HEALTH HAZARDS OF RADON

By

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This Work is dedicated to Men and Women of Science who labored for the wellbeing of all humanity.

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Abstract

The human environment is one in which ionizing radiations are present at all times and at all places on the Earth from the deepest caves to the highest mountains and on the space. Radon and its decay products are present wherever radium and thorium exist in the Earth or in any planetary material. In the terrestrial environment the inhaled radon isotopes and their daughter products make up almost two–thirds of the total dose to living tissue.

In this project the great attention is directed to detailed description of the radiations that comes from radioactive gas found naturally in the environment (radon) from natural radio nuclides such as uranium (radium) and thorium and their health effects upon living tissue especially on breathing organ (lung).

In general radon gas and short lived radon daughters (SLRDs) reaches human body via inhalation with air or ingestions with foods and waters, results health hazards particularly lung cancer related to radon gas inhalation or ingestion.

CHAPTER 1

Introduction

Things that we have but we cannot know and remember on ourselves and as well we cannot give for and take from the other is our health that can be affected by naturally occurring radioactive (NOR) heavy nuclides such as uranium (U), thorium (Th), radium (Ra) and radon (Rn) without knowing (SHA, 2002). Hence main objective of this study is focused on health hazards of radon (ARPANSA, 2015).

1.1. WHAT IS RADON?

Radon is radioactive gas that mixes with air in the environment which can undergo radioactive decay by losing an alpha particle and forming the polonium element during this process. The major source of radon gas is the soil, but ground water, natural gas, and building materials also contribute.

Radon has three main isotopes ^{222}Rn, ^{220}Rn and ^{219} Rn which are direct descendent of radium isotopes (^{226}Ra, ^{224}Ra and ^{223} Ra) which is U and Th daughters (Read and Hayder 2011).

1.1.1 Physical and Chemical Properties of Radon

Radon is an odorless, tasteless, electrically uncharged, invisible means not detectable by human senses alone, colorless at standard temperature and pressure, and forms a mono atomic gas:

- with a density of 9.73 kg/m^3, i.e. about 8 times the density of the Earth's atmosphere (1.217 kg/m^3) at sea level,
- having freezing point of 202 K (-71 °C; -96 °F) and boiling point (-61.7 °C, -79.1 °F, 211.5 K),
- has atomic number 86, relative atomic mass 222,
- densest noble gas /substance that remain a gas under normal condition and one of the densest gas at room temperatures,
- is capable of diffusion through rock and soil.

Radon is chemical element, chemically inert, essentially non-reactive, highly or appreciably more soluble in non-polar solvents or organic liquids than in water, sparingly soluble in water but more soluble than lighter noble gases, moderately soluble in cold water, highly fat soluble and actively transported through the body and does not undergo metabolism in biological systems.

1.2. RADIOACTIVITYY IN THE ENVIRONMENT

Humankind has been exposed to natural radiation ever since his existence on Earth. Natural radiation has been the only source of exposure to ionizing radiation until recent times when the growth of nuclear energy has created other sources of radiation exposures like fallout from weapon tests, radioactive releases from nuclear reactor operations and accidents, exposures due to radioactive waste disposals and other industrial, medical and agricultural use of radioisotopes.

Levels of natural or background radiation can vary greatly from one location to the next. For example residents a city at higher altitude are exposed to more cosmic radiation. Similarly more terrestrial radiation from soils rich in naturally occurring uranium and thorium form high background radiation area.

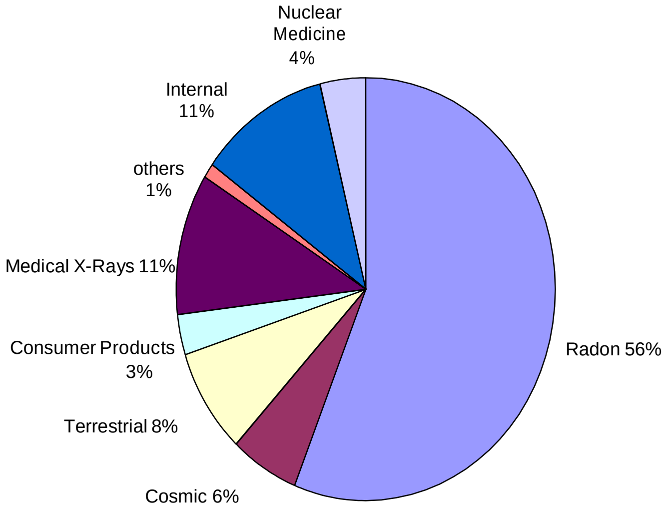


Figure 1.1: Percentage contributions to the per capita annual effective dose equivalent

As can be seen from Fig 1.1 the major contribution to the average annual background radiation dose received comes from the natural radiation sources

Radiation exposures from natural sources are categorized as to their origin as:

(a) Primordial Radionuclides (radioactive nuclides present in Earth's crust, in atmosphere and in the building materials),

(b) Cosmogenic Radionuclides: formed as a result of cosmic ray interaction with the Earth's atmosphere and

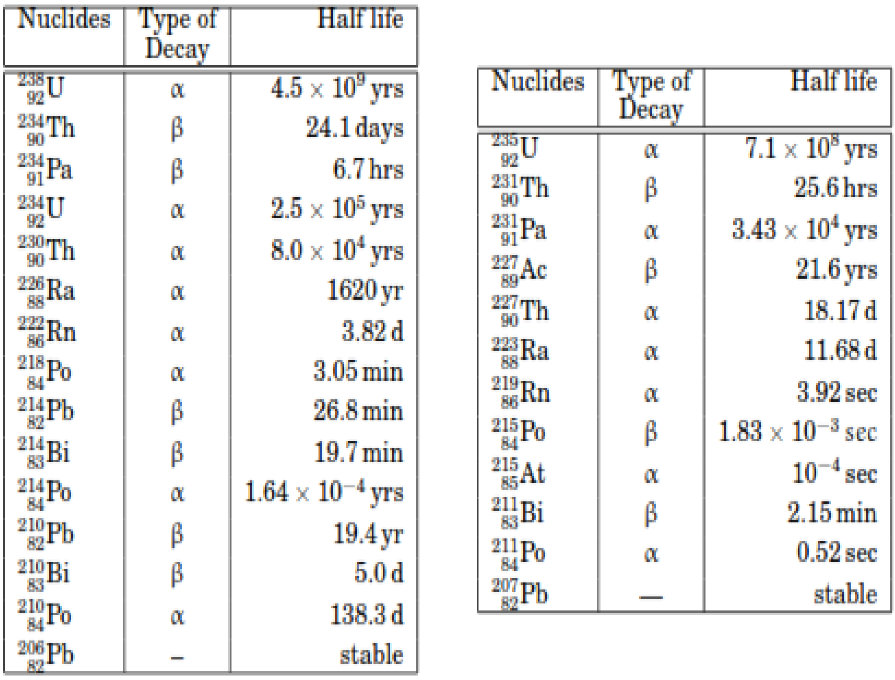
(c) Internal sources: which are the naturally occurring Radionuclides taken into the human body through ingestion of food materials etc. and by inhalation.

Some of these exposures are relatively constant and uniform to all individuals throughout the world. Other exposures vary widely depending on location and due to elevated levels of uranium and thorium in localized areas. All exposures except those from the direct cosmic radiation are produced by radiation coming from natural Radionuclides in the environment.

1.2.1 Successive Radioactive Transformations

In nature there are three long chains, or radioactive series, of radio elements stretching through the last part of the periodic system of elements. These are the Uranium, Actinium and Thorium series. In the Uranium series the mass number of each member can be expressed in the form 4n+2, where n is an integer. Similarly in the Actinium and Thorium series, the mass numbers are given by 4n + 3 and 4n respectively.

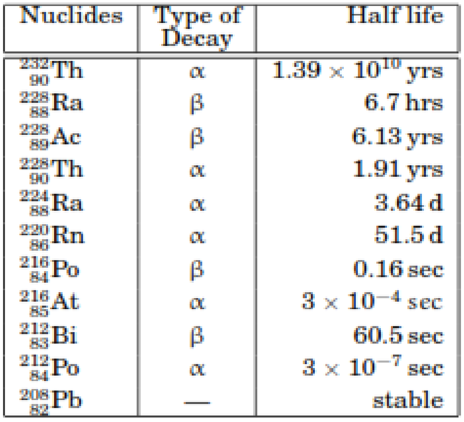
The 4n + 1 series (Neptunium series) is missing in nature because its longest-lived radionuclide ^{237}Np (2.20 × 10^6 yr) has a relatively short half-life compared with the approximate age of the Earth's crust, 5 × 10^9 yr. The Uranium series, Thorium series, Actinium series and the Neptunium series are as given in the following tables.



