month - 1 Working Level Month (WLM) is the amount of radiation accumulated by working in a Radon daughter concentration of 1 WL for 170 hours.

2.2 Darcy's Law

The general expression for the flow of gas through a porous medium is obtained from Darcy's Law. In its differential form, Darcy's law states that the velocity of the soil gas flow at any point (x, y, z) within the soil matrix is proportional to the difference between the gradient of the absolute pressure in the soil and the specific weight of the soil gas. For isotropic soils, the differential form of Darcy's law can be expressed as

$$\bar{q} = (-\frac{k}{\mu})(\bar{\nabla} P - \rho g) \tag{2.5}$$

where,

k = Soil permeability at the point (x, y, z) in the soil

μ = Soil gas dynamic viscosity,

$\bar{\nabla}$ = gradient operator

$\bar{q}$ = Soil-gas seepage velocity vector, (equal to the volume of soil gas flowing per unit of time, per unit of geometric cross-sectional area)

2.3 Indoor Radon Concentration

the change in radon concentration due to creation, decay and ventilation is given by:

$$\frac{dC_{indoor}}{dt} = \frac{S}{V} - \lambda_{Rn} C_{indoor} - \lambda_v (C_{indoor} - C_{outdoor}) \tag{2.6}$$

where S is the radon source and λ_v is the ventilation rate with the outside atmosphere (Perrier et al, (2005). We see that the ventilation is a mechanism for loosing ^{222}Rn and acts similarity to the ^{222}Rn decay term.

The indoor radon concentration will be calculated based on a mass balance within the house, represented by the following differential equation:

$$\frac{d}{dt}C_{indoor} = \frac{4R_{total}}{V} - (\lambda_{Rn} + \lambda_v)C_{indoor} + \lambda_v C_{outdoor} \qquad (2.7)$$

where,

C_{indoor} = Indoor radon concentration, in $[Ci/m^3]$

R_{total} = Total radon entry rate into a quarter of the house volume in $[Ci/s]$

V = Total volume of the house, in $[m^3]$

λ_v = Air exchange rate (ventilation rate), in $[s^{-1}]$.

λ_{Rn} = Radon decay constant, in $[s^{-1}]$.

$C_{outdoor}$ =Outdoor radon concentration, in $[Ci/m^3]$

According to the above Equation the indoor radon concentration is given by:

$$C_{indoor} = \frac{4R_{total}}{V(\lambda_{Rn} + \lambda_v)} + \frac{\lambda_{Rn}}{(\lambda_{Rn} + \lambda_v)}C_{outdoor} \qquad (2.8)$$

In the numerical calculations of the model, the outdoor radon concentration $C_{outdoor}$ is neglected, and the indoor radon concentration is then expressed as:

$$C_{indoor} = \frac{4R_{total}}{V(\lambda_{Rn} + \lambda_v)} \qquad (2.9)$$

CHAPTER 3

LITERATURE REVIEW

3.1 Overview

The need to assess the risk of exposure to radon and its daughters stems from the reality that radon is a potential carcinogenic. We report Radon-222 risk assessment, from measurements on soil and sediments taken from six towns along the Lake Bosomtwi basin at two levels of 10 cm and 20 cm. The current and future prospects of Lake Bosomtwi, the largest natural lake in Ghana, make this assessment imperative, since radon forms half of natural background radiation. Spatial Analyser Decision Assistant (SADA) algorithms were used to model the measured radon concentrations under two land-use scenarios, namely residential and recreational. Setting the data under a targeted risk of 1×10^{-6},we found that the external exposure was below that of the maximum concentrations to the measurements. This indicates that the radon levels around those towns as of the time of the measurements is low and below limits which can cause carcinogenic threats. The mean risk associated with the sampled locations was found to be 9×10^{-11} at the recreational areas and 2×10^{-8} at the residential centres. To confirm the authenticity of the point risk analysis, geospatial modelling based on inverse distance interpolation schemes were performed. The results tally closely with that of the measured point risk analysis with and error margin of 2% and 1.3 % for both land use scenarios at 10 cm and 20 cm depth respectively. This work was conducted by Andam

A.A.E, Amankwah E.A, Addison E.C.K, and Nani E.K,

A study conducted at the Department of Physics, National Nuclear Research Institute of the Ghana Atomic Energy by Nsiah-Akoto I, Fletcher J.J, Oppong O.C, and Andam A.B from March 2010 to May 2010 using the LR-115 type II detectors which were hanged in the various bedrooms of the people in Dome at a height of 2 m from the ground level. The sensitive lower surface of the detector was freely exposed to the emergent radon so that it was capable of recording the alpha-particles resulting from the decay of radon in the room. The survey shows that the indoor radon concentration obtained varied from (278.09 to 740.12) Bq m^{-3} with an overall mean value and standard error of (466.89±1.24) Bq m^{-3} which is within the recommended ICRP action level of 200-600 Bq m^{-3} (ICRP, 1993) . The lowest value concentration was found to be 278.09 Bq m^{-3} , whereas the highest concentration was found to be 740.12 Bq m^{-3} .

Another work by Asumadu-Sakyi A.B., Oppong O.C, Quashie F.K, Adjei C.A , Akortia E, Nsiah-Akoto I, Appiah K on Levels of radon gas in groundwater, using High Purity Germanium (HPGe) Detector and Nuclear Track Detector (N.T.D) techniques at the Kassena Nankana District in the Upper East region of Ghana. The radon concentrations obtained ranges from 7.86×10^{-6} to 8.18×10^{-5} Bq/l with a mean of 4.38×10^{-5} Bq/l using the Gamma Spectrometry (G.S) whiles that of N.T.D ranged from 5.40 to 46.74 Bq/l with a mean of 19.54 Bq/l. In terms of Bq/m^3, the concentrations ranged from 1.2×10^{-2} to 8.1×10^{-2} with a mean of 3.67×10^{-2} and 200.00 ± 0.23 to 1731.00 ± 1.73 with a mean of 723.7 Bq/m^3. The estimated annual effective dose by inhalation ranged from 6.05 to 40.66 $mSvy^{-1}$ with a mean value of 21.91 $mSvy^{-1}$ using N.T.D, whiles that of G.S ranged from 1.39×10^{-4} to 2.45×10^{-3} $mSvy^{-1}$ with a mean value of 1.14×10^{-3} $mSvy^{-1}$. Also the estimated annual effective dose by ingestion ranged from 1.71×10^{-5} - 1.32×10^{-4} μ Svy^{-1} with a mean value of 5.60×10^{-5} μ Svy^{-1} obtained using N.T.D technique. G.S ranged from 2.87×10^{-11} to 2.99 $\times 10^{-10}$ μ Svy^{-1} with a mean value of 1.60×10^{-10} μ Svy^{-1} respectively. The concentrations delineate that inhabitant need to be advised on levels of ^{222}Rn in water.

In many countries exposure in the home to short lived radioactive disintegration products of the chemically inert gas radon-222 is responsible for about half of all non-medical exposure to ionizing radiation. Radon-222 arises naturally from the decay of uranium-238, which is present throughout the earth's crust. Radon-222 has a half life of 3.825 days, allowing it to diffuse through soil and into the air before decaying by emission of a particle into a series of short lived radioactive progeny. Two of these, polonium-218 and polonium-214, also decay by emitting alpha particles. If inhaled, radon itself is mostly exhaled immediately. Its short lived progeny, however, which are solid, tend to be deposited on the bronchial epithelium, thus exposing cells to irradiation. Air pollution by radon is ubiquitous. Concentrations are low outdoors but can build up indoors, especially in homes, where most exposure of the general population occurs. The highest concentrations to which workers have been routinely exposed occur underground, particularly in uranium mines. Studies of exposed miners have consistently found associations between radon and lung cancer. Extrapolation from these studies suggests that in many countries residential Exposure of person to high concentration of radon and its short-lived progeny for a long period leads to pathological effects like the respiratory functional changes and the occurrence of lung cancer (Lubin and Boice, 1993; Ramola et al., 1997; UNSCEAR, 2000). Radium and radon are soluble in water due to this when ground water moves through radium or radon bearing soil and rocks they are dissolved and transported with the water. Radon concentration level and radon risk will be increased with high radium and Uranium content in ground water. The adverse health effects of radon in water are largely due to the transfer of radon to the air, where it decays and its short-lived radioactive daughter inhaled rather than direct ingestion (Cross et al.,1985). Large scale mobility characteristics are influenced by additional factors such as rock and soil geochemical characteristics and geological structures like faults, shears, thrusts, etc. (Choubey and Ramola, 1997). This is of practical relevance because radon concentrations in existing buildings can usually be reduced at moderate cost for example, by increasing under floor ventilation while low concentrations can usually be ensured at reasonable or low cost in new buildings for example, by installing a radon proof barrier at ground level. These extrapolations, however, depend on uncertain assumptions because the levels of exposure in miners that produced evident risk were usually much higher. A region having many active faults are generally highly permeable compared to the surrounding rocks. Therefore, fault zones are preferential pathways for fluid transport. During their transport, the gases (radon, methane, helium, etc.) escape from the rocks and minerals to the surroundings fluid phase such as groundwater and air, finally into the atmosphere and also, high radon concentration in groundwater has been associated with faults.

Another work by Amponsah P, Banoeng-Yakubo B, Aba Andam, and Daniel Asiedu on radon gas emission from soils in parts of southeastern Ghana (Accra) have been measured to find a possible correlation of the gas emanation with faults and seismic activity in the area. LR-115 alpha track sensitive plastics were used for the detection of the gas at 47 sampling points within a 500 m $\times$ 500 m spaced grid. The obtained radon data was analyzed and superimposed on the geological and structural map to highlight the correlation between the gas emission and seismicity. In the highly faulted area, radon activity up to 115.00 kBq m^3 was measured; on the contrary in non-faulted areas radon activity was less than 20.00 kBq ^{3}. In the highly faulted area radon activity above 50.00 kBq ^{3} have been considered anomalous. The background level increased to 115.00 kBq ^{3} before a magnitude 1.5 earthquake struck the area.

