# Review of Radon Studies: Health Perspectives

By

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A PROJECT PRESENTED TO

THE SCHOOL OF GRADUATE STUDIES
ADDIS ABABA UNIVERSITY

IN PARTIAL FULFILLMENT OF THE REQUIREMENTS
FOR THE DEGREE

MASTER OF SCIENCE in PHYSICS

ADDIS ABABA, ETHIOPIA

JUNE 2010

Addis Ababa University

School of Graduate Studies

## Review of Radon Studies: Health Perspectives

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Dated: June 2010

**This Work is Dedicated to**

**My Father & Mother**

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# Acknowledgments

Some grateful acknowlegdments are certainly stated in the following manner for those who assist my graduate study in different aspects.

Above all, my innocent heavenly father the God for his graceful help to cope with my challenges. My adviser, Dr.Tilahun Tesfaye have offered me valuable guide, advise, comments, as well as encouragement and technical help in computer usage (Latex) in writing my project. For my graduate instructors. My spouse, Mesay Asefa for taking the challenging responsibility of our family and for coping with the challenges. Asefa Yimer for his financial aid and a remarkable continuous encouragement. Ato Asrate Negash and his spouse Tina Yimer (specially considerable), Deresse Tadesse and his spouse Emebet Bogale, Mekonnen Desta and his spouse Addis Deresse, Adanech Asefa, Fikade Dejene and Momina Gebe and her sister shega for their heartfelt helping of my family. Hailu Kabtihyimer for his repeated visiting and encouragement. Mekuriya Dagne and Gebeyehu Eshete for receiving my monthly salary on behalf of me at different times. Dersem Gutela for sending my monthly salary through the bank. Finally, the oromiya education bureau and the Arsi Negelle woreda education bureau who are sponsored my graduate study. And the Arsi Negelle high and Kilturee Preparatory schools for their help in different aspects.

Addis Ababa University Tafesse Kabtihyimer

June, 2010

# Abstract

Since 2005 WHO played the initiative role to increase the interest of radon studies in many countries around the world. Specially, in the the 30 member countries of the Organization for Economic Co-operation and Development (OECD). The current radon studies around the world show that the interest of radon study also increased in other countries of the world including the countries of our continent Africa.
In order to reduce the worldwide health impact of the radioactive radon gas, a new project the WHO International Radon Project (IRP) was formed in 2005. More than 100 scientists from 30 countries had participated in this project. In this project a new technologically improved and invented radon detecting and measuring devices were implemented. WHO now suggests that homeowners take action when radon levels exceed 2.7 pCi/l. This is a much more conservative figure than the Environmental Protection Agency (EPA's) action level of 4.0 pCi/l, which has been the U.S. standard for over 20-years. The United Nations also broke new ground in the international fight on radon-induced lung cancer earlier in 2009 when they released their acknowledgement of the radon problems throughout the world. Now, there is no doubt about the health hazards due to radon. That is why many countries around the world started to take measures.

# INTRODUCTION

Radon was suspected as a health hazard, for the first time, due to high incidence of lung cancer among miners. Miners in Schneeberg in German and Jachymov in Czechoslovakia, were suffering from respiratory disease more than the general population farther back in the $16^{th}$ century. Initially it was believed that ore dust was the reason for the high incidence of lung cancer. In 1879, autopsy findings that documented pulmonary malignancy in miners in Joachimstal was described.

By early in the 20th century the malignancy was shown to be primary carcinoma of the lung. The finding of high levels of radon mines in these regions, where miners also had high lung cancer rates, led to the hypothesis that radon was the cause of the lung cancer. So that Initially, investigations focused on underground miners exposed to high concentration of radon in their occupation environment.

Radon was also found to be present in indoor air since 1950s. This have been investigated for several decades. Now, it is confirmed that, the most notable health effects of occupational as well as residential radon is lung cancer.According to recent studies conducted throughout the world, radon is identified as the leading cause of lung cancer for non-smokers.

Today, there is also a technological improvement and invention of radon measuring, preventing and mitigating instruments. The recent findings using these instruments and epediomological studies have lead to the establishment of a new standard for action of 2.7 for indoor radon levels. Homes with elevated radon levels (even at 2.7) can be fixed using current radon remediation technology.

This project aims to prepare a review literature that present:

1. how radon was established as a health hazard
2. indoor, outdoor and mining area distribution of radon across the globe
3. proposed safe limits of radon in different workplace and residential areas

4. ways of radon detection and measurement

5. methods of reducing and controlling high indoor radon concentrations

6. compiled information available in radon study area for future researchers in Ethiopia.

This review literature is organized by five related units. These are:

1. historical perspectives of radon studies

2. properties of radon and its health effect

3. current status of radon studies

4. radon detectors and measuring methods and

5. summary, conclusion and recommendation

It focuses mainly on health perspectives of radon studies. Because, it is the crucial problem related to radon and which does not received high attention to make a systematic study or research in relevant areas of our country. Such as underground mining areas and residential dewllings environment. "Understanding the problem is half of solving of the problem". So we should know the health problem related to radon to protect our environment from the dangerous radiations emitted by radon and its progeny. I hope that this review literature contributes in filling the gap of knowledge of the health risks of radon and can be used as a bench mark for other future studies.

Chapter 1

# RADON: DISCOVERY AND PROPERTIES

## 1.1 Discovery of Radon and its health hazards

### 1.1.1 Discovery of radon

No single phenomenon has played so significant a role in the development of nuclear physics as radioactivity. The discovery of radioactivity left a bright spot on the birth and progress of nuclear investigations. While Bequerel was investigating the possibility of that fluorescent materials emit X-rays when stimulated by light, he discovered the radioactivity of uranium in 1896 before the sensitive nuclear investigations was started in 1899. Soon afterward, Pierre and Marie Curie, in the course of extracting uranium from the ore pitchbiende at the same laboratory, found two other elements that are also radioactive. They named one polonium, after Marie Curie's native Poland. The second, which turned out to be thousands of times more radioactive than uranium,was called radium (Beiser, 1981).