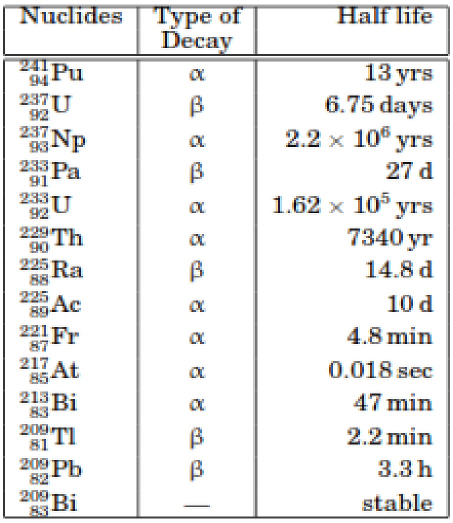
Nuclides	Type of Decay	Half life
$^{238}_{92}$U	α	4.5×10^9 yrs
$^{234}_{90}$Th	β	24.1 days
$^{234}_{91}$Pa	β	6.7 hrs
$^{234}_{92}$U	α	2.5×10^5 yrs
$^{230}_{90}$Th	α	8.0×10^4 yrs
$^{226}_{88}$Ra	α	1620 yr
$^{222}_{86}$Rn	α	3.82 d
$^{218}_{84}$Po	α	3.05 min
$^{214}_{82}$Pb	β	26.8 min
$^{214}_{83}$Bi	β	19.7 min
$^{214}_{84}$Po	α	1.64×10^{-4} yrs
$^{210}_{82}$Pb	β	19.4 yr
$^{210}_{83}$Bi	β	5.0 d
$^{210}_{84}$Po	α	138.3 d
$^{206}_{82}$Pb	–	stable

Nuclides	Type of Decay	Half life
$^{235}_{92}$U	α	7.1×10^8 yrs
$^{231}_{90}$Th	β	25.6 hrs
$^{231}_{91}$Pa	α	3.43×10^4 yrs
$^{227}_{89}$Ac	β	21.6 yrs
$^{227}_{90}$Th	α	18.17 d
$^{223}_{88}$Ra	α	11.68 d
$^{219}_{86}$Rn	α	3.92 sec
$^{215}_{84}$Po	β	1.83×10^{-3} sec
$^{215}_{85}$At	α	10^{-4} sec
$^{211}_{83}$Bi	β	2.15 min
$^{211}_{84}$Po	α	0.52 sec
$^{207}_{82}$Pb	—	stable

Table 1.2: (a) The Uranium Series (4n + 2) (d) the Actinium Series (4n + 3)



Nuclides	Type of Decay	Half life
$^{232}_{90}$Th	α	1.39×10^{10} yrs
$^{228}_{88}$Ra	β	6.7 hrs
$^{228}_{89}$Ac	β	6.13 yrs
$^{228}_{90}$Th	α	1.91 yrs
$^{224}_{88}$Ra	α	3.64 d
$^{220}_{86}$Rn	α	51.5 d
$^{216}_{84}$Po	β	0.16 sec
$^{216}_{85}$At	α	3×10^{-4} sec
$^{212}_{83}$Bi	β	60.5 sec
$^{212}_{84}$Po	α	3×10^{-7} sec
$^{208}_{82}$Pb	—	stable



Nuclides	Type of Decay	Half life
$^{241}_{94}$Pu	α	13 yrs
$^{237}_{92}$U	β	6.75 days
$^{237}_{93}$Np	α	2.2×10^{6} yrs
$^{233}_{91}$Pa	β	27 d
$^{233}_{92}$U	α	1.62×10^{5} yrs
$^{229}_{90}$Th	α	7340 yr
$^{225}_{88}$Ra	β	14.8 d
$^{225}_{89}$Ac	α	10 d
$^{221}_{87}$Fr	α	4.8 min
$^{217}_{85}$At	α	0.018 sec
$^{213}_{83}$Bi	α	47 min
$^{209}_{81}$Tl	β	2.2 min
$^{209}_{82}$Pb	β	3.3 h
$^{209}_{83}$Bi	—	stable

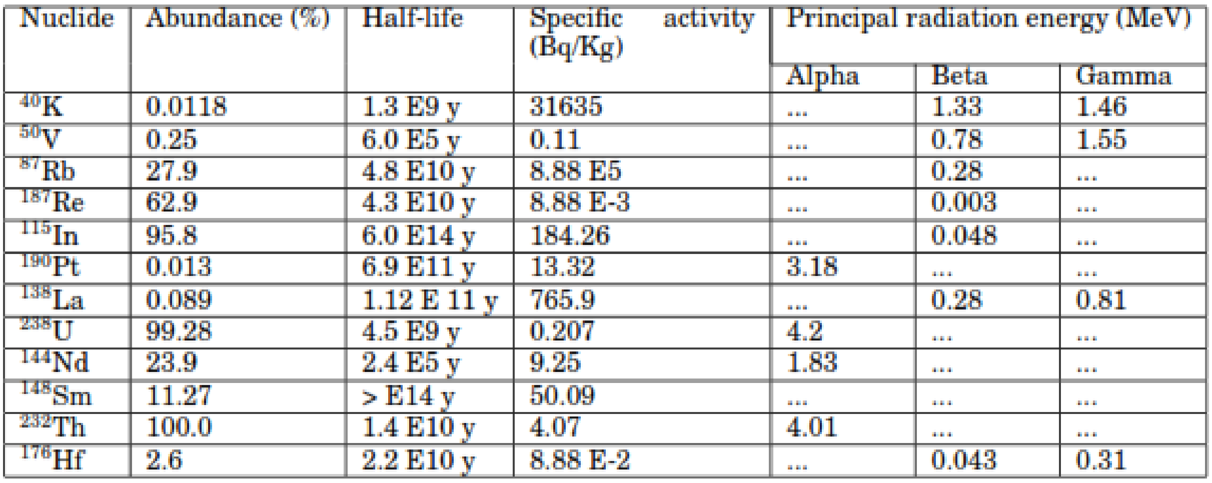
Table 1.2: (c) The Thorium Series (4n) (d) The Neptunium Series (4n + 1)

1.2.2 Primordial Radionuclides

Primordial Radionuclides are isotopes of heavy elements in existence since the origin of the Earth together with their decay products. Main primordial nuclides are singly occurring (like ^{40}K and ^{87}Rb) and the isotopes of the series ^{238}U and ^{232}U.

^{40}K is only 0.0118% of natural potassium but is wide spread, ^{40}K is important in soil, food etc. Although the abundance of ^{87}Rb is significantly higher, its concentration itself is very small (see table 1.3).

Table 1.3: Singly Occurring Primordial Radionuclides



Nuclide	Abundance (%)	Half-life	Specific activity (Bq/Kg)	Principal radiation energy (MeV)		
				Alpha	Beta	Gamma
^{40}K	0.0118	1.3 E9 y	31635	...	1.33	1.46
^{50}V	0.25	6.0 E5 y	0.11	...	0.78	1.55
^{87}Rb	27.9	4.8 E10 y	8.88 E5	...	0.28	...
^{187}Re	62.9	4.3 E10 y	8.88 E-3	...	0.003	...
^{115}In	95.8	6.0 E14 y	184.26	...	0.048	...
^{190}Pt	0.013	6.9 E11 y	13.32	3.18	...	...
^{138}La	0.089	1.12 E 11 y	765.9	...	0.28	0.81
^{238}U	99.28	4.5 E9 y	0.207	4.2	...	...
^{144}Nd	23.9	2.4 E5 y	9.25	1.83	...	...
^{148}Sm	11.27	> E14 y	50.09	...	...	...
^{232}Th	100.0	1.4 E10 y	4.07	4.01	...	...
^{176}Hf	2.6	2.2 E10 y	8.88 E-2	...	0.043	0.31

Concentration of Radionuclides in soil, is largely determined by the activity levels in the source rocks. Igneous rocks are generally found to exhibit higher concentrations than the sedimentary rocks. But, certain sedimentary rocks notably shale and phosphate rocks, are found to have higher activity.

1.2.3 Cosmogenic radioactivity

The radiation penetrating Earth’s atmosphere and originating from space (galaxies and sun) outside the Earth is called cosmic (extra terrestrial) radiation and continually bombarded by high-energy particles. These cosmic rays interact with the nuclei of atmospheric constituents, producing a cascade of interactions and secondary reaction products that contribute to cosmic ray exposures which decrease in intensity with depth in the atmosphere, from aircraft altitudes to ground level. The cosmic ray interactions also produce a number of radioactive nuclei known as cosmogenic radionuclide. Most of the cosmogenic radionuclide are relatively scarce and have in significant contribution to the dose from naturally occurring radioactivity. Some of the cosmogenic radionuclide’s produced by the interactions of cosmic radiation with the atmosphere. Best known of these are exposures to the worldwide population (UNSCEAR, 2008a).

1.3. RADIOACTIVITY OF RADON

1.3.1 Radon decay chain

Throughout the entire Earth, the naturally occurring element uranium is found in at least trace (small) amount. This element is naturally radioactive and with time, the uranium decays into several other elements (called "daughters"), one at a time. Each time a transformation into a new element takes place, the atom is said to undergo decay. During each decays, energy is released from the atom. The released energy is collectively given the term "ionizing radiation" and the atom is said to exhibit "radioactivity". The list of subsequent daughter products is known as the “decay chain.” Along this decay chain, one of the elements that are produced is the naturally occurring material called radon. Radon is unique from the other uranium decay products because it is a gas and as a gas, it is capable of migrating from the location of the original uranium atom into the surrounding soil gas.