A seemingly harmless gas that emits from the ground may be slowly and negatively affecting the health of people who live at Dunkonaa and its environs in the Ga-South municipality in the Greater Accra Region. Known as radon gas, the fume, which is colorless, odorless and tasteless, is known to be a major cause of respiratory infections, blood poisoning and lung cancer where it is highly concentrated. In 2000, studies conducted by a team of scientists, including scientists from the Ghana Atomic Energy Commission, indicated that the gas coming out of the Dunkonaa area was highly concentrated. The study found that the potency of the Dunkonaa radon gas measured 2,000 Becquerel per square metre.

Indoor radon survey using cr-39 track etch detectors was also technique used in this survey is based on passive nuclear track detectors (NTDs), which is commercially marketed as CR-39, poly-allyl diglycol carbonate (PADC) Tastrak. These detectors are manufactured by TASL (Track Analysis Systems Ltd, Bristol, United Kingdom). The CR-39 is a small piece of plastic that is sensitive to tracks of highly ionizing particles such as alpha particles.

As early as the 16th century, two scientists, Paracelsus and Agricola, discovered and described a wasting disease present in many miners. In 1879, this condition was identified as lung cancer by Herting and Hesse in their investigation of miners from Schneeberg, Germany. Radon itself was discovered some 20 years later by Rutherford. Eventually, an increase in the incidence of lung cancer among miners was linked to radon daughter exposure in mines. Miners are particularly at risk of developing lung cancer for two reasons: miners are constantly being exposed to large quantities of radon. Radon is formed from the radioactive decay of radium and uranium. The latter two elements are naturally occurring elements in certain rocks and soils and will lead to excessive buildup of radon in the confined spaces of mines. Miners are constantly being exposed to other chemicals, compounds, and particulate matter that have also shown an association with lung cancer incidence. Underground uranium mines found throughout the world, including the western United States and Canada, pose the greatest risk because of their high concentration of radon daughters in combination with silica dust, diesel fumes, and, typically, cigarette smoke. Iron ore, potash, tin, fluorspar, gold, zinc, and lead mines also have significant levels of radon. It is also important to note that in the past, it was not uncommon to use the tailings from these mines as fill on which to build homes, schools, and other structures, leading to elevated levels of radon in these indoor environments.

In 1994, the research project on radon 'Criteria for indoor radon concentration - An experimental study considering especially the Leipzig-Hall brown coal area' was initiated within the European Union (EU) program Human Capital and Mobility (ERB-CHRX-CT 930422). The project intends to improve the understanding of the specific behaviour of the radon gas and it is being carried out by six research groups belonging to five European countries (Jonsson et al. 1995).

Radon concentration in dwellings from the Barcelona area was measured in a survey carried out by the Grup de Fisica de les Radiacions (GFR) of the Autonomous University of Barcelona (UAB) in collaboration with the Spanish institution CIEMAT in the period June 1991 - June 1992. The annual average of indoor radon concentration in the Barcelona area was 34 Bqm^{-3}, with a geometric mean of 28 Bqm^{-3}, a geometric standard deviation of 1.86 Bqm^{-3}, and a range (2-622) Bqm^{-3}. A total number of 204 dwellings was monitored in the Barcelona area, measuring radon concentration in both living-room and bedroom by means of track etch detectors exposed for two consecutive periods of six months. The fraction of dwellings monitored represents more than 1 in 10000 of the housing stock, according to the suggestion of the UNSCEAR (1993) report. Due to its proximity to the UAB, several dwellings from Cerdanyola del Valles were monitored in preliminary studies to perform the very first measurements in dwellings and to carry out a preliminary survey (Gutierrez et al. 1992).

3.2 Radon Dose

Health physicists define the biological radiation dose as the amount of energy actually deposited in your body. The more energy absorbed by cells, the greater the biological damage. The absorbed dose, the amount of energy absorbed per gram of body tissue, is usually measured in units called rads. The relationship between exposure to radon and the dose of radiation from decay products that reaches target cells in the respiratory tract is complex. A radioactive dose primarily depends on such factors as: The number and energy level of the radiation particles emitted by the source (the source's activity, measured in units called curies). The distance from the source (distance is especially important with alpha radiation; more than a few centimeters from the source, the amount of the dose approaches zero). The amount of exposure time. The degree to which radiation dissipates in the air or in other substances between the source and the recipient. Extensive research has developed a one-to-one or linear relationship hypothesis between the radon dose and its effect. This technique, known as the linear no-threshold hypothesis, uses mathematical models to estimate the risks of very low exposures based on the known risks of high-level exposures. A brief description of the hypothesis is supplied below: Whereas an increase in alpha particle exposure causes an increase in the number of affected cells, an increase in exposure does not affect the amount of insult to any one particle interacted cell. That is, small doses have a small risk in direct proportion to the known effects of large doses. This relationship holds true for rising concentrations of radon exposure, until a point where cells interact with more than one particle in its lifetime. Some scientists question the linear hypothesis because of the lack of evidence of health effects from extremely low radiation doses, as well as the fact that many other hazardous substances harmful at high doses have little or no effect at low doses. The U.S. Committee on the Biological Effects of Ionizing Radiation (BEIR), convened by the National Academy of Sciences (NAS), acknowledged that there is no data showing that low doses of radiation cause cancer. The BEIR Committee, however, recommended the use of the linear no-threshold hypothesis because it is consistent with other approaches to public health policy. The United States and other countries use linear estimates to set limits and standards on all potential exposures to radon and other types of radiation, both for the public and for workers in jobs that expose them to ionizing radiation. The International Commission on Radiation Protection has calculated the effective dose to the lung from radon inhalation to be 1.1 mSv per mJ.h/m^3 at home and 1.4 mSv per mJ.h/m^3 at work (ICRP, 1993). An exposure to 100 Bqm^{-3} in a building with 80% occupancy translates into a dose of 1.8 mSv/year. One factor influencing the concentration of radon activity at the earth's surface is the variable uranium and radium content in rock and soil substrata. High values are found, for example, in the Ore Mountains (Erzgebirge), an extensively mined mountain range in Germany and the Czech Republic, as well as in other regions. Further factors include processes influencing the transport and release of radon within rock and soil, as well as climatic and meteorological conditions in the atmosphere.

3.3 Occupational effect of Miners

Epidemiological studies of uranium miners have shown a clear correlation between high levels of radon exposure and lung cancer. The Committee on the Biological Effects of Ionizing Radiation (BEIR VI, 1999) reviewed the major studies of underground miners exposed to radon. Eleven cohort studies were considered representing minors from across the world. The lung cancer rate increased approximately linearly with increasing cumulative radon exposure in all eleven studies. The average increase in the lung cancer death rate was 0.44% (95% confidence interval 0.20-1.00%), with the highest percent age risk occurring 5-14 years after exposure.

3.4 General population

Recent major studies from Europe (Darby et al, 2005, 2006), North America (Krewski et al. 2005, 2006) and China (Lubin et al. 2004) pooling studies found: Radon in homes increase the risk of lung cancer based on a measured radon concentration of 10 pecent per 100 Bqm^{-3}. The dose-response relationship to be linear, with no evidence of a threshold below which radon exposure presents no risk. Substantial increase in risk even below 200 Bqm^{-3}, the exposure limit in many countries. The proportion of lung cancer linked to radon range from 3% to 14% depending on the average radon concentration and on the method of calculation. Radon is the most important cause of lung cancer after smoking. The majority of radon-induced lung cancers are caused by low and moderate radon concentration rather than high concentrations, because in general fewer people are exposed to high level of indoor radon concentrations.

3.5 Exposure Limit

Based on recent studies of radon exposure in homes, the World Health Organization (WHO 2009), has recommended maximum level of residential radon gas to be 100 Bqm^{-3} if possible or 300 Bqm^{-3} at a minimum. Above those levels, remediation action is recommended.

CHAPTER 4

MATERIALS AND METHODS

4.1 Description of experimental Site

The site surveyed for radon gas concentration was the Kwame Nkrumah University of Science and technology, Kumasi, Ghana. The main university campus, which is about seven square miles in area, is located about eight miles (13 km) to the east of Kumasi, the Ashanti Regional capital. The map of the KNUST not drawn to scale, including the sampling points, is shown in Figure 4.1. The survey of radon concentration in the campus is to estimate the

Figure 4.1: A map showing the study area KNUST

radon concentration to the public from ^{222}Rn and its progeny only covered thirteen (13) offices among fifty eight (58) departments because of the limited number of detectors that are available, and also due to the difficulty in placing the detectors in various offices because permission was not granted.

4.2 Flushing the TEL

The TEL is flushed by Connecting nitrogen tank or AB-5 pump, tubing, flow meter, flow through charcoal column, drying column, an alpha particle filter and TEL and flush to a fume hood or the outdoors as shown below:

Nitrogen or AB-5 pump ⟶ Flow meter ⟶ Dryer ⟶ Filter ⟶ TEL ⟶ Outside

The TEL is flushed with a nitrogen gas for about 20 minutes with a pressure of about 0.5 kg/cm^2 or flush it with air from the AB-5 internal pump for ten times the volume of the TEL. Once flushing is finished, all tubes are then disconnected.

4.3 Method of making Measurements Using TEL/AB-5

The TEL/AB-5 system can be used for making measurements in houses, offices and other buildings. The following guidelines have been adopted from the 'Interim Indoor Radon and Radon Decay Product Measuring Protocols' issued by the U.S. Environmental Protection Agency in April 1986.