Marie and Pierre Curies were the first to observe that the emanation from radium is radioactive. But it was not known to, the Curies, the gaseous state of the emanation which was the back bone of the discovery. Radon-222 was discovered by Friedreich Ernest in 1900. The Curie had detected radon-222, half-life 3.8 days. The work of Ernest Dorn (1900) and Rutherford(1901) confirmed that the emanation from radium were a radioactive gas. Ramsay and Gray in 1908 gave the name niton to this emanation. It was called radon since 1923. An other naturally occurring isotopes of radon were also discovered. Rutherford and Owns had discovered radon-220 (Thoron), half-life 55.5s in 1899. Friedreich Giessel and Andre-Lousi Debjerne also showed the existence of an other isotope called Actinon(Radon-219), half-life 4s in 1904.

### 1.1.2 Origin of Radon

There are three naturally occurring radioactive series in nature. These are Uranium, Radium, and Thorium series that start by Uranium-238, Thorium-232, and Uranium-235, respectively.

$^{222}$Rn is a descendant of $^{238}$U while $^{220}$Rn(thoron) and $^{219}$Rn(actinon) are the descendant of $^{232}$Th and $^{235}$U respectively.

$^{222}$Rn is the first and the most abundant natural isotope among the naturally occurring three isotopes of radon. It seems that radon has accepted the idea and implementation of globalization of the world by making available itself everywhere. Its existence is strongly tied with the presence of other elements. It is the direct radioactive product of radium ($^{226}$Ra) which is the member of the radioactive series of $^{238}U$ by $\alpha$-emission. Saying it in different words, it is the descendant of Uranium 238. see Fig 1.1
The second natural isotope of Radon is $^{219}$Rn (actinon). It has a relatively low abundance

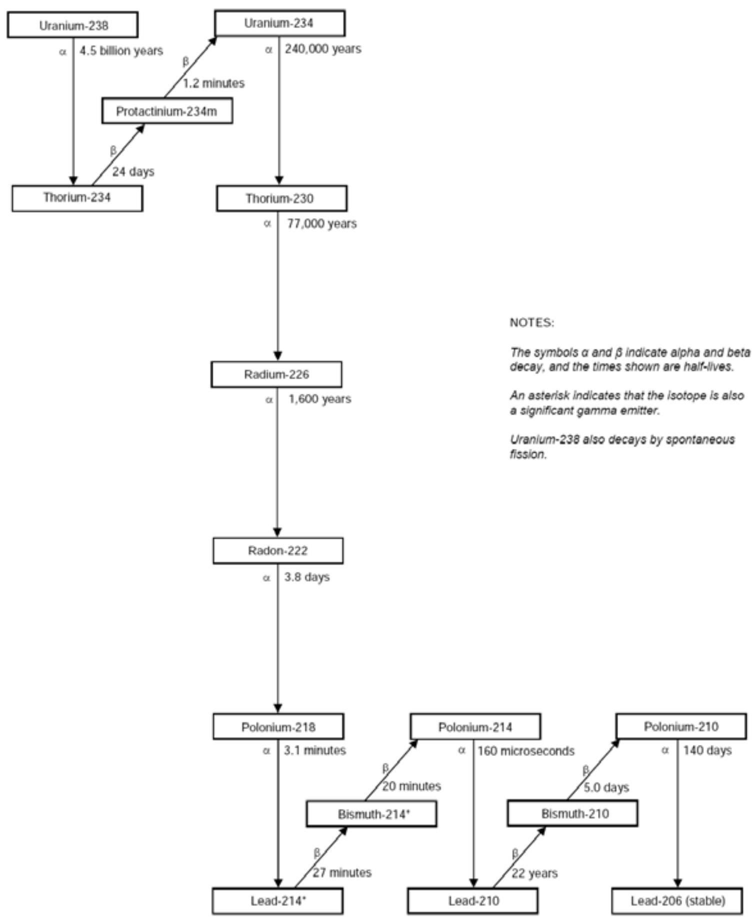


Figure 1.1: Natural decay series of U-238.

in earth's crust; that is only about 0.7 percent and has the shortest half life of 4 seconds. As describbed above it is a descendent of Uranium-235 which is shown in the following figure 1.2.

The third natural isotope of radon is $^{220}$Rn(thoron). It is much more abundant than $^{219}$Rn but less abundant than $^{222}$Rn. It is repeatedly said that uranium is the basic component of the earth. This fact leads us to say radium which is the progeny of uraniumis also found