CHAPTER 2

Review of Related Literature

2.1. HISTORY OF RADON AS A HEALTH HAZARD

Hazard is defined as the potential to cause harm; therefore, radiological hazard can be defined as the potential of radiation to cause biological effects on human cell, tissue, organ or organ system.

Biological effects of ionizing radiation in humans, due to physical and chemical processes, occur following the passage of radiation through their body. These processes will involve successive changes at the molecular, cellular, tissue and whole organism levels. For acute the whole body exposure above a few gray of radiation of low linear energy transfer as a result of cell killing. This can give rise to organ and tissue damage and, in extreme cases, death. These effects, termed early or deterministic (immediately seen when our body affects; e.g. Skin injury, hair removal, infertility means unproductiveness etc), occur principally above a threshold dose and stochastic (seen within a long period of time; e.g. Cancer and genetic effect) effect has no threshold dose where the effect may or may not occur (UNSCEAR, 2008b).

In the literature there are different data on the histological types of lung cancer induced by radon. Radon is a radioactive gas found naturally in the environment, discovered by Friedrich Ernst Dorn, a German chemist, in 1900 while studying radium’s decay chain. Originally named niton after the Latin word for shining, nitens, radon has been known as radon since 1923.

According to ICRP publication, radiation is a causative agent of cancer in many organs and tissues of the body (ICRP, 1993). Especially National and international scientific organizations have concluded that radon causes lung cancer in humans (EPA, 2000). Through the natural process of radioactive decay, radon transitions spontaneously through a series of elements known as radon decay products. As it does so, it emits alpha radiation that has the potential to do the most damage to human tissue.

When you inhaled/breathe in radon, radioactive particles from radon gas can get trapped (locked) in your lungs. Over time, these radioactive particles increase the risk of lung cancer, the only cancer proven to be associated with inhaling radon. Radiation exposure from radon is indirect means the health hazard from radon does not come primarily from radon itself (Cember, 2009), but rather from the radioactive products formed in the decay of radon. When radon decays, it too produces a "decay chain, with its own daughters. During its decay, it releases a large atomic alpha particle and the atom is changed into polonium. An alpha particle is essentially a helium atom stripped of (divisible to) its electrons and easily stopped by a single piece of paper or layer of clothing. Since the alpha particle is large and easily stopped because of its large mass, it can transfer almost all of its energy (linear energy transfer or LET) to the material which has stopped the particle. It is at this point that the real hazards associated with radon are encountered (come across). It is not the radon which is responsible for the health problems, but rather the short lived radon daughters (SLRDs), (^{218}Po, ^{214}Pb, ^{214}Bi and ^{214}Po) and their decay product (alpha particles). The radon may be thought of only (simply) a source and a vehicle (intermediate) for the SLRDs. Since the radon is airborne (carried by air) its daughters have a high probability of being airborne (carried by air). If the daughters are inside the lung when they decay, the lining (interior coverage) of the lung wall becomes the stopping alpha particles like a paper sheet. Since the alveolar (air sac) cells of the lung wall do not have a significant protective coating, an alpha particle can collide with the live cell, imparting an enormous amount of energy to the cell, possibly disrupting the DNA within the cell. If the body's DNA repair mechanisms fail, the cell may encode (provide) improper genetic information that enables a polypeptide, RNA molecules or one of their constituent groups to be produced or may loss of distinctive cell future (dedifferentiate); this is the interaction which is thought to initiate the cancers associated with the SLRDs.

When a daughter is airborne, it has an electrical charge associated with it and it has a higher probability to adhere (follow) to other airborne particulates and dust. When the daughters adhere to airborne particles, it is said to be attached. An inhaled attached daughter has only about a 3% chance of adhering to the lung lining. An inhaled unattached daughter, on the other hand, has a 50% chance of striking and adhering to the lung wall, increasing the chances of an alpha particle/cell collision. Ironically, where dust levels are high, the risks from elevated radon are lower than in dust free areas with the same radon level.

2.1.1 Early uses of Radon

In the early 1900s, the public showed interest in radium, which was considered at that time as a self-contained source of energy for treating illness successfully (cure). Thereafter and for about three decades, several radium-based medicines and nostrums (medication) made their appearance in pharmacies throughout the world. Radium-rich waters from bathing (spas) and mineral springs were sold as tonics and for their hypothetical curative properties. Chemist Frederick Soddy (1877–1956) proposed in 1905 air bubbling of radium solutions as a method to obtain radon gas, which was suggested as a treatment for tuberculosis. At that time, radon was proposed for several medical uses, as for example, in sufficiently into various body cavities. At spasm (sudden strong feeling lasted for short time), the practices were not limited to bathing and water consumption, but were extended to inhalation of radon collected in a specially enclosed room known as an emanate thorium (Th) or inhale thorium (Th). In 1951, the “Free Enterprise Mine” in Montana U.S. begun operations as the radon exposure was considered beneficial by its founders for the treatment of medical condition affecting a joint or joints, causing pain(disease), swelling (becoming big), and stiffness (arthritis), respiratory disease (asthma), inflammation of the membrane lining (covering) a sinus of the skull (sinusitis), and similar ailments (disease).

Radon has been used in some spas for presumed medical effects. In addition, radon is used to initiate and influence chemical reactions and as a surface label in the study of surface reactions. It has been obtained by pumping the gases off of a solution of a radium salt, sparking the gas mixture to combine the hydrogen and oxygen, removing the water and carbon dioxide by adsorption, and freezing out the radon. Radon decays into radioactive polonium emitter of alpha particles. This emitted radiation made radon useful in cancer treatment (therapy). Radon was used in some hospitals to treat tumors by sealing (closing off or shutting off) the gas in minute tubes, and implanting (inserting) these into the tumor, treating the disease in situ. Other, safer treatments are now more commonly used. Radon concentrations can be used to track air masses to a limited degree. This fact has been put to use by some atmospheric scientists. Because of radon’s rapid loss to air and comparatively rapid decay, radon is used in hydrologic research that studies the interaction between ground water and streams. Any significant concentration of radon in a stream is a good indicator that there are local inputs of ground water. Radon soil concentration has been used in an experimental way to map underground (buried) close subsurface geological faults (mistake) because concentrations are generally higher over the faults. Similarly, it has found some limited use in prospecting for geothermal gradients (temperature change within the Earth). Radon has a half-life of approximately 3.8 days, which means that it can be found only shortly after it has been produced in the radioactive decay chain. For this reason, it has been hypothesized that increases in radon concentration is due to the generation of new cracks underground, which would allow increased ground water circulation, flushing out radon.

An interesting application of knowledge of radioactive elements is made in determining the age of the Earth. One method of determining geologic time is based on the fact that in many uranium and thorium ores, all of which have been decaying since their formation, the alpha particles have been trapped (helium atoms) in the interior of the rock. By accurately determining the relative amounts of helium, uranium, and thorium in the rock, the length of time during which the decay processes have been going on (the age of the rock) can be calculated. Another method is based on the determination of the ratio of uranium-238 to lead-206 or of thorium-232 to lead-208 in the rocks (that is, the ratios of concentration of the initial and final members of the decay series). These and other methods give values for the age of the Earth of between 3 billion and 5 billion years. The generation of new cracks might not unreasonably be assumed to precede major Earthquakes (SEAMIC, 2006).

Radon is a known pollutant emitted from geothermal power stations because it is present in the material pumped from deep underground. It disperses rapidly, and no radiological hazard has been demonstrated in various investigations. Radon was used for industrial radiography, Other X-ray sources, which became available after World War II, quickly replaced radon for this application, as they were lower in cost and had less hazard of alpha radiation. Radon has been produced commercially for use in radiation therapy, but for the most part has been replaced by radionuclide made in accelerators and nuclear reactors. Radon has been used in implantable seeds, made of gold or glass, primarily used to treat cancers. The gold seeds were produced by filling a long tube with radon pumped from a radium source, the tube being then divided into short sections by crimping and cutting. The gold layer keeps the radon within, and filters out the alpha and beta radiations, while allowing the gamma rays to escape (run away). Source now known to have high radon content have been used for therapeutic bathes for many centuries.

2.1.2 Miners problems

The general effects of radon to the human body are caused by its radioactivity and it consequently carries a risk of radiation induced cancer. In the studies of uranium miners, the workers who were exposed to the high levels of radon have shown an increased frequency of chromosomal abnormality in blood lymphocytes (the immune system that produce antibodies to attack infected and cancerous cells).