Steps for setting up the TEL and AB-5 are presented below. Before starting these steps, the AB-5 and TEL must be switched off. Figure 4.2 shows a schematic diagram of the layout of the TEL/AB-5 system which show how the equipments were set for measurement to be taken at each office. After the tubing has being connected to the TEL/AB-5 system as shown in figure 4.2, the TEL is switched on with the AB-5. the pump of the AB-5 is also switched on to draw air into the TEL. Before taking measurement, windows and doors

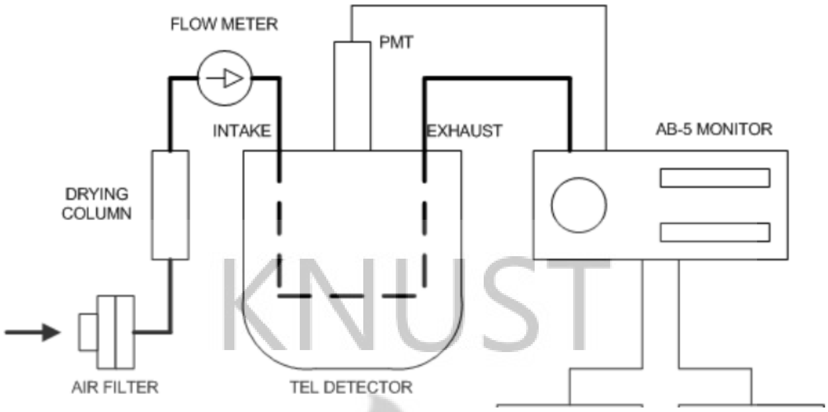

Figure 4.2: TEL, PMT and AB-5 layout

Figure 4.3: Making a setup for measurements in an office

was kept closed for twelve (12) hours before measurement begins and while measurements are being taken, with opening and closing of windows and external doors must be kept to a minimum. Air exchange systems should be switched off. Measurements were not conducted during severe storms or strong winds. Taking measurements in or near drafts caused by heating, ventilation, or air conditioning vents, doors, windows, or fireplaces were avoided. The measurement location was kept well away from outside walls. The air intake end of the tubing should be at least 50 cm above the floor. Air to be tested for radon gas is drawn into the TEL by the AB-5's internal pump. Radon gas in the air which has been drawn into the TEL decays into RaA+ which is attracted to the negatively charged cathode. RaA^{+} decays into RaB which in turn decays into RaC and RaC'. RaA+ and RaC' emit alpha particles; some of these particles strike the scintillator which then produces light pulses. The light pulses are transmitted by the light pipe to the PMT where they are amplified according to the AB-5's High Voltage dial. The PMT then converts the amplified pulses into electronic pulses and sends them via the coaxial cable to the AB- 5 for counting. The sampling period was twenty four (24) hours, not including 3.5 hours for the system to reach equilibrium because the longer the measurement period the better. Once the measurement data have been obtained they were divided into time periods ('windows') in hours and an average count per minute for each window calculated. The sensitivity and the count per minute are then substituted into equation 5.1 to obtain the radon concentration for that window.

4.4 Radon Concentration Calculation

Once data has been collected, the radon gas concentration can be determined. Counts for the interval (24 hours) were all converted into counts per minute (CPM) as mentioned in the methodology. The appropriate formula to use for calculating radon gas concentration is given below

$$Concentration = \frac{CPM - BG}{S} \tag{4.1}$$

Where

CPM = is the count(s) for the one hour interval expressed in counts per minute, BG = is the background of the TEL/AB-5, S = is the sensitivity of the TEL/AB-5. Background and sensitivity were determined as part of calibration. The Calibration techniques are in appendix

A1.

4.5 Constraints in Making Measurement

There were some challenges encountered during the research, these are: Getting approval from Heads of departments, electricity not been constant thus power going off, Positioning of equipments due to office nature, workers tempering with apparatus and the getting access to the laboratory for flushing of the TEL after taking measurement.

4.6 Constraints in using the TEL

There are a number of factors which can affect the accuracy of the TEL/AB-5. The most common of these are described below along with ways to minimize their effects.

4.6.1 Insufficient Internal Voltage

The TEL works by generating an internal voltage of approximately -1200 volts to attract RaA+ to the cathode. If the internal voltage is too low because the four "C" cells are low, the cathode takes a longer time to attract RaA+ with the net result of lowering the sensitivity of the TEL.

4.6.2 High Flow Rate

The rate of air flow through the TEL is set by adjusting the AB-5 internal pump and monitored by observing a flow meter inserted into the tubing. When the flow rate is faster than 10 liters per minute the air passes through the TEL too quickly and there is a tendency for some of the RaA+ to collect on the exhaust port rather than on the cathode.

4.6.3 Improper HV/DISC Setting

If the HV dial is set too high or the DISC dial is set too low, the TEL/AB-5 will be overly responsive, resulting in measurements containing a high level of background or noise. If the HV is set too low or the DISC is set too high, the TEL/AB-5 will not respond to all the alpha radiation present.

4.6.4 Overlapping Samples

If a new sample is measured while there is still radon gas remaining from the previous sample, the radon gas concentration will be exaggerated. This problem can be overcome by flushing the TEL before use, taking a background measurement before use, flushing the TEL after use, measuring background after use, and allowing at least 24 hours between samples; longer if the sample had a high concentration.

4.6.5 Long Term Background Build Up

After prolonged use of about two or three years, deposits of Po-210 and Pb-210 will build-up on the cathode. These deposits build up gradually and can act as a background which interferes with the measurement of very low levels of radon gas.

4.6.6 Thoron Gas

A sudden increase in background may be caused by the presence of thoron daughters due to thoron gas in the unit. Although the TEL is sensitive to thoron gas, the mechanism of collection is different. The presence of thoron gas can be determined by the decay characteristics of the activity collected on the cathode.

4.6.7 Fluctuating Concentrations

If the TEL/AB-5 is used to measure constantly changing radon gas levels, a lag will be introduced in the short term response. While nothing can be done about this, the average radon level count will be only marginally affected.

4.7 Software used in Data Analysis

MATLAB as a software was used in plotting of graphs as presented in the discussion. The analysis of the offices studies provides models for estimating the risk per unit exposure, as a function of time. However, exposure conditions in offices differ from those in mines, with respect to both the physical properties of the inhaled radon decay products

CHAPTER 5

RESULTS AND DISCUSSIONS

5.1 Introduction

All the results from the study at the selected offices as well as the laboratory investigations will be presented in this chapter. This includes the determination of the radon concentration using a continuous radon monitor (the TEL with AB-5 radiation monitor) to measure the radon concentration from those offices. The actual raw data from the experiments in the various offices are presented as well as a summary thereof. The plots of the data collected are presented to show the trend of radon build up in each of the offices will be discussed in this chapter. The calibration results are also presented in this chapter.

5.2 Mode of Data Collection

Thirteen (13) department in the Kwame Nkrumah University of Science and Technology were assessed for the radon concentration. For each department the office of the head was selected as a common sampling point. Due to different office setup and availability for assessment, there are different starting times for measurement, but all data were sampled for 24 hours therefore analysis were done by re-arranging each data to cover from 3:00 pm to the following day 2:00 pm. All the data collected from the measurement at all the selected offices are presented in appendix C, including the pre-measurement background readings for that offices.

5.3 Calibration Results for the Sensitivity of TEL

The sensitivity of the TEL was determined by measuring the background counts for 10 minutes interval Table 5.1. The background count per minute was 0.5 cpm. The activity of the source was 82432 pCi. The transfer of Radon from a known source into the TEL took a time of 10 minutes, the counts for the 30 minutes interval were taken as shown in Table 5.2

Time/minutes	count recorded
10	3
20	5
30	6

Table 5.1: Background counts for sensitivity of TEL

Time/minutes	count recorded
30	116
60	114
90	104

Table 5.2: 30 minutes counts for sensitivity of TEL

$$Radon\ Concentration\ (RC) = \frac{Q(1 - e^{-\lambda t})}{V} = 0.47\ pCi/l$$

where Q is the source activity, V is the total volume and λ is the decay constant in minutes. The net count per minute for the first interval is:

$$Net\ Count\ Per\ Minute\ (NCPM) = \frac{interval\ count - background}{interval\ length} = \frac{104 - 0.5}{30} = 3.9cpm$$

(The NCPM for the second interval 3.8 cpm and for the third, 3.5 cpm). The corrected net count per minute for the first interval is:

$$Corrected\ NCPM = \frac{NCPM}{e^{-\lambda t}}$$

where t is the time in minutes from t_1 to the midpoint of the interval. For the first interval the midpoint is 219 minutes (as the midpoint of a 30 minute interval is 15 minutes and the first interval began 204 minutes after t_1)

$$Corrected\ NCPM = \frac{3.9}{e^{-0.0001258x219}} = 4.0\ cpm$$

(The corrected NCPM for the second interval is 3.9 cpm and for the third, 3.6 cpm). The sensitivity for the first interval is:

$$sensitivity\ S\ = \frac{Corrected\ NCPM}{RC\ at\ t_1} = \frac{4.0}{0.47} = 8.5\ cpm/pCi/l$$

The sensitivity value for the second interval is 8.3 cpm/pCi/l and for the third, 7.6 cpm/pCi/l. The average sensitivity (S) is

$$Average\ S\ = \frac{S1 + S2 + S3}{3} = \frac{8.5 + 8.3 + 7.6}{3} = 8.1\ cpm/pCi/l$$

5.4 Outline of the Calibration Process

The process used for the calibration of the system(AB-5 DISC and HV settings, and the sensitivity of the TEL) are all illustrated in appendix A1.