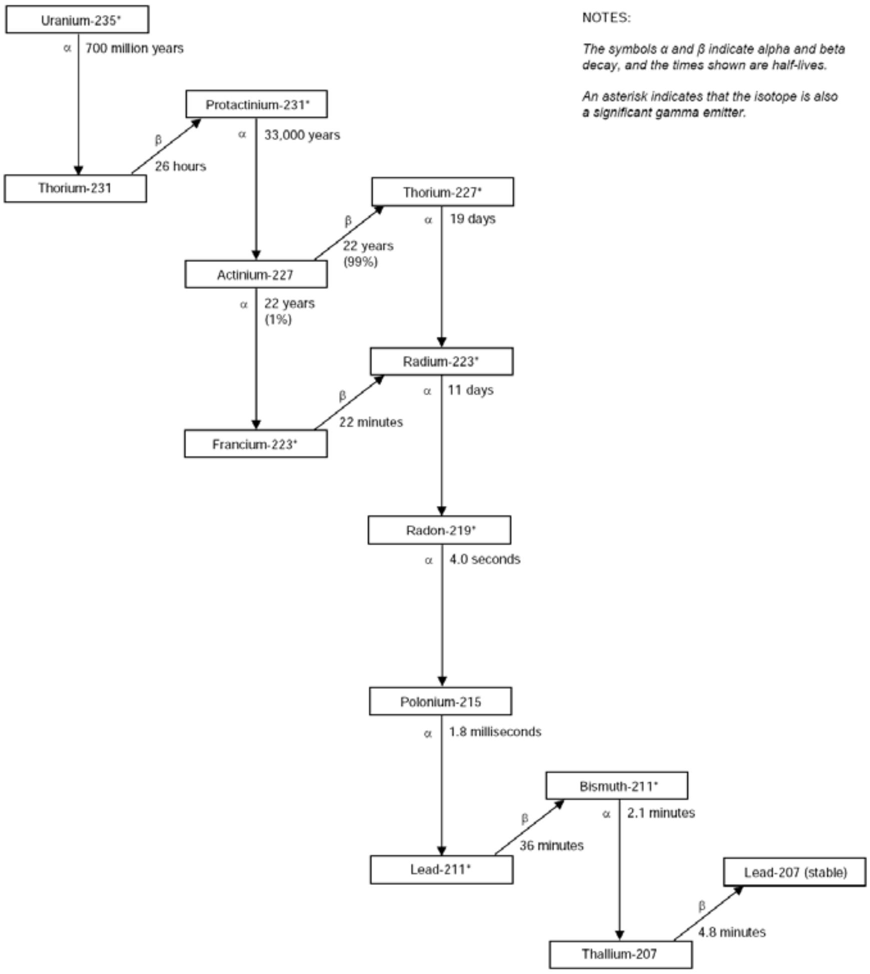


Figure 1.2: Natural decay series of U-235.

there and practically it is assured. Consequently, radon and its isotope thoron are the only gaseous descendants of radium found in any terrestrial material initially being part of the solid matrix of the soil. Thus the earth is responsible for the emission of radon and thoron to the atmosphere around us. As their parents decay, radon and thoron recoil and it could happen that they might escape from the solid matrix and join the atmosphere. $^{220}$Rn(thoron) is the direct radioactive product of radium($^{224}$Ra) which is the member of the radioactive series of Th-232 as shown in fig 1.3.

Due to emanation and exhalation radon reaches the surface of the earth. For a radon atom to escape from the mineral grain into the pore space, the decay must occur within the recoil distance of the grain surface. The range of recoil distance for $^{222}$Rn is 20-70 nm in common minerals, 100 nm in water, and 63 m in air (UNSCEAR, 2000). Radon atom entering the pore space are then transported by diffusion and advection through this space until they in turn decay or are released into the atmosphere (exhalation). Radon generation and transport in porous materials involve solid, liquid, and gas phase in the

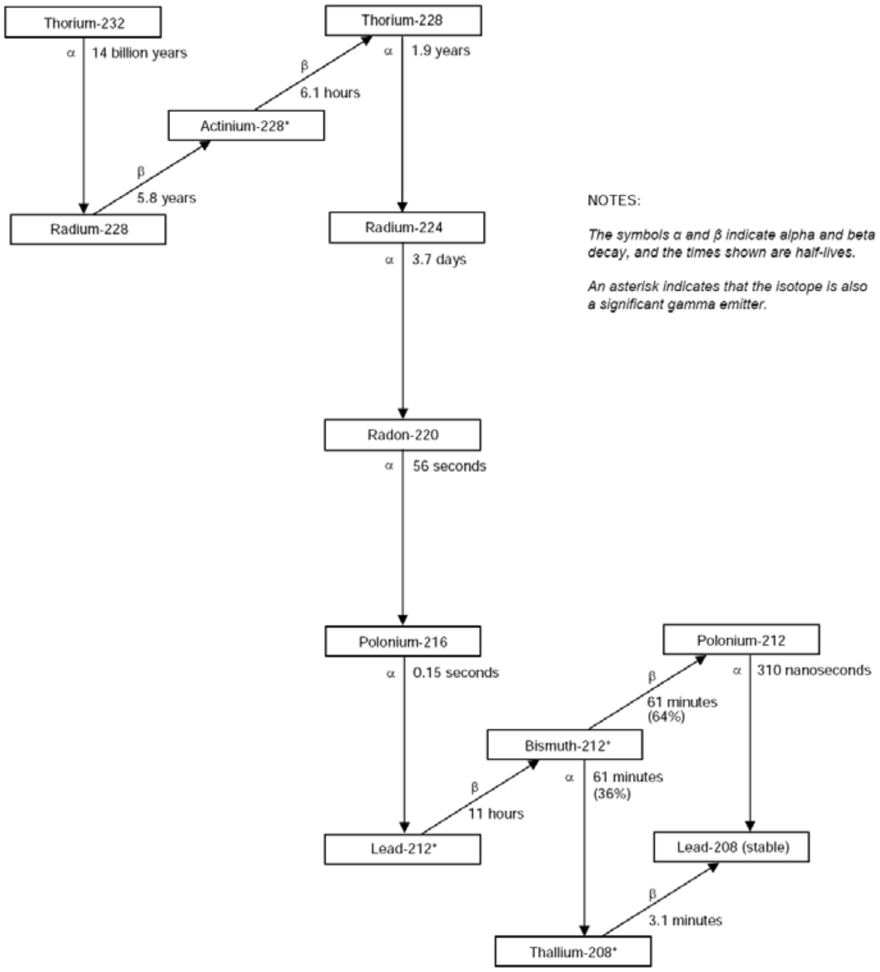


Figure 1.3: Natural decay series of Th-232.

process of emanation, diffusion, advection, absorption in the liquid phase, and adsorption in the solid phase.