Many studies have shown a correlation between the frequency of chromosomal abnormalities and a cancer risk. (Pop petal) studied the chromosomal aberrations (abnormalities) as biomarkers of genetic damage in blood lymphocytes of the former East German uranium miners who have been exposed to radon for estimation health risk for lung carcinogenesis (cancer production). The authors found an increase of the frequency of chromosomal aberrations in blood lymphocytes of radon exposed population in comparison with control population. In experiments of Wolf et al. it was demonstrated an increase in chromosomal aberrations in human peripheral lymphocytes after in vitro exposure to 18cGy of radon and its progeny. Increased risk of lung cancer in radon exposed miners with elevated frequency of chromosomal aberrations was demonstrated by Smerhovsky Pop petal.

2.2. RADON SURVEY METHODS

The adverse health effects of radon have been noticed since the fifteenth century. At that time, a German physician named Georgius Agricola (1494–1555), noted high fatality of miners due to lung diseases. Paracelsus (1493–1541) for more than 10 years surveyed the lung diseases occurred in many underground miners in the Erz Mountains of Eastern Europe. His research findings showed that the main reason for the deaths was the present of dust and gases in the mines. Later, the “Erz Mountain lung disease” was identified as lung cancer. Harting and Hess found in 1879 that approximately 75% of uranium miners of Germany and Czechoslovakia died unexpectedly. Later, Margaret Uhlig suggested that another possible cause of lung cancer is radium emanation. Between 1924 and 1932, it was hypothesized that radon exposure caused high rate of lung cancers among miners of Joachimstal in Czechoslovakia and Schneeberg in Germany. Pirchan and Sikl concluded in 1932 that radium emanation causes lung (operations to remove excess fat, skin and tissue from the abdomen) tumors among the miners at Jachymov.

2.2.1 Radon measurement methods

There are different broad categories of radon concentration measuring methods that have been explained hereafter. The choice between these categories will depend on the costs involved, the time over which an instrument can be devoted to measurements at a single location, the kind of information required, and the desired accuracy with which measurements can be related to an estimate of risk.

Grab sampling

Grab samples consist of essentially instantaneous measurements of the radon or radon progeny concentration in air over time intervals that are short (on the order of minutes) compared to the time scale of fluctuations in concentration. The air is collected in a container and brought back to the laboratory for analysis. Typical containers include plastic bags, metal cans and glass containers. The volumes of the containers are usually between 5 liters and 20 liters.

Continuous sampling

Continuous sampling involves the automatic taking of measurements at closely spaced time intervals over a long period of time. The result is a series of measurements which can give information on the pattern with which the concentration varied throughout the measurement interval.

Two-filter methods

For measurement of both radon and radon daughter concentrations, the tow filter method can be used. In this method, air is passed through the first filter where daughter products are removed. Then the air is passed through a long decay chamber, where daughter products are allowed to grow in and are collected on a second filter. The filters can be counted separately to determine the concentration of radon (from the second filter) and daughter products (from the first filter). This method is used for measurement of both grab samples and continuous samples.

Alpha-particle scintillation counting with ZnS (Known as Lucas Cell)

One of earliest methods for measuring concentrations of radon in air is the scintillation cell, which usually is utilized as a grab sample. This cell has been known historically as a Lucas cell. In this technique, the radon gas sample is introduced into a counting cell. The inside wall of the cell is coated with zinc sulfide (ZnS), except one end which is covered with a transparent window for coupling to a photomultiplier tube. When an alpha particle strikes the wall of the cell, a flash of light is emitted from the ZnS coating. The light is detected by the photomultiplier tube and translated into an electrical signal. The efficiency of these cells is typically 70 to 80%. Background rates in typical Lucas cells are low, about 0.1 or 0.2 counts per minute (cpm).

Internal ionization chamber counters

Alpha particles from the decay of radon and its daughters can also be detected in ionization chambers. In these counters, an electrical signal is produced without the intermediary of scintillation counting. Ionization counters can be used either to count electrical pulses from individual decay events or to measure currents resulting from the integrated effect of all decays. In general, ionization chambers are not as widely used as scintillation counters, since ionization chambers are more expensive to construct than Lucas cells and for radon measurements they do not appear to have a major advantage over Lucas cells.

Integrating Sampling

Integrating devices collect information on the total number of radiation events which occur throughout some fairly long period of time, usually on the order of several days to months. The result from integrating devices is an estimate of the approximate average concentration through the environment interval.

Charcoal Canisters (detectors) method

The charcoal canister (CC) method of radon concentration estimation is the most widely used method of screening. Like virtually (almost) all other "radon measurement devices" the CC method does not actually measure radon but rather it measures the gamma radiation associated with the short lived radon daughters (SLRDs). Several assumptions as to relative humidity, equilibration ratio, transient peaks and others are then incorporated in the final analysis.

There are several advantages of using the CC method. They are relatively cheap. The placements of charcoal canisters need no special training. Although the sampling error associated with the CC is very high, the analytical precision associated with the CC is very good. The charcoal canisters are inconspicuous (not clearly seen), which allows for undisturbed sampling; and they are fast; sample periods can be a little as three days and results can be obtained within three or four hours.

There are some disadvantages associated with the CC as well. The uncertainty for attempting to extrapolate the yearly radon concentration from a five to seven day sample is huge: about 90% (at the 90% confidence level). For this reason, a single CC reading (or indeed several) cannot be used to estimate the annual radon exposure in a house. Also, charcoal canisters are susceptible to humidity changes. Often, the analyzing laboratory will assume a standard percent relative humidity and use that in their calculations. The CCs are erroneously thought (based on an incorrect assumption) to integrate the radon concentration over the sample period (usually three to five days), but this is not quite true. The CC will bias the results to reflect the last 10 to 12 hours of sample time. Therefore, if during the last 12 hours of sampling time a rain storm has occurred, or the outside temperature has dropped or the wind was particularly strong, then it is likely that the results will be biased high. If on the other hand, the day was calm, unusually dry and warm the results may be biased low.

Alpha-track monitors

Alpha-track monitors are typically small cylindrical containers (about 5 cm high) which contain a piece of plastic film. The opening to the cylinder is often covered with a dust cover. Filtered alpha-track devices always bias the results high. During the decay of the radon and its SLRDs, the alpha radiation strikes the film and creates microscopic areas of damage which mark the path of the alpha particle. These paths are referred to as "alpha-tracks". After a period of not less than one month (shorter if the radon is particularly high), the film is removed and etched (fixed) with a solvent to enhance the tracks and the tracks are optically counted under a microscope (there are some automated counting devises). The number of alpha tracks is a function of the radon concentration.

The advantages for alpha-track include simplicity, cost and conspicuousity (clearly visibility). They are slightly more expensive than the charcoal canisters. The alpha-tracks are as easy to use as charcoal canisters and are small and unobtrusive (strong). They are not affected by either temperature or humidity. Alpha-tracks can be used for long periods of time, integrating the exposure over that time.

Typically, they are set for a period of three months to one year.

One disadvantage of the alpha-track method is the fact that they are slow. Generally, they should be exposed for periods not less than one month. Also, the analysis is more subjective than that of charcoal canisters. A 50% uncertainty must be applied to a three month alpha-track measurement (at the 90% confidence level) when extrapolating the mean annual concentration.

Some studies have shown that in using the alpha-track principal some materials may be capable of "remembering" their alpha exposure over the course of several decades. One method uses the glass found in windows, picture frames, and even old spectacles from a building's occupant. A long term decay product of radon is lead-210, which in turn decay to polonium 210, the polonium 210 becomes embedded in the glass via recoil processes and can be analyzed using alpha spectroscopy. The method provides an excellent opportunity to evaluate what the historical radon concentration of the building has been.

Continuous Working Level Meters (CWLMs)

In a CWLM, air is drawn through a filter which traps and retains (keeps) the SLRDs but allows the radon to pass. The alpha from the SLRDs is counted in a preselected energy window (typically 2 to 8MeV) over a specified period of time. The counts are automatically converted to WL by means of a calibration factor.

The advantages of the method include the ability to determine the actual extent of the true hazard; i.e. the SLRDs. The method can evaluate the efficacy (usefulness) of mitigation techniques which aim at reducing the SLRDs but do not address radon gas. Sources of radon such as showers (ionized particle caused by cosmic rays), sumps (mineral extract) etc can be determined using CWLM. The results are relatively quick, and are obtained at the site of activity (on-site means without taking the sample in to lab) without need for laboratory analysis allowing for real-time monitoring of SLRDs.

Some of the disadvantages include the high initial cost of the instrument or rental fees. The instruments are not simple black-boxes and require the use of a trained operator and the instruments need to be site calibrated.