5.5 Plots of Trend of Radon

These are the plots for the various offices showing the trends of radon concentration buildup at some selected heads of departments offices within the Kwame Nkrumah University of Science and Technology, Kumasi, Ghana. Figure 5.1 shows the plots for the following departments: Anatomy, Civil Engineering, and Architecture. Figure 5.2 shows the plots for the following departments: Chemical Engineering, Nuclear laboratory, pharmacognosy and modern languages. Figure 5.3 shows the plots for the following departments: Medical Laboratory Technology, Chemistry, and Agric Engineering. Figure 5.4 shows the plots for the following departments: Geography and Rural Development, Optometry and Visual Science, and Biochemistry and Biotechnology.

5.6 Radon Concentration Measurement using TEL

The the counts per minutes and their corresponding radon concentrations for the various offices on KNUST campus are listed in appendix C (tables C.1 to C.4). The accumulated radon concentrations are listed for the experiments that were done for different durations at various offices. Table C.1 lists the radon concentration results obtained by using the TEL/AB-5 system described in in chapter four for the following heads of department offices Anatomy, Civil Engineering, Architecture and Chemical Engineering.

Figure 5.1 represent the trend of radon buildup in the department of Anatomy, Architecture and Civil Engineering. The department of anatomy recorded the highest radon concentration at 0.099 pCi/l while the architecture recorded the least at 0.019 pCi/l, with civil Engineering recording 0.074 pCi/l as their maximum concentrations. All the three departments in figure

5.1 follow almost the same pattern interms of radon buildup. They all rise and fall almost at the same time frame. From figure 5.1 it was observed that radon turn to buildup at mid night and thus reduces during the day. This can be attributed to the fact that during the day the rate of opening of office doors allows outdoor air to disperse the indoor air. In general, the radon concentration the department of Anatomy, Civil Engineering and Architecture are all below the EPA action level of 4 pCi/l for which radon reduction method must be employed.

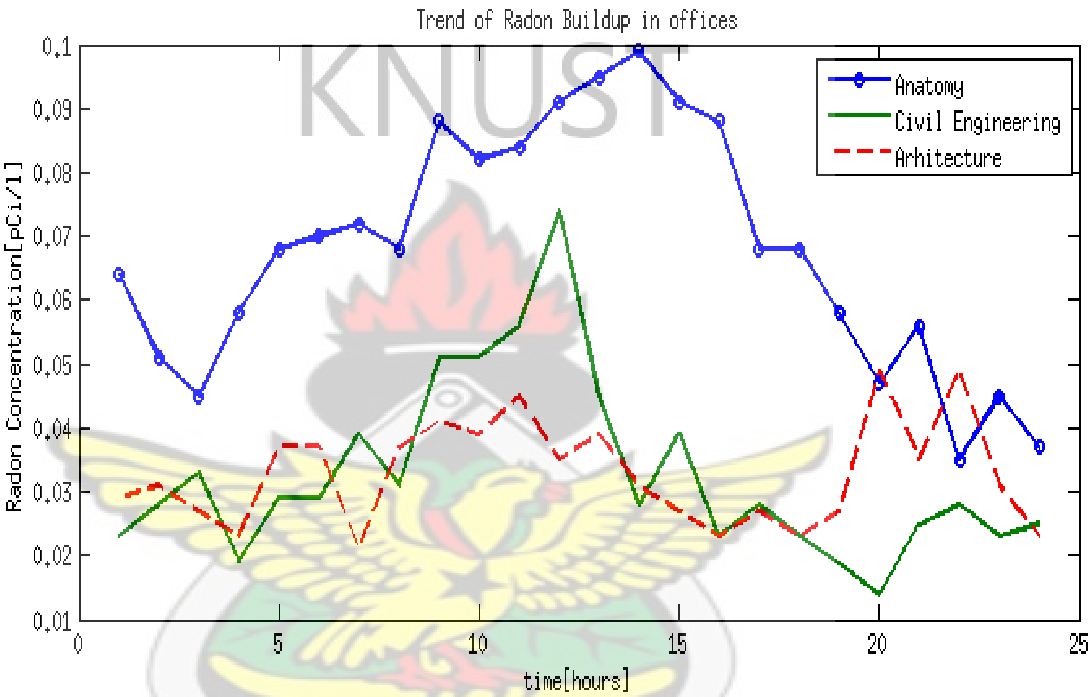

Figure 5.1: Trends of radon buildup

Figure 5.2 represents the trend of radon buildup in the following offices, Chemical Engineering, Nuclear Laboratory, Pharmacognosy, Modern Languages. The office that recorded high radon concentration was the nuclear laboratory (0.346 pCi/l as the highest concentration) and Pharmacognosy recorded the least(0.054 pCi/l as it highest interms of concentration), while the department of modern languages also recorded a highest concentration of 0.054 pCi/l. Although the nuclear laboratory is on the first floor as the others on ground floor, it should have recorded the lowest radon concentration due to the fact that radon concentration decreases with height. This could be attributed to the frequent flushing of the TEL and other lucas cells by other students in the laboratory or the presence of a radon source in the laboratory. From table C.1 and C.2 the nuclear laboratory recorded 0.346 pCi/l as the highest and 0.025 pCi/l as the lowest concentrations, pharmacognosy had between 0.054 - 0.012 pCi/l. The department of Modern Language also recorded very low radon concentration (0.054 -0.012 pCi/l). The department of chemical Engineering also shown in figure 5.2 with it concentration ranging from 0.115 - 0.031 pCi/l. This could be attributed to the fact the department is located at the ground floor of the college of Engineering and therefore the rate radon diffusion and advection might be high and since radon decreases with height, the reason for high concentration.

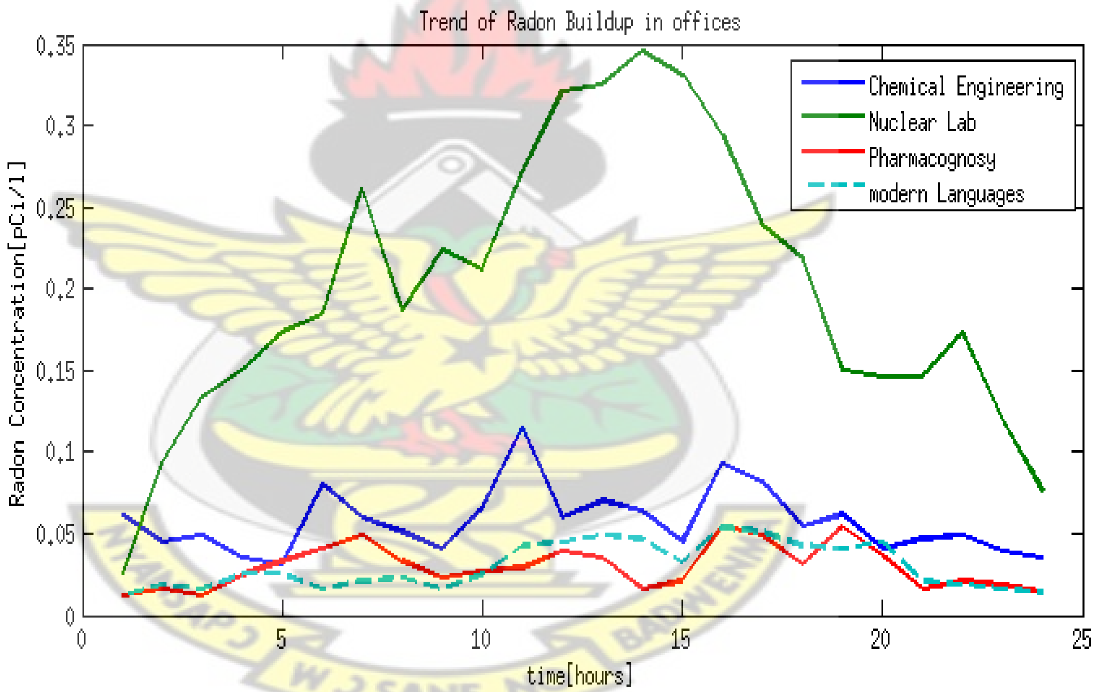

Figure 5.2: Trends of radon buildup

Figure 5.3 represent the trend of radon buildup in the department of Medical Laboratory Technology, Chemistry and Agricultural Engineering. The office with high radon concentration was the Medical laboratory Technology with a concentration between 0.160 - 0.027 pCi/l and Agricultural Engineering recording between 0.035 - 0.010 pCi/l, while chemistry recorded between 0.091 - 0.031 pCi/l. The three offices follows the same trend of radon

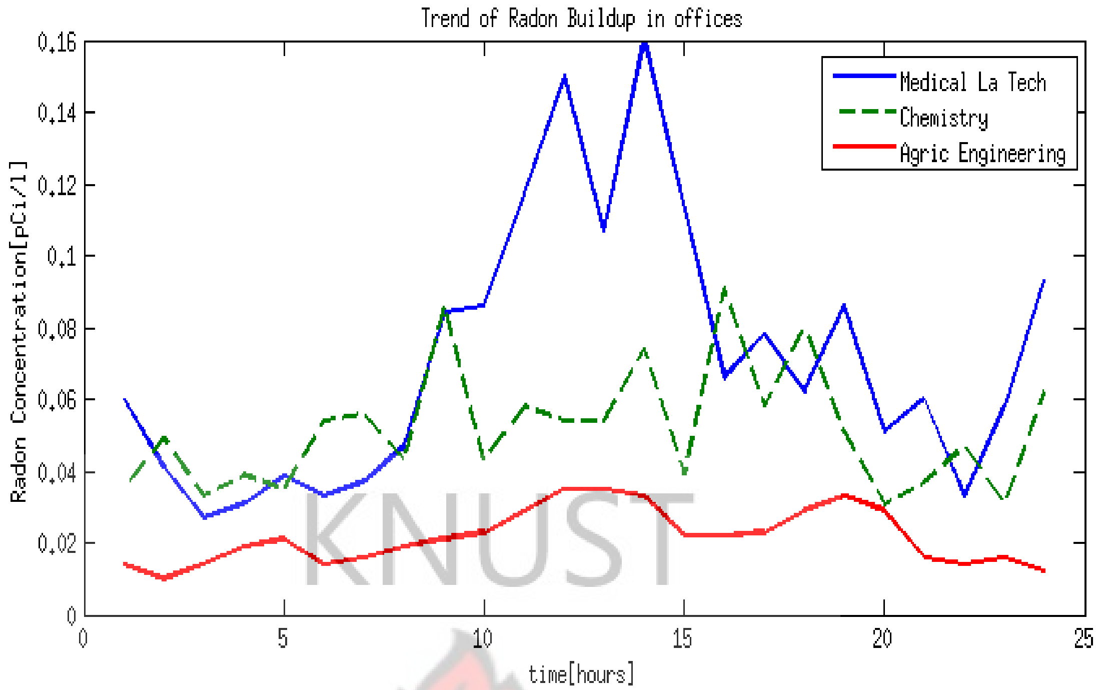

Figure 5.3: Trends of radon buildup

buildup, but Agricultural Engineering department recording very low radon concentration during the measurement might due to the fact that, the rate of ventilation was very high due to the absence of air condition at the office. The appreciable radon concentration recorded for chemistry and medical laboratory Technology departments could be interpreted that the amount radium content was low in the soil-gas and therefore the rate of emanation is low.