The fraction of radon atoms released into rock or soil pore space from a radium-bearing grain is called the emanation coefficient, the emanation factor or the emanating power. Grain size and shape are two important factors that control the emanation of radon in soil. They determine how much radium is near enough the grain surface to allow radon to escape into pore spaces.

Because of its very short half life, $^{219}Rn$ usually disappears soon after its production. $^{220}Rn$ is also not able to travel far (i.e it decays before reaching the earth's surface due to its short half-life of 55.5 seconds).The most important isotope of radon is $^{222}Rn$. Its half life is 3.8 days and can move a substantial distances from its point of origin(Durrani and

Ilic,1997). Again, it is being a noble gas (nonreactive), it has greater ability to migrate freely through soil, air, etc. (Matiullah et al ,1993a). So $^{222}Rn$ is the threat of our health risks which reach and enter into our home.

Radon gas, which has a half-life 3.8 days, emanates from rocks and soils and tends to concentrate in enclosed spaces like underground mines and houses. The source of $^{222}$Rn in homes are :

1. soil gas emanations from soils before decaying
2. off-gassing of waterborne $^{222}$Rn into indoor air
3. building materials and
4. outdoor air

Of these four sources, soil gas represents the predominant source of indoor Radon-222 gas. The radon measurements revealed that radon is a ubiquitous constituents of atmospheric air. Now it is understood that radon is a ubiquitous element worldwide. As a result of this, the largest contributor to public radiation dose is radon, which comprises approximately 55 percent of the annual background dose(see Fig.1.4 ).

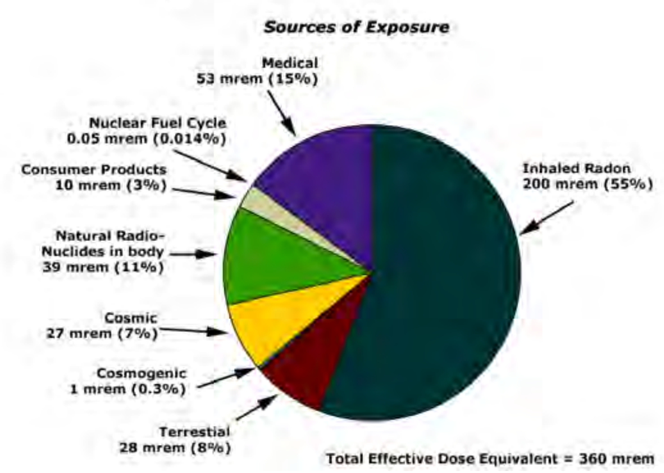


Figure 1.4: Sources of Exposure.

### 1.1.3 Discovery of the health hazards due to radon

BACKGROUND

The connection between inhaling radon and the resulting health hazards was recognized quite some time ago. Although the fact that radon was the causative agent was not fully understood until fairly recently. In fact, there was a time when radon was thought to be healthful. There are still some places where this belief persists. The respiratory disease among underground miners was occurred back to in 16th century. But the causative agent of radon to the chronically unusual high mortality from respiratory disease among these underground miners was not discovered until early in the 20th century. The first radon measurements were made in 1901 (Nagaratnam,1994) by Elster and Geitel. Both radon measurements and epidemiological studies, which started early in the 20th century and continued till now, confirmed that there is connection between inhaling radon and the respiratory disease(lung cancer). Next, let us see how the health risks due to radon was discovered in different mining regions and other areas.

### *In the mining region*

In Schneeberg and Joachimstal mining regions:

Extensive mining of silver had started in 1481 in the Schneeberg region in southern Germany. Silver was also found in Joachimstal in the Czechoslovakia Republic, and a mine was opened in 1516. By the 16th century, it was found that young miners in Schneeberg died early of a lung disease. A German physician, Agricola (1494 to 1555), was employed in Joachimstal as a municipal medical officer. He suggested that the Bergsucht (a lung disease so called by the miners) resulted from inhaling dust, and he developed methods to ventilate the mine galleries. He also recommended that miners wear protection against the dust in the air. At the same time another physician, Paracelsus (1493 to 1541), suggested that the Bergsucht also resulted from breathing metallic gases that were deposited in the lungs.

During the 1800s 75 percent of the miners in the Schneeberg region died of lung cancer. "In 1879, autopsy findings that documented pulmonary malignancy in miners in Joachimstal was described. By early in the 20th century the malignancy was shown to be primary carcinoma of the lung. The finding of high levels of radon mines in the region and in the nearby mines of Joachimsthal, where miners also had high lung cancer rates, led to the hypothesis that radon was the cause of the lung cancer. That hypothesis was not uniformly accepted until the findings of epidemiological studies of other groups of radon exposed underground miners were reported during the 1950s and 1960s. Those studies continue to support the implementation of regulatory programs to reduce exposure of underground miners to radon and to provide compensation for occupational lung cancer" (National Research Council, 1999).

"Some association between cancer and radioactivity had been demonstrated as early as 1902, starting from the first cases of skin cancer induced by x-rays or radium emanation. Since detailed measurements showed a high concentration of radon in the air of mines at Schneeberg and Jachymov, a relation between radon and lung cancer came to be suspected. Probably the first person to suspect this casual line was H.E.Muller, a miner from Saxony. It is interesting to recall that as early 1907, Lord Rutherford in a lecture in Canada, speculated that the inhalation of radon and its progeny may play some part in the physiological processes, but it was no more than a wild speculation. The hypothesis of correlation between lung cancer and radon inhalation was supported by more precise radon measurements carried out in the 1920, leading Ludewig and Lorenzer in 1924 to make a definitive statement of the link. However, this hypothesis was not generally accepted. An expert pathological study group in Germany in its 1926 report ascribed the cancer to inhalation toxic ore dusts" (Nagaratnam, 1994) (Tsega, 2007).