2.2.2 Radon study in dwelling

The primary NORMs radio nuclides are uranium, thorium, radium, and radon (Jason,1998). Usually, these naturally occurring radio nuclides are present at only trace level (approximately 10 ppm by mass). However, their presence throughout the environment is responsible for approximately half of the radiation dose (approximately 1mSv/year) to people (Long et al, 2012). Radioactive material containing no significant amounts (the term ‘significant amounts’ would be a regulatory decision) of radio nuclides other than naturally occurring radio nuclides is called NORM (IAEA, 2007). Material in which the activity concentrations of the naturally occurring radio nuclides have been changed by a process is included in naturally occurring radioactive material. On the other hand, the term Technologically Enhanced Naturally Occurring Radioactive Materials (TENORM) is used to describe situations where human activities have increased the potential for exposure to these radio nuclides in comparison to the naturally occurring situation. These activities which can enhance NORM levels directly are the mining, milling (extracting) and processing of uranium ores and mineral sands, fertilizer manufacture and use, phosphate manufacture, burning of fossil fuels, metal ore processing (including tinstone (tin), tantalite, colombite, fergusonite, koppite, asenopyrites, etc) and general underground mining and open-pit (open-hole in the ground) mining activities like tantalum mining (O’Brien and Cooper, 1998). This implies that, in the process of tantalum ore mining at Kenticha tantalum mine can cause the concentration of NORM activity to increase and used to exposure of inhabitants of the area. In addition, the use of buildings material containing NORMs to construct dwellings and work places can also lead to exposure to NORM. Furthermore; the uses of disposed waste materials (e.g. mine tailings, phosphor-gypsum, and fly ash) and is associated NORM concentrations could pose significant radiological problems if use for construction purposes (O’Brien and Cooper, 1998). These activities may bring people into closer contact with ores containing higher concentrations of radioisotopes (radio nuclides) and the processing of ores may concentrate one or more of NORMs into a particular product or waste stream. NORM can also be present in consumer products, including common building products (like brick and cement blocks), granite counter tops, glazed tiles, phosphate fertilizers and tobacco products (CNSC, 2014).

The human activities mentioned above could produce NORM that is associated with at several pathways by which the radioactive material can reach humans. Hence, radioactive sources need to be handled with extreme care. Safety precautions must be taken when using the radioactive source: - it should be

Handled with tongs or forceps, never with bare hands.

Kept at arm's length, pointing away from the body.

Always kept as far as possible from the eyes, hands must be washed after the experiment and definitely before eating.

The pathway largely depends on the processes involved and can be broadly categorized into; onsite, off-site, airborne, waterborne, food products, etc. For on-site pathways, the exposures tend to be direct from internal exposure resulting from Inhalation (virtually all human exposure occurs through the respiratory system), Ingestion (minimal exposure) and Dermal (no significant exposure) of radioactive dust or radon progeny. Due to the presence of NORM in most soils and rocks, underground mining activities can lead to enhanced levels of radioactive dust, and radon isotopes and other radioactive isotopes. These NORMs can reach humans via several pathways, including the food chain, inhalation or ingestion of airborne radioactive dust and the inhalation of radon isotopes and their progeny which reach the atmosphere as a result of the exhalation of radon isotopes from the ground surface or from the surface of building materials (O'Brien and Cooper, 1998).

2.2.3 Radon study in mines

Kenticha Tantalum Mines:- The Kenticha tantalum mine in Ethiopia is considered to be one of the largest world class tantalum producing assets in Eastern Africa The mineral is currently experiencing global (significant increase in amount) boom. This mine is operated by a state-owned company, Ethiopia Mineral Development Share Company (EMDSC) since 1990 in the Adola Greenstone Belt. A deposit in weathered crust was delineated (outlined) in 1988 with proven reserves of 25,850 tons of columbic tantalite ore at 0.02 to 0.03% tantalum (SEAMIC, 2006). The small scale open pit mine has started with a pilot plant producing about 60 tons per year. The deposit is both a weathered crust ore (the top 60 meters) with proven reserve of 2400 tons of tantalum pentaoxide and
2300 tons of niobium pentaoxide and primary ore with proven reserves of 2393 tons Ta_2O_5 and 2362.5 tons Nb_2O_5. At present it is producing over 190 tons of tantalite concentrate of tantalite-colombite ore per annum (MME, 2009). The study is focused on Kenticha tantalum mine, for the following reasons:

Kenticha Ta-Nb ore is known to host a number of elements such as rare Earth elements including K and others (like Li, Be, beryl, sulphides, etc.), Ministry of mine of Ethiopia (MME, 2010).

The bulk of the Oddo Shakiso population is distributed around Kenticha tantalum mine.

According to ERPA report, the radium-226 and its daughter, uranium-238 and its daughter and thorium-232 and its daughters in the tantalum ore, solid waste, tailing dam samples was found with high activity concentration and radiation doses higher than that of the background radiation measured at that site (ERPA, 2013) and this agreed with Ministry of mine of Ethiopia report which said that the uranium content of tantalum concentrate is high (MME, 2014).

Figure 2.1 illustrates the parts of the study area. Kenticha tantalum mine in Southern Ethiopia and the distribution of sampling points also described sampling co-ordinates for ore, soil, solid waste, waste tailings and water samples. Figure 2.1: Map of Kenticha tantalum open-pit (open-hole in the ground) mining site (MME, 2009).

Figure 2.1: Tantalum mine study area.

2.3. RADON HAZARD MITIGATION METHODS

Radon mitigation is any process used to reduce radon gas concentrations in the breathing zones of occupied dwelling (buildings, or radon from water supplies, mine etc).

Mitigation techniques are divided mostly into three groups; those that address:

Reduction of radon gas,

Reduction of SLRDs and

The Pressure Differential, delta P(DP).

The average radon gas reduction, as of 1989, from mitigation techniques is 70%. However, it is more practical to speak of absolute reductions rather than per cent reductions. For example, it is easy to get a 98% reduction when reducing the radon in a building from 500 pCi/l to 10pCi/l but it is extremely difficult to get a 20% reduction when attempting to reduce the radon from 5 pCi/l to 4pCi/l.

2.3.1 Different mitigation method Ventilation

Ventilation as a radon reduction technique usually addresses reduction of the radon gas rather than the DP, because usually when a contractor is referring to ventilation, they are referring to ventilation of a crawl (horizontal access) space, not a living area. When this is the case, the radon contractor usually refers to "isolation and ventilation. The Building Official's Code Agency recommends 1 square foot (865 cm^2) of passive vent per every 150 square feet (14 m^2) of floor space with vents within 6 feet (1.8 m) of each corner.

Passive ventilation of a working or living area

Typically consider inappropriate technique for building in temperate climates because of the difficulty of maintaining comfort zone temperatures during the winter months. An additional problem with passive ventilation is that one does not have good control of the ventilation. A window may be open one minute until someone else feels cold and closes the window.

Additionally, it has been shown that if other than the very lowest level of the building is passively ventilated (say by opening a window) then winds blowing through the building can create a venture effect and actually increase the radon concentration. As discussed earlier, there is no correlation between air changes per hour and radon concentration, but there is a strong correlation between DP and radon concentration.

Passive ventilation of some heating cellars where the pipes are insulated and the room contains a storage tank (sump) may be a viable option. Ventilation systems designed for radon reduction are often fitted with heat recovery devices to help reduce the loss of heated air to the outside.

Passive ventilation is obviously cheap and easy but it has met with rather checkered results. It is most appropriate for small buildings with very low levels of radon.

Active ventilation

On the other hand; is usually in the form of heat, ventilation and air conditioning (HVAC) systems and are not specifically designed as radon reduction systems. Nevertheless, because the HVAC systems are designed to maintain the building at slightly positive pressure, they address the DP issue. By maintaining a slight positive pressure, HVAC systems overcome the negative pressures of the stack effect and prevent radon from entering a building. The system should be capable of maintaining a positive pressure of at least 0.02 inches of water column (5 Pa) above the pressure in the environment or surrounding area (ambient pressure).

Filtration Devices

Filtration device addresses (deals with) the SLRDs without addressing the radon problem or the DP problem. Filtration devices circulate the room air through a filter which scrubs out the SLRDs. On the surface, this type of technique appears to be an excellent solution; however, the filters will also remove the airborne particulates (ultrafine particles, dust, pollen, etc.). Thus increasing the ratio of unattached daughters and actually increasing the bronchial radiological dose. As mentioned earlier, the unattached daughters have a much higher probability of adhering (attaching) to the lining of the lung wall. Therefore, the sole use of filtration devices is not considered to be an appropriate mitigation technique.

Air Movement Device: Ceiling Fans

This type of a system addresses (deals with) neither the DP problem nor the radon entry problem, but rather the SLRDs themselves. Unlike a filtration device, a ceiling fan does not remove the desirable airborne particulates but rather encourages the plate-out of the SLRDs. Since this types of technique can be installed by the homeowner (as a rather attractive addition to a living room or dining room), radon contractors do not have an incentive to disclose this technique to the general public.

Remarkably good reductions (as high as 95%) of SLRDs have been achieved by simply placing a "Casablanca" type ceiling fan in a room. The fan should be capable of complete air movement within the room. Where the desired reduction is on the order of 50%, the ceiling fan alone can correct most of the problems. Where a reduction of 80% or better is needed, the ceiling fan in conjunction with a positive-ion generator may correct the problem. The ceiling fan/positive-ion generator combination has been tested in the U.S., Denmark, Finland and Canada with similarly excellent results. The reduction in SLRDs has been consistently as high as 95% and where bronchial doses have been measured, the reduction in bronchial dose has been as high as 87%.