Figure 5.4 represent the trend of radon buildup in the following offices,Geography and Rural Development, Optometry and Visual Science, Biochemistry and Biotechnology, the office with high radon concentration is the department of optometry and Visual science (0.498 pCi/l) and the department of biochemistry and biotechnology recorded the least (0.107pCi/l). Optometry and visual science high radon concentration can be attributed to the fact that it is located at basement of the science complex, since radon emanate from the ground, any office close to the ground will have high concentration of radon and those above it would have low concentrations in order of height. Geography and Rural Development department also recorded appreciable concentration (0.200 - 0.051 pCi/l) although located on a first floor could be attributed to the location of the office, it has very poor ventilation, as the head of department will put it as the worst office ever built in the university. The department of Biochemistry and Biotechnology also recorded very low radon concentration as shown in figure 5.4. This could be that the ventilation level of that office was very high, since the Head of department will always open her windows for fresh air.

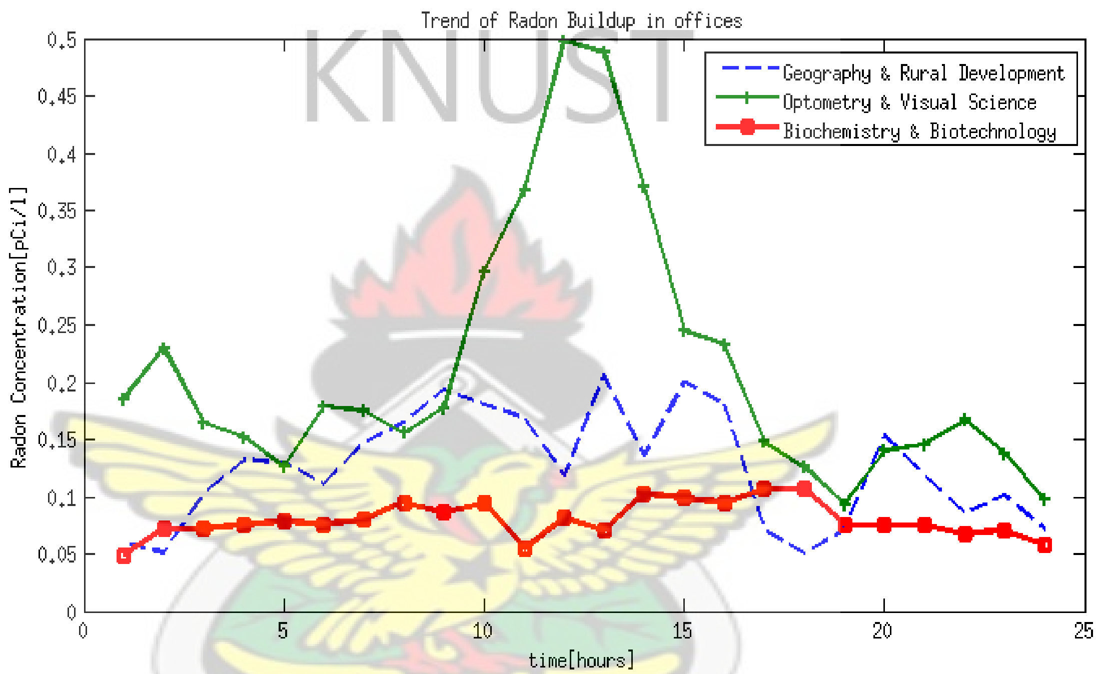

Figure 5.4: Trends of radon buildup

5.7 Summary

Among all the departments sampled the department of Optometry and Visual Science has the highest risk of effects of radon, while Agricultural Engineering has less risk to radon and its effects.In order to reduce radon concentration in an office the following simple steps could be taken

1. Install a sub-slab (or sub-membrane) depressurization system: The objective of these systems is to create a vacuum beneath the foundation which is greater in strength than the vacuum applied to the soil by the house itself. The soil gases that are collected beneath the home are piped to a safe location to be vented directly outside.

2. Use mechanical barriers to soil gas entry: Plastic sheeting and foundation sealing and caulking can serve as barriers to radon entry, entry of other soil gases, and moisture.

3. Reduce stack effect: Sealing and caulking reduce stack effect,and thus reduce the negative pressure in lower levels in the home.

4. Rate of ventilation should be high

CHAPTER 6

CONCLUSION AND RECOMMENDATIONS

Results Obtained

The review of the most relevant parameters and processes affecting indoor radon concentration has shown that the behaviour of soil and indoor radon concentration depends on a lot of parameters and that the values of these parameters found in the literature can span a very wide range. Therefore, it is necessary to characterise the source, the interface source-indoor and the indoor media considering simultaneously all the relevant parameters, especially those driving the dynamics.

Radon Concentration Measurements

In most countries the distribution of indoor radon concentrations is highly skewed, with a small proportion of homes having much higher concentrations than the mean. Policy to date, both in the UK and elsewhere, has usually focused on these high concentrations. As a result, most radon related lung cancers, which are caused chiefly by the lower radon levels experienced by most of the population, have not been addressed . Direct evidence now shows that indoor radon causes lung cancer in the general population not only at high concentrations but also at concentrations below 200 Bq m^{-3}. Radon measurements are relatively simple to perform and are essential to assess radon concentration in homes. They need to be based on standardized protocols to ensure accurate and consistent measurements. Indoor radon concentration varies with the construction of buildings and ventilation habits. These concentrations not only vary substantially with the season but also from day to day and even from hour to hour. Because of these fluctuations, estimating the annual average concentration of radon in indoor air requires reliable measurements of mean radon concentrations for at least three months and preferably longer.

The table below shows the maximum and minimum concentrations recorded for the respective office.

Table 6.1: Summary of the radon concentrations from the offices surveyed

	Radon Concentration(pCi/L)	
Department	minimum	maximum
Anatomy	0.035	0.099
Civil Engineering	0.019	0.074
Architecture	0.021	0.049
Chemical Engineering	0.031	0.115
Nuclear Laboratory	0.025	0.346
Pharmacognosy	0.012	0.054
Modern Language	0.012	0.054
Medical Laboratory Technology	0.027	0.160
Chemistry	0.031	0.093
Agriculture Engineering	0.010	0.035
Geography and Rural Development	0.051	0.200
Optometry and Visual Science	0.093	0.498
Biochemistry and Biotechnology	0.049	0.107

From the analysis of indoor radon concentration data from a small scale Campus survey of thirteen (13) offices, it was found that the department of optometry and visual science recorded the highest radon concentration, with department of Agricultural Engineering with the least concentration. Not everyone exposed to elevated levels of radon will develop lung cancer, but your risk of getting radon-induced lung cancer increases as your exposure to radon increases (either because the radon levels are higher or you live in the home longer).

Recommendations

Since the 1980s, a large number of studies have directly examined the relationship between indoor radon and lung cancer in the general population. Individually, these studies are generally too small either to rule out a material risk, or to provide clear evidence that one existed. The investigators of the major studies in Europe, North America, and China have therefore brought their data together, and re-analyzed it centrally (Lubin et al. 2004, Krewski et al. 2005, 2006, Darby et al. 2005, 2006). These three pooled-analyses present very similar pictures of the risks of lung cancer from residential exposure to radon. Together, they provide overwhelming evidence that radon is causing a substantial number of lung cancers in the general population and they provide a direct estimate of the magnitude of the risk. They also suggest that an increased risk of lung cancer cannot be excluded even below 200 Bq m^{-3}, which is the radon concentration at which action is currently advocated in many countries. Since the general public is often unaware of the risks associated with indoor radon, special risk communication is recommended. Radon risk communication needs to be focused on informing the different audiences and recommending appropriate action on reducing indoor radon. A cooperative effort is required, involving technical and communication experts, to develop a set of core messages. Radon risk messages should be kept as simple as possible and quantitative risk information must be expressed to the public in clearly understandable terms. It is useful, for example, to place the risk of lung cancer due to radon in comparison with other cancer risks, or with common risks in everyday life.Public health programmes to reduce the radon risk should be ideally developed on national level. Such national radon programmes would be designed to reduce the overall population's risk from the national average radon concentration as well as the individual risk for people living with high radon concentrations. It is also recommended that the trend of radon at each office should be measured for longer period other than just a day.

References

1. A report of a task group of the International Commission on Radiological Protection. Protection against radon-222 at home and at work. An ICRP 1993;23:1-45.