In the mining industry and mining region of America:

In the boom uranium mining industry in the American Southwest during the postwar 1940s and 1950s, the first casualty was occupational safety. That lapse engendered a harsh legacy: roughly fifty percent of the miners developed lung cancer over the next ten to twenty years, an outcome to which their excessive exposure to the decay products of radon gas emitted by the uranium ore may have contributed. The inside of a uranium mine on the Colorado Plateau in the 1950s might seem literally and figuratively very far from a basement of a suburban home in 1980s Pennsylvania, and yet these two contexts became linked in dual crises involving radon, risk, and regulation. These related events at the beginning and the end of the Cold War illustrate connections between conceptions of risk and danger, contested scientific data, risk communication, and changing expectations of governance. In the first case, the uranium mining industry in the American Southwest during the postwar 1940s and 1950s, exposures to the decay products of radon gas emitted by uranium ore were implicated in the subsequent pulmonary pathologies of underground miners. In the second case, which occurred in the mid-1980s, radon made another appearance in the realm of public health and public policy when private homes in Pennsylvania and New Jersey were found to have high levels of radon gas. The Environmental Protection Agency (EPA) set standards for residential environments in response to this radon crisis. Significantly, EPA used epidemiological studies of uranium miners, including those who worked in American mines during the 1940s, 1950s, and 1960s and who were tracked over several decades by a U.S. Public Health Service study, as a fundamental data set (Bales, 2008).

The Watras Incident

"Although, the progeny of radon are now a well recognized cause of lung cancer, radon itself has become a topic of controversy and public health concern because it has been found to be a ubiquitous indoor air pollutant to which all persons are exposed. Radon was found to be present in indoor air as exactly as the 1950s, but the potential health implications received little attention until the late 1970s. Arguably, the most significant event to draw the radon problem to the attention of the media and ultimately the public at large were the remarkable circumstances surrounding a person called Stanley Watras and the event is often refereed as The Watras incident. Stanley Watras was living in Boyertown, near to Philadelphia, and was an employee of the Limerick Nuclear Power plant in Pennsylvania. The home of the unfortunate Watras was built on an excavated vein of uranium in the Reading Prong, a Precambrian rock body relatively high in uranium. During December 1984, Watras set off radiation alarms on his way into work. This happened every working day for two weeks and he was regularly decontaminated while the authorities attempted to find the radioactive source. Eventually, the source was found to be radon gas in his domestic dwelling, not a discharge at the plant itself. The levels of radon in his home appeared astonishing to those monitoring at the time, being in the region of 100,000 Bq/$m^3$. The risks associated with living in that house were estimated to be equivalent to smoking 135 packs of cigarettes per day" (National Research Council, 1999).

A review of the major studies of underground miners exposed to radon that were available in the 1990s was carried out by the committee on the Biological Effects of Ionizing Radiation (BEIRVI, 1999). Eleven cohort studies were concidered, including a total of 60,000 miners in Europe, North America, Asia and Australia among whom 2600 deaths from lung cancer had occurred.

### *In human residential*

Lung Cancer Risks due to indoor Radon:

Radon was found to be present in indoor air starting from 1950s. Its progeny was a well recognized cause of lung cancer since 1940s.But the potential health implications of radon itself received high attention in the late 1970s. The World Healthy Organization (WHO) drew attention to the healthy effects from residential radon exposure in 1979. Radon gas was classified as a human **carcinogen** in 1988 by the International Agency for Research on Cancer (IARC) the WHO specialized cancer research agency.

The magnitude of lung cancer risk seen in underground miners exposed to radon strongly suggests that radon may be a cause of lung cancer in the general population due to the exposure that occurs inside houses and other buildings. The conditions of exposure in mines and indoors differ appreciably (NRC 1991), and the smoking-related risks in the miners that have been studied differ from the smoking-related risks in the general populations of today. Other determinants of lung cancer risk differ between exposure in mines and indoors. For example, many of the miners were exposed to other lung carcinogens, such as arsenic, in addition to radon. All these differences mean that there is substantial uncertainty in extrapolating from the miner studies to obtain a quantitative assessment of the risk of lung cancer from radon in the home.

Much of the uncertainty associated with quantitative extrapolation from the studies of miners can be avoided by directly studying the association between indoor radon and risk of lung cancer. In such studies, radon exposures are usually expressed as the average concentration of radon gas per cubic metre of air to which an individual has been exposed at home over the previous few decades, and the unit is Becquerel per cubic meter (Bq/$m^3$), where 1 Bq corresponds to one disintegration per second. Indoor radon concentrations in an individual house are usually subject to systematic diurnal and seasonal variation and the annual average radon concentration is also usually subject to substantial random year-to-year variation related to numerous factors (e.g. weather patterns and occupant behavior such as window opening). The health perspective of WHO tried to compare the findings of the different case-control studies of radon and lung cancer in indoors as follows.