The positive ion generator

Should not be confused with an electrostatic precipitator (ESP), Using an ESP could result in the removal of airborne particulates and an increase in unattached daughters. Also, negative ion generators have been shown to be less effective than the positive ion generators. While the fan speed is not critical, the fan should be placed in the center of the room and be large enough to effectively move the air in the room.

A disadvantage to this type of reduction technique is that post-mitigation monitoring would have to involve a continuous working level monitor, instead of the charcoal canisters. Another disadvantage to this technique is that it can be readily turned off if not properly installed. The fan and the positive ion generator should be wired such that it cannot be deactivated by unauthorized personnel. The system should be labeled as a "radon reduction" system and allowed to run continuously.

Sealing Floor and Foundation Wall Cracks

Since some 90% of the radon comes from sub-slab infiltration, one of the earliest mitigation techniques involved simply sealing floor and foundation wall cracks to prevent entry. The advantages of this method are its relative ease and low cost.

The disadvantages of the technique include its poor record of success, its limitation to only unfinished basements and the fact that it does not address DP or SLRDs. It has been shown that where high levels of radon are present, sealing alone is a very poor mitigation technique. However, sealing of floor and foundation wall cracks is often a necessary supplement to sub-slab depressurization (this will be discussed below). When such sealing is required, the crack needs to be properly routed out first and then sealed back in with an appropriate material, such as backer-rod and foam. Where high levels of radon are present, this technique is not recommended as a sole corrective action.

Positive Pressure

When a building is constructed, pressure differentials between the interior of the building and the exterior of the building are inadvertently created, especially when there is a significant temperature difference between the interior of the building and the outdoors. This pressure differential, delta P (DP) is mostly due to a phenomenon known as the Stack Effect. The building mimics an exhaust stack and is under negative pressure with regard to the surrounding environment including the atmosphere and the soil gas below the slab. Typically, the DP is greater toward the bottom portion of the building and is equalized near the top of the building.

To satisfy the negative pressure in the building, the net air movement toward the bottom of the building is from the outside of the building to the inside of the building. In some mitigation cases, the technique was to positively pressurize the basement. This technique has a poor record of success because it involves upsetting the normal use of the basement. It has a potential ability to blow out pilot lights and can be noisy. It is no longer generally considered to be an acceptable mitigation technique.

Sub-slab Depressurization (SSD)

Approximately 90% of the reduction techniques used in the U.S. today is SSD. The idea of SSD is to address the driving force of the radon entry; the DP between the sheet of rock (slab) and soil gas. Instead of increasing the pressures within the building, SSD reduces the soil gas pressure below the slab. This **author has** measured in-house/sub-slab pressure differentials of as high as 89 Pa. The SSD technique involves penetrating the slab with a 7 cm to 20 cm inside diameter of pressure ventilating conditioning (PVC) pipe and running the pipe up through the structure and exhausting to above the roof line. A centrifugal fan capable of developing high static pressure is mounted at the exhaust (outside the shell of the structure) to depressurize the slab. The fan should be capable of maintaining a pressure of at least 5 Pa below the highest DP recorded or expected. In some cases, a passive turbine has been used with encouraging results. The driving force for the depressurization is the stack effect and a wind driven turbine at the exhaust.

SSD has a proven track record of achieving 80% to 90% reduction in radon gas levels in favorable structures. SSD works best when the soil type is sand or a loam. Additionally, the slab should be in good condition; slab cracks and expansion joints will limit the extent of the pressure field. If the slab is damaged or the soil has high clay content, then SSD can still be used by inserting more and more collection pipes in the slab to extend the pressure field. Prior to SSD, soil communication tests should be performed. Pilot holes are drilled into the slab and a vacuum cleaner is used to create a negative pressure field below grade. The DP is measured at each of the pilot holes. If the DP at each of the holes is acceptable (5 Pa or greater) then only one hole is needed. If the DP at any one of the pilot holes is less than 5 Pa, then that hole should be enlarged and incorporated as a collection point. Typically, one collection point is needed for every 65 m^2.

SSD works well for recessed floating slabs, slab-on-grade and floating slab-on-grade structures.

One of the disadvantages of the SSD type systems is the cost. The initial cost of the installation is higher than most other techniques. The operating costs and the maintenance costs are also higher. The system can become noisy, prompting complaints from the building occupants and even prompting the occupants to deactivate the system.

CHAPTER 3

Radon Dosimetery

Dosimetery is defined as the measurement of the amount, type, rate, and distribution of radiation emitted from a source of ionizing radiation and the calculation of both spatial (relating to space) and temporal (time based) patterns of energy deposition in any material of interest as a result of ionizing radiation.

Radon is radioactive; therefore, a radiation dose is associated with radon exposure. Radon concentration and radon dose are two terms that are widely in use for routine communication to the public regarding radon and its health risk.

Radiation dose due to Radon and progeny depends on factors like

Concentration:- Concentration of radon gas and progeny in air is the major factor that determines radiation dose from radon progeny. The measurement of concentration of ^{222}Rn is, however, adequate (suitable) only for estimating upper limits of exposure.

Particle size distribution:- Radon is an inert gas, but its decay product is solid and behaves as an airborne particle. The behavior is easily influenced by circumstances. Initially, the decay product is free atom in the air. But it is so small that it easily attach to aerosol particles. The attaching fraction depends strongly on the size and concentration of carrier aerosol particles. The smaller mode, ranging from 0.5 to 3 nm, is commonly referred to as the "unattached" fraction of the decay products, while the larger mode, from 50 to 300 nm, consists of decay products attached to aerosol particles. They are called "attached fraction". It is well known that dose conversion factor (DCF) from concentration to effective dose strongly depends on the particle size of radon decay products. Thus the size information is very important for evaluation of exposure dose (Yamada, 2009).

Respiratory deposition:- Respiratory deposition is the process that determines what fraction of the inhaled particles is caught in the respiratory tract and, thus, fails to exit with exhaled air. It is likely that all particles that touch a wet surface are deposited; thus, the site of contact is the site of initial deposition. Distinct physical mechanisms operate on inspired particles to move them toward respiratory tract surfaces. Major mechanisms are inertial forces, gravitational sedimentation, Brownian diffusion, interception, and electrostatic forces. The extent to which each mechanism contributes to the deposition of a specific particle depends on the particle's physical characteristics; the subject's breathing pattern, and the geometry of the respiratory tract. Therefore respiratory deposition is one of the factors in the calculation of dose from exposure to radon and progeny.

Lung Clearance:- is a natural mechanism of getting rid off foreign matter from respiratory tract.

Other important parameters affecting radiation dose, from radon and progeny, are the morphometery of lungs and the breathing characteristics.

3.1. QUANTITIES AND UNIT RELATED TO RADON

In order to determine the effects of the radiations from radon and its decay products, exposure and dose are defined as follows (Wilkening, 1990):

Potential Alpha Energy Concentration (PAEC)

The Potential Alpha Energy Concentration (PAEC) is the concentration of radon daughter products, in air, in terms of the alpha energy that will be released during complete decay through ^{214}Po.

Equilibrium Equivalent Concentration (EEC)

The Equilibrium Equivalent Concentration (EEC) is calculated from the radon concentration in equilibrium with its short-lived daughters that has the same potential alpha energy per unit volume as exists in a sample mixture. Basically it amounts to 5.57×10^{-8} J/Bq for ^{222}Rn and 7.56×10^{-8} J/Bq for ^{220}Rn.

Working Level

The Working Level (WL) is any combination of short-lived Rn daughter products in one liter of air that will result in the emission of 1.3×10^{5} MeV of potential α-energy.

Table 3.1 shows quantities and units related to radon dosimetery. It is helpful in making the transition from radon activity and concentration to exposure and dose.

Quantity	SI Units	Equivalents
Strength of activity	Becquerel (Bq)	1 pCi = 0.037 Bq
Radon concentration	Bq/m3	1 pCi l`$^{-1}$
Equilibrium Equivalent Concentration	EEC 222 EEC 220	1 WL = 3,740 Bq m^{-3} 1 WL = 276 Bq m^{-3}
Absorbed dose	Gy	1 Gy = 100 rad
Dose equivalent	Sv	1 J kg^{-1}=100 rem
Working level	WL	1 WL=1.3 × 10^{5} MeV`$^{-1}$
Working level monthes	WLM	1 WLM = WLh/170
Potential Alpha Energy Concentration	PAEC	1 PAEC = 1J m^{-3}

Table 3.1: Radiation quantities and units from (James, 1988)

Characteristic energies for the alpha particles from ^{222}Rn and its short-lived decay products is 6.17 MeV (^{222}Rn, ^{218}Po and ^{214}Po). The corresponding range in air for an alpha particle of this energy is about 5 cm, in living tissue it would be only about 0.05 mm. The beta particles (electrons) have characteristic end point (maximum) energy of about 1.1 MeV. Those with this energy could penetrate about 1.5 mm in tissue. The beta particle of average (not maximum) energy would have a much shorter range. The gamma rays from ^{212}Bi with a mean energy of about 1 MeV would not be absorbed to any appreciable extent in the local tissue.