2. Aldenkamp, F.J. (1994) In situ radon exhalation meter, In Doctorate thesis of F.J. Aldenkamp and P. Stoop, Groningen: Rijksuniversiteit Groningen.

3. Amponsah P, Banoeng-Yakubo B, Aba Andam, Daniel Asiedu, (April 2008). Soil radon concentration along fault systems in parts of south eastern Ghana, Journal of African Earth Sciences Volume 51, Issue 1, Pages 39-48

4. 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, Journal of the Ghana Science Association Vol. 9 (2), pp. 85-94

5. Asumadu-Sakyi A.B., Oppong O.C, Quashie F.K, Adjei C.A , Akortia E, Nsiah-Akoto I, Appiah K. (2012). Proceedings of the International Academy of Ecology and Environmental Sciences, 2(4):223-233

6. Auvinen A, Makelainen I, Hakama M, et al. (1996). Indoor radon exposure and risk of lung cancer: a nested case-control study in Finland. J Natl Cancer Inst, 88:966-72.

7. Biological Effect on Ionizing Radiation(BEIR VI), (1999). National Reseacher Council: Health effects of exposures to indoor radon. Washington D.C. National academy press.

8. Choubey, V.M., Ramola, R.C. (1997). Correlation between geology and radon levels in ground water, soil and indoor air in Bhilangana Valley, Garhwal Himalaya, India. J. Environ. Geol. 32, 258-262.

9. Cross, F.T, Palmer R.F, Dagle G.E, Busch R.E and Buschbom R.L. (1984). Influence of radon daughter exposure rate, unattachment fraction, and disequilibrium on occurrence of lung tumors. Radiat. Prot. Dosimetry 7, 381-384.

10. Darby S, Hill D, Auvinen A, Barros-Dios J.M, Baysson H, Bochicchio F. (2005). Radon in homes and lung cancer risk: a collaborative analysis of individual data from 13 European case-control studies. BMJ. 330:223-7.

11. Darby S, Hill D, Deo H, Auvinen A, Barros-Dios JM, Baysson H. (2006;) Residential radon and lung cancer detailed results of a collaborative analysis of individual data on 7148 persons with lung cancer and 14 208 persons without lung cancer from 13 epidemiologic studies in Europe. Scand J Work Environ Health 32 suppl 1:1-84.

12. Darby, S. (2006). Residential radon and lung cancer, the risk of lung cancer Scandinavian Journal of Work, Environment and Health, 32

13. Environmental Protection Agency (EPA) (1992). A Citizens's Guide to Radon: The Guide to Protecting Yourself and Your Family from Radon, second edition, ANR-464. Washington, DC: US Government Printing Office.

14. Environmental Protection Agency (EPA). (1986). A Citizen's Guide to Radon. Washington, D.C., U.S. Environmental Protection Agency and U S Department of Health and Human Services, report EPA-86-004.

15. Environmental Protection Agency,(2003). Air and Radiation: Assessment of Risks from Radon in Homes (6608J) EPA 402-R-03-003 June 2003.

16. Environmental Protection Agency, Office of Air and Radiation (6604J) (1992), Indoor radon and radon decay product measurement device protocols: (Online) http://www.epa.gov/radon/pubs/devprot1.html. Last updated 24 March 2003.

17. George, A.C. (1984) Passive integrated measurements of indoor radon using activated carbon. Health Physics, Vol.46, no. 4, pp 867-872.

18. Gervino G, Bonetti R, Cigolini C, Marino C, Prati P, Pruiti L. (2004). Environmental radon monitoring: comparing drawbacks and performances of charcoal canisters, alpha-track and E-PERM detectors. Nuclear Instruments and Methods in Physics Research A, Vol. 518, pp 452-455

19. Godoy M, Hadler J.C, (2002). Effects of environmental conditions on the radon daughters spatial distribution. Radiation Measurements, Vol. 35, pp 213 - 221.

20. Gutierrez J, Baixeras C, Robles B, Saez J.C, and Font L.I. (1992). Indoor radon levels and dose estimation in two major Spanish cities. Radiate. Prot. Dosim. 45:495-498.

21. ICRP-65. (1993) Protection against radon-222 at home and at work. Annals of the ICRP, December 1993 issue. Pergamon Press.

22. James, A.C. (1988) Lung dosimetry. Radon and its decay products in indoor air. Editors W. Nazaroff and A. Nero, John Wiley and Sons, Inc. pp 266.

23. Jonsson G, Baixeras C, Enge W, Freyer K, Treutler H.C, Monnin M.M, and Sciocchetti G. (1995). Criteria for indoor radon concentration - an experimental study considering especially the Leipzig-Halle brown coal area. Radiat. Measurements, 25:627-630.

24. Krane, K.S. (1988) Alpha Decay. Introductory Nuclear Physics. John Wiley and Sons, Inc., New York, pp 246 - 271.

25. Kreienbrock L, Kreuzer M, Gerken M, Dingerkus G, Wellmann J, Keller G. And Wichmann1 H.E.(2001). Case-control study on lung cancer and residential radon in western Germany. American Journal of Epidemiology, 153:42-52.

26. Krewski D (2006). A combined analysis of North American case-control studies of residential radon and lung caner. J Toxicol Environ Health 69:533-597

27. Krewski D. (2005). Residential radon and risk of lung cancer: a combined analysis of 7 North American case-control studies. Epidemiology. 16:137-145.

28. Letourneau E.G, Krewski D, Choi N.W, Goddard M.J, McGregor RG, Zielinski J.M. (1994). Case-control study of residential radon and lung cancer in Winnipeg, Manitoba, Canada. American Journal of Epidemiology, 140:310-22.

29. Lubin J.H , Boice J.D Jr, Edling C, Hornung R.W, Howe G, Kunz E, Kusiak R.A, Morrison H.I, Radford E.P, Samet J.M, Tirmarche M, Woodward A, and Yao S.X. (1993). Radon-exposed underground miners and inverse dose-rate (protraction enhancement) effects

30. Lubin J.H, Boice J.D Jr, Edling C, Hornung R.W, Howe G.R, Kunz E. (1995). Cancer in radon-exposed miners and estimation of risk from indoor exposure. Journal of the National Cancer Institute, 87:817-27.

31. Lubin J.H, Steindorf K. (1995). Cigarette use and the estimation of lung cancer attributable to radon in the United States. Radiation Research, 141:79-85.

32. Lubin J.H. (2004). Risk of lung cancer and residential radon in China: pooled results of two studies. Int J Cancer, 109:132-137.

33. NCRP Report no. 78, (1984). Evaluation of Occupational and Environmental Exposure to Radon and Radon Daughters in the United States.

34. National Academy of Sciences, (1990). Health Effects of Exposure to Radon, BEIR VI.

35. National Research Council. Biological Effects of Ionizing Radiation (BEIR) IV Report. (1988). Health Effects of Radon and Other Internally Deposited Alpha Emitters. Washington, DC: National Academy Press.

36. Nazaroff, W.W, Moed B.A, Sextro R.G, Revsan K.L, and Nero A.V. (1985). Factors Influencing Soil as a Source of Indoor Radon: A Framework for Geographically Assessing Radon Source Potentials, LBL-20645, Lawrence Berkeley Laboratory, Berkeley, CA.

37. Nero, A.V. (1988) Radon and its decay products in indoor air: An overview. Editors W. Nazaroff and A. Nero, John Wiley and Sons, Inc., pp 1 - 53.

38. Nsiah-Akoto I, Fletcher J.J, Oppong 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, 2011

39. Perrier, F., Richon, P., Sabroux, J.C., and Brown, K., (2005). Modeling the effect of air exchange on ^{222}Rn and its progeny concentration in a tunnel atmosphere. Science of the Total Environment. 35: 143-154

40. Pylon Electronics Inc. 147 Colonnade Road, Ottawa, ON K2E 7L9 Canada. Trace level radon gas detector-instruction manual. Document No.: A900005 Revision 4

41. Radford E.P, Renard K.G. (1984). Lung cancer in Swedish iron miners exposed to low doses of radon daughters. New England Journal of Medicine, 310:1485-94.

42. Ramola R.C, Choubey V.M, Prasad Y, Prasad G, Bartarya S.K. (1997). Variation in radon concentration and terrestrial gamma radiation dose rates in relation to the lithology in southern part of Kumaon Himalaya, India

43. Schoenberg J.B, Klotz J.B, Wilcox H.B. (1990). Case-control study of residential radon and lung cancer among New Jersey women. Cancer Res, 50:6250-4.

44. Sogaard-Hansen J, Damkjer A. (1987). Determining ^{222}Rn diffusion lengths in soils and sediments. Health Physics, Vol.53, no. 5, pp 455 - 459.

45. UNSCEAR (2000) Sources and effects of ionizing radiation. Report to the General Assembly of the United Nations with Scientific Annexes, United Nations sales publication E.00.IX.3, New York.

46. UNSCEAR (United Nations Scientific Committee on the Effects of Atomic Radiation).(1993). Sources, effects and risks of ionizing radiation; New York, NY.

47. UNSCEAR, (2000). Exposures from natural radiation sources (Annex B). Report to the General Assembly, United Nations, New York.

48. UNSCEAR, (2000). United Nations Scientific Committee on the Effect of Atomic Radiation. Exposure from Natural Radiation Sources. United Nations, New York.

49. United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR).(2000). Sources and effects of ionizing radiation. New York (NY): United Nations, report to the General Assembly, with scientific annexes,vol I: sources.

50. World Health Organization (2009). WHO Handbook on Indoor Radon: A Public Health Perspective / edited by Hajo Zeep and Ferid Shannoun.