In order to compare the findings of the different case-control studies of radon and lung cancer appropriately, and to ensure that the different smoking-related risks for different individuals are fully taken into account, it is necessary to assemble the component data on radon concentration, smoking history and other relevant factors for each individual in each of the original studies and to collate the data in a uniform way. When this has been done, parallel analyses of the different studies can be carried out, and the findings from the individual studies can be compared. Then, if the data from the different studies are consistent, they can be combined and an estimate of the risk of radon-related lung cancer can be derived based on all the studies included. Three analyses collating and comparing the individual information from a number of component studies have now been carried out, including 13 European studies (Darby et al. 2005, 2006), 7 North American studies (Krewski et al. 2005, 2006), and 2 Chinese studies (Lubin et al. 2004), respectively. All three analyses concluded that it was appropriate to derive a pooled estimate of the risk of lung cancer from radon in the home from the component studies. A summary of the findings of these pooled analyses are presented below.

The European pooling study:
The European pooling study (Darby et al. 2005, 2006) included data from all thirteen European studies of residential radon and lung cancer that satisfied selected inclusion criteria. When this was done, a clear positive association between radon and lung cancer emerged.

The majority of radon-induced lung cancers are caused by low and moderate radon concentrations rather than by high radon concentrations, because in general less peopl e are exposed to high indoor radon concentrations. In the European pooling study, the exposure-response relationship appeared to be approximately linear with no evidence for a threshold below which there was no risk (combined Analysis of 13 European case-control studies, 2004).

U.S.A:

One study by U.S.A Environmental Protection Agency [EPA,2005] showed that radon is estimated to cause about 21,000 lung cancer deaths per year (See Fig.1.5).

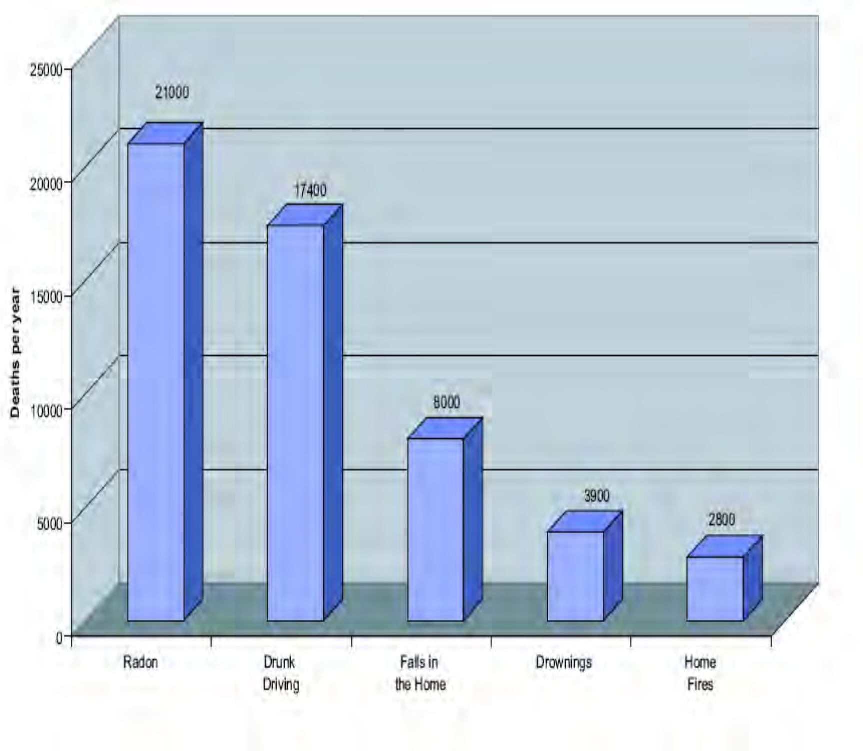


Figure 1.5: Death due to Radon as compared to other causes in U.S.A[EPA,2005].

The North American pooling study:

The North American Pooling study (Krewski et al. 2005, 2006) involved 3662 cases and 4966 controls from seven studies in the USA and Canada. The methodology was similar to that used for the European study. As with the European study, the radon-related risk in the component studies was found to be consistent, once the data for individual subjects had been collated. When data from all seven studies were combined, as with the European pooling study, the results of the North American pooling were consistent with a linear dose-response relationship with no threshold. When the analyses were restricted to the subsets of data with greater exposure accuracy, the lung cancer risk estimates increased (7 North American Case-Control Studies, 2005).

The Chinese pooling study:

Lubin and colleagues (2004) analyzed 1050 cases and 1996 controls from two studies in two areas: Gansu and Shenyang. For the pooled data, the risk per 100 Bq/$m^3$ measured radon concentration increased by 13 percent (95 percent confidence interval 1-36 percent). This effect was chiefly due to the data from the much larger Gansu study, although the results of the two component studies were compatible with each other. As with the European and North American pooling studies, the results were consistent with a linear dose-response relationship with no threshold. As described above,the three pooling studies present a very similar picture of the risk of lung cancer from residential exposure to radon. Next,let us see the findings of studies in the following few countries.

West and East Germany:

From 1990-1997,the lung cancer risk due to exposure to residential radon was investigated in West and East Germany. The results in these countries are compatible with studies from Sweden and England. As a result of this new evidence for the influence of exposure to radon on the lung cancer risk is found within the population.

Ireland:

In Ireland,between 1998 and 2001,over 33,800 individual radon measurements were carried out in all ground floor offices and classrooms in 3,444 schools nationwide as part of a program undertaken jointly with the department of education and science. Where the average indoor radon concentration in one or more rooms exceeded 200 Bq/$m^3$,remedial measure were implemented. For concentrations up to 400Bq/$m^3$,this involved increased ventilation while for higher concentrations an active sump was normally installed. The result of the survey,as well as the effectiveness of the different remedial strategies, are discussed. Eventually,the national legislation,which implements European council Directive 96/29/EURATOM, in Ireland came into effect in may 2000. Ireland has a very active program of workplace radon measurement involving show caves,mines and schools.