It is the alpha particles that can be expected to expend their energy in the sensitive surface tissue in the bronchial epithelium or lung. The beta and gamma rays play only a very minor role.

3.2. RADON DOSE TO HUMANS

Radon and its decay products in both “attached” and “unattached” forms are delivered to sensitive tissue in the human respiratory system. An adult not engaged in more than light activity can be expected to breathe at a rate of about 0.75 m^{3} /min. typical aerosol concentrations indoors or outdoors are of the order of 10^{10} per cubic meter with radii centered around 0.5×10^{-5} m. Indoor air can be expected to contain some 50 Bq m^{-3} of radon. Hence, some 40 Bq of radon are taken into the lungs per minute with perhaps about 3% of the daughter-product dose on the unattached fraction made up of ions and molecular clusters of very small size.

After entering the upper respiratory system, the aerosol particles with the radon decay products attached find their way to the bronchial tissue in the lungs. Typically the surface wall of the bronchi leading to the lungs is where most damage by radiation from the decay product alpha particles occur. The mucous layer on the surface of the bronchial tubes is not heavy enough to absorb alpha particles which can damage the basal cells underneath.

It is clear that lung dose models must take into account a complex combination of factors including the activities of the short-lived daughters of ^{222}Rn as a fraction of their equilibrium activities in the decay chain, the half-lives of these daughters, deposition probabilities for attached and unattached activities, fraction of the activities deposited in the trachea-bronchial region, and allowance for natural clearance of aerosols from the surface tissues.

3.2.1 Radon Dose Assessment Methods

Radon dose assessments can be divided in to two main categories: the dose from epidemiological assessment and dose from physical dosimetery (Chen, 2005).

Radon Dose from Epidemiological Assessments

Epidemiological approach is the scientific and medical study of the causes and transmission of disease within a population. The ICRP has not provided values of the doses per unit intake for radon and its decay products from application of the respiratory tract model. Because lung cancer has been observed and studied extensively (widely) in miners exposed to ^{222}Rn, the ICRP has adopted a conversion convention for radon exposures that is based on equality of detriments from epidemiological determinations. A conversion from radon exposure to effective dose was obtained by a direct comparison of the detriment (damages) associated with a unit effective dose and a unit radon exposure (ICRP, 1993b). The detriment per unit effective dose is

$$7.3 \times 10^{-5}/\mathrm{mSv} \qquad (3.1)$$

for the general public based mainly on studies of A-bomb survivors. The detriment per unit exposure to radon progeny is

$$8.0 \times 10^{-5}/\mathrm{mJhm^{-3}mSv} \qquad (3.2)$$

$$=0.282\,\mathrm{WLM} \qquad (3.3)$$

where WLM is the exposure unit of Working Level Month commonly used in workplaces.

The ICRP conversion from radon exposure to effective dose has nothing to do with any dosimetric parameters and does not rely on tissue or radiation weighting factors. This is not a dose in the sense of dosimetery. It is solely based on equality of detriments resulting from two totally different exposure scenarios.

Assuming 7000 hours per year indoor (an occupancy factor of 80%) and an equilibrium factor of 0.4, then 1 Bq/m^3 is equivalent to 1.56×10^{-2} mJ hm^{-3}. Based on the ICRP radon dose conversion, exposure to radon at 100 Bq/mm^{-3} will be equivalent to an annual effective dose of 1.72 mSv.

Radon Dose from Physical Dosimetery

Many publications have dealt with radon dose to the lung determined from physical dosimetery (Porstendörfer & Mercer, 1978). There are absorbed dose, equivalent dose and effective dose. Typically, estimates of absorbed dose to the critical cells of the respiratory tract per unit of radon exposure are derived from the analysis of information on aerosol size distribution, unattached fraction, breathing rate, fractional deposition in the airways, mucous clearance rate, and location of the target cells in the airways. Such estimates are strongly model-dependent and subject to many uncertainties associated with the input data as well as the assumptions built into particular computing models. Literature values of absorbed doses to lung vary from 5 to 71 nGy per (Bq h m^3) (UNSCEAR, 2000a). The central value is estimated to be 9 nGy per (Bq h m^3).

Again assuming 7000 hours per year indoor (an occupancy factor of 80%) and an equilibrium factor of 0.4 as used in ICRP publications, the annual absorbed dose to lung at a radon concentration of 100 Bq/m^3 will be 2.5 mGy.

The equivalent dose is the radiation-weighted absorbed dose. The radiation weighting factor for alpha particles is 20 as recommended by ICRP (ICRP, 2012). Applying the weighting factor of 20, the annual equivalent dose to lung at a radon concentration of 100 Bq/m^3 will then be 50 mSv. When concerned with effective dose, one has to apply a tissue weighting factor in addition to the radiation weighting factor. According to ICRP (ICRP, 2012), the tissue weighting factor for lung is 0.12; the radiation weighting factor for alpha particles is 20. With these two weighting factors, the absorbed dose of 2.5 mGy to lung for one year exposure at 100 Bq/m3 becomes an annual effective dose of 6 mSv. In terms of effective dose, for one year of radon exposure at 100 Bq/m^3, the estimate from a dosimetric approach is 6 mSv, while the estimate from an epidemiological approach is 1.7 mSv. The dosimetric estimate is thus about 3.5 times higher than the epidemiological estimate.

3.2.2. UNSCER's Radon Effective Dose Conversion

In the literature, there are discussions on the discrepancy (difference) between dosimetric and epidemiological effective doses for radon exposure (Stabher, 2004; Birchall & Marsh, 2005). UNSCEAR, in its last report UNSCEAR 2000, noted the difference in radon doses and recommended a radon effective dose conversion factor of 9 nSv per (Bq h m^{-3}). Note that this is a conversion factor for an effective dose, not for the dose to lung. This conversion factor lies between dosimetric and epidemiological dose conversions and is somewhat closer to the dose conversion from epidemiological assessments.

Assuming 7000 hours per year indoor (an occupancy factor of 80%) and an equilibrium factor of 0.4, using UNSCEAR recommendation of 9 nSv per (Bq h m^{-3}), the effective dose for one-year radon exposure at 100 Bqm^{-3} is 2.5 Sv.

3.3. LUNG MODEL

The human lung is a complex respiratory organ, the major purposes of which are to bring life-giving oxygen into the body and to rid (release) the body of toxic carbon dioxide wastes. Although the lung is complex, closely regulated, and interconnected with the nervous and circulatory systems, it's basic functioning, and the respiratory system as a whole, can be represented by a model.

The respiratory system starts from the nasal passages, where air enters; filtered and warmed. A series of passageways lead to the tiny air sacs in the lungs called alveoli, which have very thin walls and are richly supplied with blood. The transfer of gases (oxygen into the blood and carbon dioxide out of the blood) occurs by simple diffusion.

Air is pumped in and out of the system in response to the movement of muscles in the chest cavity, which are controlled by the brain in response to prevailing blood conditions, especially the concentration of carbon dioxide dissolved in the blood. Inside the air passageways (trachea, bronchi, bronchioles) epithelial cells line and protect the airways, secreting mucus to help trap (catch) foreign substances, which are removed by the beating of tiny hairs called cilia.

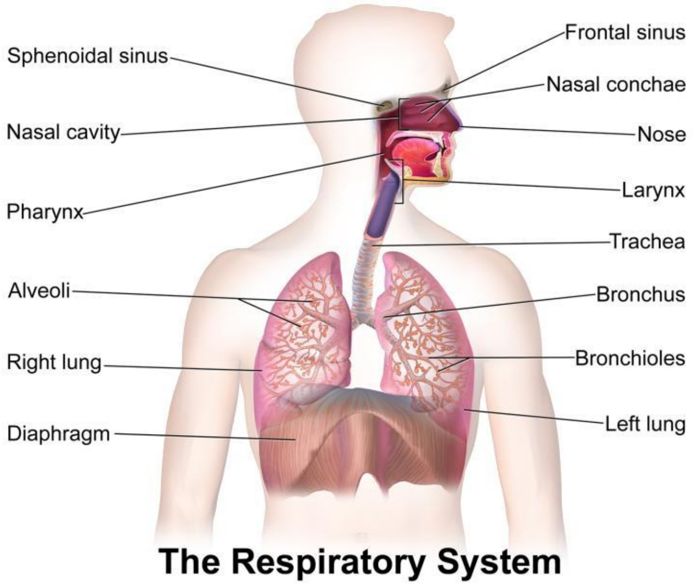


Figure 3.1: The human respiratory system

As can be seen in figure 3.1, humans have two lungs, a right lung and a left lung. They are situated within the thoracic cavity of the chest. The right lung is bigger than the left, which shares space in the chest with the heart. The lungs together weigh approximately 1.3 kilograms and the right is heavier. The lungs are part of the lower respiratory tract that begins at the trachea and branches into the bronchi and bronchioles, and which receive air breathed in via the conducting zone. The conducting zone ends at the terminal bronchioles. These divide into the respiratory bronchioles of the respiratory zone which divide into alveolar ducts that give rise to the microscopic alveoli, where gas exchange takes place. Together, the lungs contain approximately 300 to 500 million alveoli.