Appendix A

APPENDIX

A.1 Calibrating the TEL / AB-5 System

The TEL was calibrated with the user's AB-5 when received. Calibration can be performed in two stages. It is recommended for the first time user to perform Stage 1 followed by Stage 2 on the next day or later. Stage 1 is to determine the AB-5's operating point. Stage 2 is to determine the TEL/AB-5's sensitivity to radon gas

A.1.1 Determining the AB-5's Operating Point

The operating point is the optimal setting for the High Voltage (HV) and Discriminator (DISC) dials on the rear panel of the AB- 5. If the HV is set too high or the DISC is set too low, the AB-5 will be overly responsive, resulting in measurements containing a high level of background (or noise). If the HV is set too low or the DISC too high, the AB-5 will not respond to all the alpha radiation present in the TEL. The following procedure will be used to find the AB-5's operating point. The DISC was adjusted first, then a series of HV Settings are run with radon gas in the TEL to find the best HV setting. Steps for determining the operating point are presented below. Before starting, it was ensured that the TEL has not been used for a minimum of 24 hours and ensured that the TEL and AB-5 are switched "off".

1. The equipment was dried by connecting the AB-5 Exhaust Pump Port, drying column, charcoal column, air filter, TEL, and AB-5 Intake Pump Port to form a closed loop. the AB-5 pump was then run at the maximum flow rate to obtain a volume displacement equal to a minimum of 10 times the volume of the TEL.

2. the PMT is then inserted into the Detector Barrel, and screw the PMT Housing back onto the Detector Barrel.

3. The coaxial cable was attached to the BNC connector of the PMT and the other end of the cable connected to the External PMT connector of the AB-5.

4. The TEL and AB-5 are the connected to power source and that the PMT Select Switch (AB-5 rear panel) is set at the "EXT" position. the AB-5 DISC dial is set to a recommended value of "2".

5. The AB-5 HV dial is set to a recommended HV value of 5.5. and Set the AB-5 Mode Switch to "CONT". the AB-5 Time Base Switch to "MIN". After 15 minutes have elapsed the AB-5 is turn on.

A.1.1.1 Determining DISC

The AB-5 was programed for an interval length of ten minutes. The AB-5 was then Started and count for two ten minute intervals: if the count at the end of the interval is 10 or less, the DISC is set correctly for that particular HV setting.

A.1.1.2 Determining HV

A standard Lucas cell with a count of 400 CPM was used to set the HV once the DISC settings was properly set.

A.1.2 Determining the Sensitivity of TEL

Once the operating point has been determined, the equipment's sensitivity to radon gas can be determined. Radon gas of known activity is needed in order to calculate sensitivity. Once the sensitivity is known, the equipment can be used to measure radon gas. AB-5/TEL Background was determined by making three counts of five minutes. Calculate the average and record in the System Sensitivity. The AB-5 exhaust pump port was replaced with a vacuum pump which was connected to the radon source (RN 150) air filter, airflow meter, TEL's air intake valve, PMT/TEL's air exhaust valve and AB-5 intake pump port to form a closed loop as illustrated in Figure A.1. Radon was then transferred into the TEL. The system was allowed to reach equilibrium (approximately 3.5 hours). time t_1 for the transfer was calibrated, the total combined volume of the TEL(18.5 L), tubing (length in inches x 0.80 ml for 1/4" I.D. tubing)(56.72), vacuum pump(183.3 L), and source (RN 150 = 20 litres).Radon concentration (RC) at t_1 was calculated and record the by using the following formula

$$RC = \frac{Q(1 - e^{-\lambda t})}{V} \tag{A.1}$$

Where

RC = radon concentration at t_1 in pCi/1

Q = Source activity in pCi

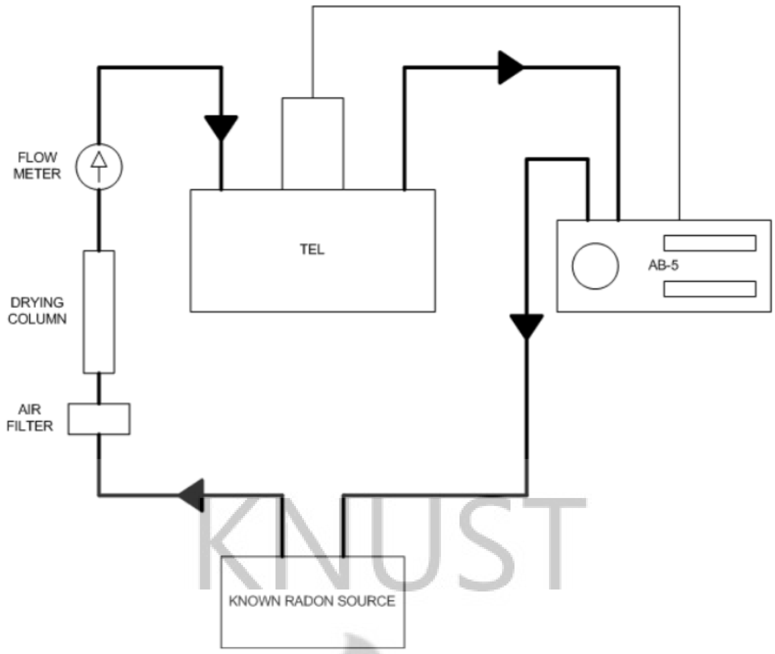

Figure A.1: Close loop of TEL, Radon Source and AB-5

e = base of the natural logarithms

λ = 0.0001258$minutes^{-1}$

t = time in minutes for t_1

v = total volume in litres.

The AB-5 was programed to make three counts for an interval length of 30 minutes and the start time of each interval was calculated in terms of the number of minutes that have elapsed since the radon was transferred to the system. The midpoint of each interval was calculated in terms of the number of minutes from t_1 (is equal to the interval start time plus half the interval length). after the three counts the TEL and AB-5 are turn off. and the TEL flushed. The net counts per minute for each interval was calculated by dividing each interval's count by the interval's length and then subtracting the background value. As the radon gas in the TEL/AB-5 will have decayed between t_1 and the time that the counts were made, each net CPM must be corrected for decay by dividing it by

$$e^{-\lambda t} \tag{A.2}$$

the time in minutes from t_1 to the midpoint of each interval and the corrected net CPM were recorded. the sensitivity for each of the three intervals was Calculated and record by dividing the corrected net CPM by the radon concentration at time t_1. the average sensitivity will then be evaluated.

Appendix B

B.1 Materials Used

B.1.1 Trace level Radon gas Detector (TEL)

The TEL is a true, real-time continuous radon monitor. The TEL is used for measuring concentrations of radon gas. The TEL detector consists of an alpha sensitive scintillator

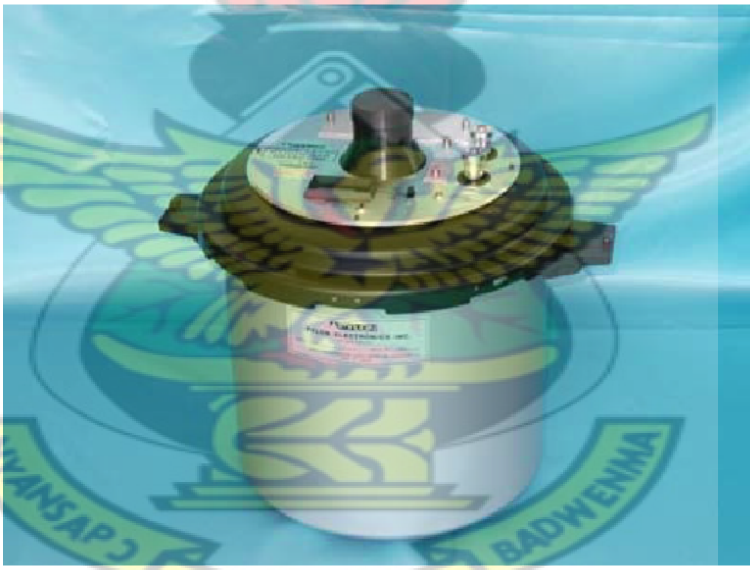

Figure B.1: The Trace level radon gas detector

which is mounted on a Lucite light pipe. The light sensitive photomultiplier tube (PMT) meets the top of the light pipe with the protruding end of PMT being protected by the PMT Housing. Air to be tested for radon gas is drawn into the TEL by the AB-5's internal pump. The TEL is a portable radon gas sampling and detection instrument designed for use with the Pylon Model AB-5 Portable Radiation Monitor. The TEL is the most sensitive active radon detection device commercially available; it can detect radon gas concentrations as low as 0.025 pCi/l (0.93 Bq/m^3). Because of its extreme sensitivity and versatility, the TEL lends itself to a number of applications, including measuring household levels of radon gas.

The TEL consists of a 18.5 liter electrostatic chamber with an aluminized Mylar conductor which serves as the collector or cathode. This cathode has a nominal electrical potential of -1200 volts and is powered through an internal step-up converter which steps up voltage from the four 'C' cells or DC voltage from a battery eliminator (the battery eliminator converts AC line power into 6 V DC voltage). The inside wall of the TEL acts as an anode and is at ground potential. The cathode overlays an alpha sensitive scintillator which is mounted on a Lucite light pipe. The light sensitive PMT meets the top of the light pipe with the protruding end of PMT being protected by the PMT Housing. Air to be tested for radon gas is drawn into the TEL by the AB-5's internal pump.

B.1.2 AB-5 Portable Radiation Monitor

AB-5 is a portable monitor and data acquisition unit which has a wide range of optional accessories for measuring different types of radioactive decay. Some accessories mount directly onto the AB-5 front panel while others via a cable to the AB-5 rear panel.

Figure B.2: AB-5 Portable radiation

Appendix C

C.1 Results from TEL/AB-5 System

The results of radon concentration obtained from the TEL/AB-5 system are presented below. The setup were all began different times but the results presented here are all arranged from a time of 3:00 PM to 2:00 PM, which lasted for a period of 24 hours. The interval on the AB-5 was set for five minute, these were later grouped into windows of one hour. The count per minute for each window was then evaluated and their respective concentrations thereof calculated using equation 5.1.