From the above occupational and residential history we can understand that, there is a good agreement between the estimates of radon-related risk based on the studies of indoor radon and the studies of underground miners with relatively low cumulative exposures accumulated at low concentrations.

**Radon entry into our home** Radon-222 is the only **gas** in the radioactive decay series that proceeds from uranium-238 to lead-206 (see Fig.1.1),thus allowing it to move out of

the rocks and soils where uranium is found and then enter into a home as shown in Fig.1.6
.

Some of the ways through which Radon enters into our home are :

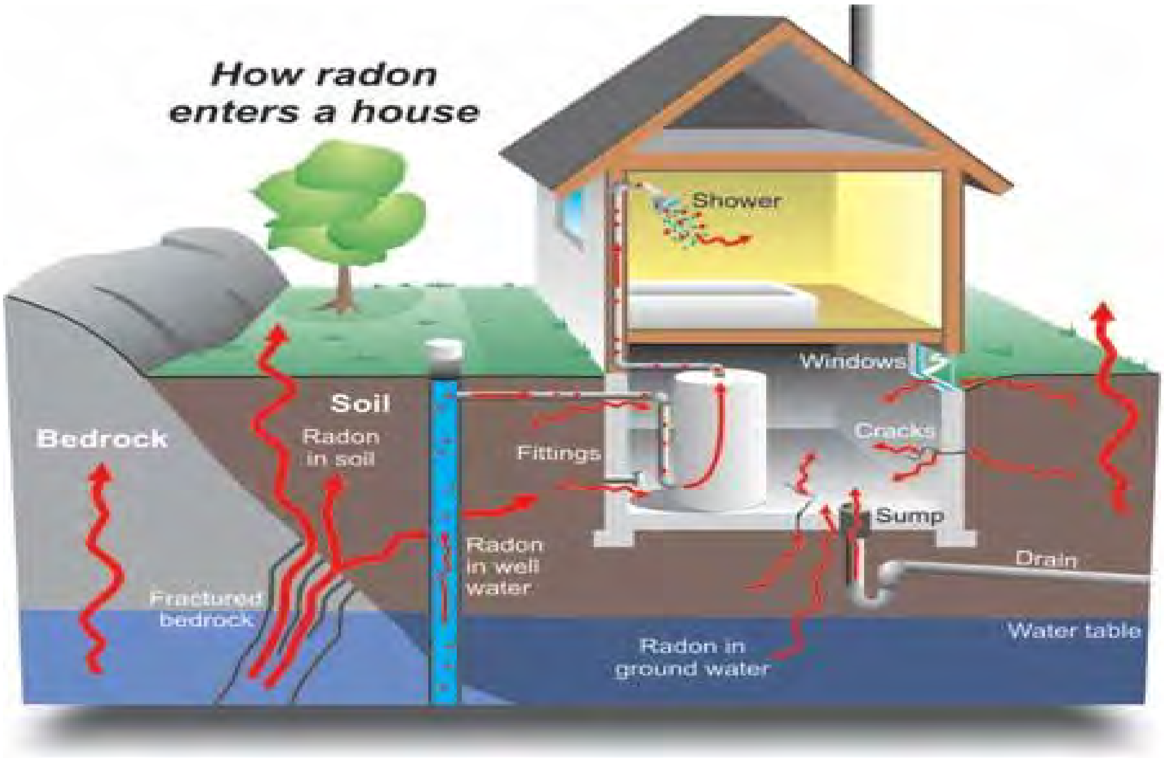


Figure 1.6: Radon entry into the house

1. Fractured bedrock
2. Cracks in floors
3. Cracks in walls
4. Construction joints
5. Gaps around service pipes
6. Cavities inside walls

The sources of radon that enters into our home may be:

1. Radon in soil
2. Radon in well and ground water
3. outdoor air

4. building materials

The high concentrations of indoor radon can be controlled and reduced up to standard international proposed safe limit of indoor radon by means of radon prevention and mitigation. These radon controlling and reducing methods are described as follows.
*Radon Prevention*:It is the radon concentrations control options during the construction of new dwellings (including extension of existing buildings or renovation work).

*Radon Mitigation*:It is the reduction of radon concentrations in already existing dwellings. It is also referred to as remediation. For instance ventilation can be used to reduce indoor radon concentrations.

In the framework of radon prevention and mitigation guidelines, training and technical criteria for radon control systems are the necessary preconditions. The most common source of indoor radon is the soil and geology under the building. However, radon sources may also include domestic and drinking water from drilled wells (groundwater supplies) and emanation of radon from building materials, including concrete, bricks, natural building stones, natural gypsum, and materials using industrial byproducts such as phosphogypsum, blast furnace slag, and coal fly ash (EC 1999, Somlai et al. 2005). Radon sources and radon transport mechanisms may have a considerable influence on the cost-effectiveness of various prevention and mitigation strategies.
Radon control should aim for an overall risk reduction in the population. This may not be achievable if there are only goals for mitigation in existing buildings. Therefore, prevention goals should also be established to reduce radon concentrations in new dwellings. Without such goal-setting the total number of dwellings with elevated indoor radon will increase when:

1. new dwellings with elevated indoor radon are added to the housing stock;

2. the number of new dwellings with elevated indoor radon exceed the number of existing houses that are mitigated.