Each lung is enclosed within a pleural sac which allows the inner and outer walls to slide over each other while breathing takes place, without much friction. This sac also divides each lung into sections called lobes. The right lung has three lobes and the left has two. The lobes are further divided into bronchi pulmonary segments and lobules. The lungs have a unique blood supply, receiving deoxygenated blood from the heart in the pulmonary circulation for the purposes of receiving oxygen and releasing carbon dioxide, and a separate supply of oxygenated blood to the tissue of the lungs, in the bronchial circulation.

As in the case of the outer body, the protection of the respiratory system cannot be provided by the skin. Protection against foreign substances, entering the system during the exchange of gases between the outside world and the inside of the body, is be provided by a clearance system like the mucus and ciliary action provided by the epithelial cells. For most particulate matter, this protective system is perfectly adequate (sufficient). In the case of some cancer producing substances, such as cigarette smoke and radon, the protective system is not able to prevent harm to the tissue.

The tissue of the lungs can be affected by a number of diseases, such as lung cancer and pneumonia (is an inflammatory condition of the lung affecting primarily the small air sacs known as alveoli. Typically symptoms include some combination of productive or dry cough, chest pain, fever, and trouble breathing. Pneumonia is usually caused by infection with viruses or bacteria).

Lung cancer, also known as lung carcinoma, is a malignant (harmful) lung tumor characterized by uncontrolled cell growth in tissues of the lung. This growth can spread beyond the lung by the process of metastasis (transfers) into nearby tissue or other parts of the body. Most cancers that start in the lung, known as primary lung cancers, are carcinomas. The two main types are small-cell lung carcinoma (SCLC) and non-small-cell lung carcinoma (NSCLC). The most common symptoms are coughing (including coughing up blood), weight loss, shortness of breath, and chest pains. Lung cancer usually caused by breathing radon gas progeny.

Therefore, the process of measuring the external shape and dimensions of living organisms (Morphometry) model of conducting airways (paths of air from nose or mouth to lung) have been developed based on measurements made by using airway corrosion casts or vivo bronchoscope (an instrument for examining airway) or radiographic measurements. These measurements have included airway diameters, segment lengths and branching angles. From these, the interior of membrane-bound compartment or organelle in a cell (luminal) surface areas and volumes can be calculated. The earliest models of the respiratory airways were made assuming symmetry of size and length for airways of a given generation (Findeisen, 1935; Landahl, 1950; Davies, 1961). These models have been summarized by Raabe (1982).

More recent morphometery models have been based on sets of data obtained primarily from measurements of conducting airway dimensions by using corrosion cast techniques (Weibel, 1963; Horsfield et al., 1971; Yeh and Schum, 1980; Phalen et al., 1985). Weibel (1963) used a plastic airway cast prepared by Liebow and measured the lengths, diameters, and branching angles completely for the first 5 airway generations and incompletely through 10 airway generations. Sampling frequencies decreased gradually from 91 to 95% for generations 6 to 18 to 21% for generation 10. The results confirmed earlier views that the conducting airway system has a characteristic irregular dichotomous branching.

For a given generation, there was a dispersion of both airway diameters and airway lengths, with a greater variability being seen in the lengths of the airway segments. The above measurements were then combined with data collected from the more peripheral regions of the lung by quantitative morphometery of histological prepared sections. These measurements were used to construct two morphometery models of the human lung: the first (Weibel lung model A), which emphasized the regular features of the airways and their patterns, and the second (Weibel lung model B), which attempted to take into account the irregularities encountered in the measurements (Weibel, 1963). The Weibel morphometery models, particularly Weibel lung model A, have been incorporated into deposition and dosimetery models by many investigators. Horsfield et al. (1971) described a morphometery model based on data obtained from measurement of a resin cast of a normal human bronchial tree (Horsfield and Cumming, 1968; Parker et al., 1971). Their measurements, which included airway diameters, segment lengths, and branching patterns, indicated that asymmetric branching was needed to produce a more realistic model of the airway structure. Thus, they developed two models that included asymmetric branching, unequal numbers of airways in different lung lobes, and variations in the airway segment lengths (Hors field et al., 1971). Of note was their determination that the mean diameter of the smallest of a pair of daughter bronchi was similar to that of a larger bronchial branch occurring four generations away from the point of original.

CHAPTER 4

Conclusions and Recommendation

4.1. CONCLUSIONS

The effects of radon and its short-lived decay products spread slowly but surely through a wide range of biological problems encountered in such areas as the mortality rates and lung cancer in uranium mines, the results of experimental work with animals, and the discovery of unusually high levels of radon in the living environments of the general population.

The increased concern on the part of scientists' and governments around the world has been reflected in international meetings such as those sponsored by the Commission of the European Communities, the United States Department of Energy and other agencies beginning with the first one on the Natural Radiation Environment in Houston in 1963, and followed by other meetings in 1972, and in 1978

Additional ones were held in Brazil (1975), Bombay (1981), Anacapri (1983), Maastricht (1985), and Lisbon (1987).

A number of books on radon have been published including (James, 1988; Wilkening, 1990; Jason, 1998; Cember, 2009; Faanu A., 2010; Todsadol, 2012). The Proceedings of the 24th Annual Meeting of the National Council on Radiation Protection and Measurements entitled Radon (1989) is edited by N. Harley and gives much information on recent studies.

In general, Radon gas and SLRDs reaches human body via inhalation with air or ingestions with foods and waters. Both Radon gas and SLRDs releases alpha particle to a sensitive living respiratory organ and results health hazards particularly lung cancer related to radon gas inhalation or ingestion. Based on health hazards of radon many literatures have been written, many researchers have been done and number of books are published on the world.

4.2. RECOMMENDATION

In our country efforts are recently started to survey radon in areas around universities (Alemayehu, 2006; Berhan, 2007; Abyot, 2008). These efforts should be extended and to mines, spas and health resorts as well as to the lowland areas of the country.

It is also imperative (essential) to diversify the methods as well as the area covered by the studies of radon.

APPENDIX A

Abbreviations Used

Ac- Actinium

At- Astatine

Bi- Bismuth

Bq- Becquerel

Bq/m^3-Becquerel Per Cubic Meter

CC-Charcoal Canisters

cGy - Centigray

Cm – Centimeter

Cm^2 – Square Centimeter

d- Day

DNA- De-Oxy Ribose Nucleic Acid

Dp- Pressure Differential, Delta P

EPA- Ethiopian Protection Authority

EMDSC-Ethiopian Minerals Developing Share Company

ERPA- Ethiopian Radiation Protection Authority

Fr- Francium

Gy- Grey

Hf-Hafnium

hr – Hours

HVAC-Heat, Ventilation and Conditioning

IAEA-International Atomic Energy Agency

ICRP- International Commission Radiological Protection

In- Indium

K- Potassium

L- Liter

La – Lanthanum

l/min- liter per minute

LET- Linear Energy Transfer

M- Meter

M^2 – Square Meter

M^3– Cubic Meter

M^{-3}– Per Cubic Meter

Mev- Mega-Electron Volt

mm – Millimeter

MME- Ministry of Minerals of Ethiopia

min –Minutes

nSv- Nano Sievert

Nb- Niobium

Nb_2O_5- Niobium oxide

NORMs-Naturally Occurring Radioactive Materials

Np- Neptunium

Pa- Protactinium

PAEC- Potential Alpha Energy Concentration

Pb- Lead

Pci – Pico Curie

Pci/L – Pico Curie Per Litter

Po- Polonium

Pt – Platinum

PVC- Pressure Ventilating Conditioning

Ra- Radium

rad- Radioactive Dose

Rb- Rubidium

Rn-Radon

SEAMIC-South and Eastern African Mineral Center

sec – Second

SI- System of International

Sm- Samarium

SLRDs- Short Lived Radon Daughters

SSD-Sub-Slab Depressurization

Sv- Sievert

Ta_2O_5- Tailem oxide

TENORMS- Technological Enhanced Norms

Th- Thorium

Tl–Tantalum

U-Uranium

USA-United-State of America

UNSCEAR- United Nations Scientific Committee on the Effects of Atomic Radiation

WL – Working Level

WLM – Working Level month

V- Vanadium

y – Years

Zns-Zinc Sulfide

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DECLARATION

ADDIS ABABA UNIVERSITY
COLLEGE OF NATURAL AND COMPUTATIONAL SCIENCES
DEPARTMENT OF PHYSICS

MSc PROJECT

HEALTH HAZARDS OF RADON

Name of Candidate: **Seid Aman Ahmed**

I the under signed declare that the project is my original work and no part of it can be claimed as an intellectual property of anybody else except me and my advisors.

Signature: ________________________