Table C.1: Trend of radon concentration calculated from data collected for the departments of Anatomy, civil engineering, architecture and chemical engineering

time	Anatomy		Civil Engineering		Architecture		Chemical Engineering	
hour	CPM	pCi/l	CPM	pCi/l	CPM	pCi/l	CPM	pCi/l
1	0.7166	0.064	0.3000	0.025	0.3334	0.029	0.6000	0.062
2	0.6166	0.051	0.3167	0.028	0.3500	0.031	0.4666	0.045
3	0.5666	0.045	0.3666	0.033	0.3166	0.027	0.5000	0.049
4	0.6666	0.058	0.2500	0.019	0.2834	0.023	0.3834	0.035
5	0.7500	0.068	0.3334	0.029	0.4500	0.043	0.3500	0.031
6	0.7666	0.070	0.3334	0.029	0.4000	0.037	0.7500	0.080
7	0.7834	0.072	0.4166	0.039	0.2666	0.021	0.5834	0.060
8	0.7500	0.068	0.3500	0.031	0.4000	0.037	0.5166	0.051

9	0.9166	0.088	0.5166	0.051	0.4334	0.041	0.4334	0.041
10	0.8666	0.082	0.5166	0.051	0.4166	0.039	0.6334	0.065
11	0.8834	0.084	0.5500	0.056	0.4666	0.045	1.0334	0.115
12	0.9334	0.091	0.7000	0.074	0.3834	0.035	0.5834	0.060
13	0.9666	0.095	0.4666	0.045	0.4166	0.039	0.6666	0.070
14	1.0000	0.099	0.3167	0.028	0.3500	0.031	0.6166	0.064
15	0.9334	0.091	0.4166	0.039	0.3166	0.027	0.4666	0.045
16	0.9166	0.088	0.2834	0.023	0.2834	0.023	0.8500	0.093
17	0.7500	0.068	0.3167	0.028	0.3166	0.027	0.7666	0.082
18	0.7500	0.068	0.2834	0.023	0.2834	0.023	0.5334	0.054
19	0.6666	0.058	0.2500	0.019	0.3166	0.027	0.6000	0.062
20	0.5834	0.047	0.2500	0.019	0.5000	0.049	0.4334	0.041
21	0.6500	0.056	0.2166	0.014	0.3834	0.035	0.4834	0.047
22	0.4834	0.035	0.3000	0.025	0.5000	0.049	0.5000	0.049
23	0.5666	0.045	0.3167	0.028	0.3500	0.031	0.4166	0.039
24	0.5000	0.037	0.2834	0.023	0.2834	0.023	0.3834	0.035

The Pre-measurement background of TEL/AB-5 reading for the departments in table C.1 are 0.2 cpm, 0.1 cpm, 0.1 cpm and 0.1 cpm for department of Anatomy, department of Civil engineering, department of Architecture and department of Chemical Engineering respectively.

Table C.2: Trend of radon concentration calculated from data collected for the departments of nuclear laboratory, pharmacognosy and modern languages

time	Nuclear lab		pharmacognosy		modern languages	
hour	cpm	conc(pCi/l)	cpm	conc(pCi/l)	cpm	conc(pCi/l)
1	0.4000	0.025	0.2000	0.012	0.2000	0.012
2	0.9500	0.093	0.2334	0.016	0.2500	0.019
3	1.2834	0.134	0.2000	0.012	0.2334	0.016
4	1.4166	0.150	0.3000	0.025	0.3000	0.025
5	1.6000	0.173	0.3666	0.033	0.3000	0.025
6	1.7000	0.185	0.4334	0.041	0.2334	0.016
7	2.3166	0.261	0.5000	0.049	0.2666	0.021
8	1.7166	0.187	0.3666	0.033	0.2834	0.023
9	2.0166	0.224	0.2834	0.023	0.2334	0.016
10	1.9166	0.212	0.3166	0.027	0.3000	0.025
11	2.4000	0.272	0.3334	0.029	0.4500	0.043
12	2.8000	0.321	0.4166	0.039	0.4667	0.045
13	2.8334	0.325	0.3834	0.035	0.5000	0.049
14	3.0000	0.346	0.2334	0.016	0.4833	0.047
15	2.8834	0.331	0.2666	0.021	0.3666	0.033
16	2.5834	0.294	0.5334	0.054	0.5334	0.054
17	2.1334	0.239	0.5000	0.049	0.5166	0.051
18	1.9666	0.218	0.3500	0.031	0.4500	0.043

hour	cpm	conc(pCi/l)	cpm	conc(pCi/l)	cpm	conc(pCi/l)
19	1.4166	0.150	0.5334	0.054	0.4334	0.041
20	1.3834	0.146	0.4000	0.037	0.4666	0.045
21	1.3834	0.146	0.2334	0.016	0.2666	0.021
22	1.6000	0.173	0.2666	0.021	0.2500	0.019
23	1.1666	0.119	0.2500	0.019	0.2334	0.016
24	0.8166	0.076	0.2166	0.014	0.2166	0.014

The Pre-measurement background of TEL/AB-5 reading for the departments in table C.2 are 0.2 cpm, 0.1 cpm, 0.1 cpm and for Nuclear laboratory, Pharmacognosy, and modern languages respectively.

Table C.3: radon concentrations calculated from data collected for medical laboratory technology, chemistry, agricultural engineering and geography and rural development departments respectively

time	medical lab tech		chemistry		Agriculture Engineering		Geo and Rural Dev	
hour	CPM	pCi/l	CPM	pCi/l	CPM	pCi/l	CPM	pCi/l
1	0.5834	0.060	0.3834	0.035	0.2166	0.014	0.6834	0.060
2	0.4334	0.041	0.5000	0.049	0.1832	0.010	0.6166	0.051
3	0.3166	0.027	0.3666	0.033	0.2166	0.014	1.0334	0.103
4	0.3500	0.031	0.4166	0.039	0.2500	0.019	1.2666	0.132
5	0.4166	0.039	0.3834	0.035	0.2666	0.021	1.2500	0.130
6	0.3666	0.033	0.5334	0.054	0.2166	0.014	1.1000	0.111
7	0.4000	0.037	0.5500	0.056	0.2334	0.016	1.4000	0.148
8	0.4834	0.047	0.4500	0.043	0.2500	0.019	1.5334	0.165
9	0.7834	0.084	0.8000	0.086	0.2666	0.021	1.7666	0.193

10	0.8000	0.086	0.4000	0.043	0.2834	0.023	1.6666	0.181
11	1.0500	0.117	0.5666	0.058	0.3332	0.029	1.5666	0.169
12	1.3166	0.150	0.5334	0.054	0.3834	0.035	1.1666	0.119
13	0.9666	0.107	0.5334	0.054	0.3666	0.033	1.3000	0.136
14	1.4000	0.160	0.7000	0.074	0.3666	0.033	1.3000	0.136
15	1.0166	0.113	0.4166	0.039	0.2770	0.022	1.8166	0.200
16	0.6334	0.066	0.8334	0.091	0.2770	0.022	1.6666	0.181
17	0.7334	0.078	0.5666	0.058	0.2834	0.023	0.7834	0.072
18	0.6000	0.062	0.7500	0.080	0.3334	0.029	0.6166	0.051
19	0.8000	0.086	0.5166	0.051	0.3666	0.033	0.7834	0.072
20	0.5166	0.051	0.3500	0.031	0.3334	0.029	1.4500	0.154
21	0.5834	0.060	0.4000	0.037	0.2334	0.016	1.1666	0.119
22	0.3666	0.033	0.4834	0.047	0.2166	0.014	0.9000	0.086
23	0.5666	0.058	0.3500	0.031	0.2334	0.016	1.0166	0.101
24	0.8500	0.093	0.6000	0.062	0.2000	0.012	0.7834	0.072

Readings for the Pre-measurement background of TEL/AB-5 for the departments in table C.3 are 0.1 cpm, 0.1 cpm, 0.1 cpm and 0.2 cpm for Medical laboratory Technology, Chemistry, Agricultural Engineering and Geography and Rural Development respectively.

Table C.4: calculated concentrations for the departments of optometry and visual science, and biochemistry and biotechnology

time	Optometry and visual Science		Biochemistry and Biotechnology	
hour	CPM	pCi/l	CPM	pCi/l
1	1.8000	0.185	0.6000	0.049
2	2.1666	0.230	0.7834	0.072
3	1.6340	0.165	0.7834	0.072
4	1.5334	0.152	0.8166	0.076
5	1.3166	0.126	0.8334	0.078
6	1.7500	0.179	0.8166	0.076
7	1.7166	0.175	0.8500	0.080
8	1.5666	0.156	0.9666	0.095
9	1.7334	0.177	0.9000	0.086
10	2.7000	0.296	0.9666	0.095
11	3.2834	0.368	0.6500	0.055
12	4.3334	0.498	0.8666	0.082
13	4.2500	0.488	0.7666	0.070
14	3.3000	0.370	1.0334	0.103
15	2.2834	0.245	1.0000	0.099
16	2.1834	0.233	0.9666	0.095
17	1.5000	0.148	1.0666	0.107
18	1.3166	0.126	1.0666	0.107

hour	CPM	pCi/l	CPM	pCi/l
19	1.0500	0.093	0.8166	0.076
20	1.4334	0.140	0.8166	0.076
21	1.4834	0.146	0.8166	0.076
22	1.6500	0.167	0.7500	0.068
23	1.4166	0.138	0.7666	0.070
24	1.0834	0.097	0.6666	0.058

The Pre-measurement background of TEL/AB-5 background readings for the departments in table C.4 are 0.3 cpm, 0.2 cpm, for Optometry and Visual Science, Biochemistry and Biotechnology departments respectively.