Radon systems for prevention as well as mitigation require the following design criteria:
∗ able to reduce radon concentrations considerably below the reference level;
∗ safe and not creating back-drafting;
∗ durable and functional for the expected life of the buildings;
∗ easy monitoring of the performance;
∗ quiet and unobtrusive;

∗ low cost for installation,operation and maintenance

## 1.2 Properties of Radon

### 1.2.1 Physical Properties of Radon

At standard temperature and pressure, radon is colorless,odorless,tasteless and inert gas radioactive natural element. It is found everywhere in different proportions. Radon is the heaviest noble gas and exhibits the highest boiling point, melting point, critical temperature, and critical pressure of all noble gases. When it is cooled below its freezing point it has a brilliant phosphorescence which turns yellow as the temperature is lowered and orange-red at the temperature air liquefies (Bemenet, 2006).

At standard temperature and pressure ,radon forms a mono atomic gas with a density of 9.73 $kg/m^3$ and is one of the heaviest gases at room temperature. It dissolves in water and becomes a clear colorless liquid below its boiling point. Upon condensation,radon also glows because of the intense radiation it produces as a result of its radioactive property.

So we can not check the presence of radon by its color, odor and taste at standard temperature and pressure. Its gaseous property and radiological characteristics also have the powerful health effect. Because it can be inhaled and emit radiations which interacts with the biological tissue in the lung leading to DNA damage.

### 1.2.2 Chemical Properties of Radon

Radon is chemically inert. It is a member of zero-valence elements that are called noble gases. It is inert to most common chemical reactions,such as combustion, because the outer valence shell contains eight electrons. Inert means incapable of reacting with other substances. Being a noble gas ,it has greater ability to migrate freely through soil, air, etc. and reach our home in order to increase its concentrations and then to attack our health. The first synthesized combined of radon, Radon-Fluoride (RnF) was obtained in 1962. Florine is the most active chemical element which combines with noble gases like radon.

### 1.2.3 Radioactivity of Radon

*Radioactive isotopes of Radon*

Radon is formed by the radioactive decay of radium. It is the $\alpha$ - particle emitter radioactive gas. As the radioactive elements release energy in the form of powerful and

Table 1.1: The general properties of radon

| | |
|---|---|
| Appearance | Colorless |
| Phase(state) | Gas |
| Melting Point | 202k(-71$^0c$) |
| Boiling point | 211.3 k(-61.7$^0c$) |
| Heat of Fusion | 3.247 KJ/mol |
| Heat of Vaporization | 18.10 KJ/mol |
| Heat Capacity | 20.786 J/mol.k at 25$^0c$ |
| Density | 9.73 $kg/m^3$ at 293 k |
| Crystal Structure | Cubic |
| Its Name, Symbol,Atomic Number | Radon, Rn, 86 |
| Its Atomic Mass | 222 g/mol |
| Its Chemical Series | Noble Gas |
| Group, Period,Block | 18, 6, p |
| Nuclear Spin | $0^+$ |
| Specific Heat | 0.094J/g.mol(at 20$^0$c) |
| First Ionization Energy | 1036.5 KJ/mol |
| Electron configuration | [Xe] $4f^{14}$ $5d^{10}$ $6s^2$ $6p^6$ |
| Its electrons per shell | 2,8,18,32,18,8 |

harmful radiations in the process of decay, radon and its progeny also emit powerful and harmful radiations. Radon does not have a very long half-life. It breaks and disappears fairly quickly. The problem is that it breaks down into elements that are solid. These include Polonium-214, Polonium-218, and Lead-214. These daughters of radon are more of a threat to our health if we inhale them, they may stick to the lining of our lungs. While there they give off radiations since they are also radioactive elements. These radiations can damage cells. This is the dangerous radioactive properties of radon and its progeny to our life.

Some isotopes of radon such as radon-219,radon-220 and radon-222 occur in nature. Others are artificially produced isotopes of radon. Radon has no stable isotopes. This means the isotopes of radon are radioactive. There are about 36 radioactive isotopes that have been characterized which range from an atomic mass of 193-228. Among all the most stable isotope is radon-222 with a half -life of 3.8 days. The Decay Mass (DM),Half-life ($T_{1/2}$) and the Potential Alpha Energy(PAE) in Mev/atom of the naturally occurring isotopes of radon are given in table 2.2.

Scientifically, radon is known to be $^{222}Rn$,which is the most abundant isotope of the element radon (Nazaroff and Nero,1988). In the literature the terms radon and $^{222}Rn$ are often used interchangeably. $^{219}Rn$ has a relatively low abundance in the earth's crust;that is only about $0.7^o/_o$ and has the shortest half life of 4 seconds.

Table 1.2: the potential alpha energy in Mev/atom of the naturally occurring isotopes of radon

| Radionuclide | DM | $T_{\frac{1}{2}}$ | PAE(Mev/atom) |
|---|---|---|---|
| $^{222}Rn$ | alpha | 3.8 d | 19.2 |
| $^{220}Rn$ | alpha | 55.5 s | 20.9 |
| $^{219}Rn$ | alpha | 4 s | 20.7 |

### *Radon Daughters*

Generally, radon is considerable to have no immediate health effects. Its short-lived solid particulate daughter products are responsible for the main health risks. In other words radon is the messenger and its short-lived daughters are the messages. Relative part of the decay chain originating from $^{238}U$ is given in table 2.3 (DM = Decay Mass or particle, $T\frac{1}{2}$ = half-life,DE = Decay Energy and DP = Decay Product).

Table 1.3: Relative part of the decay chain originating from $^{238}U$

| Radionuclide | DM | $T\frac{1}{2}$ | DE in Mev | DP |
|---|---|---|---|---|
| $^{226}Ra$ | $\alpha$ | 1,600 y | 4.6 | $^{222}Rn$ |
| $^{222}Rn$ | $\alpha$ | 3.8 d | 5.49 | $^{218}Po$ |
| $^{218}Po$ | $\alpha$ | 3 min | 6 | $^{214}Pb$ |
| $^{214}Pb$ | $\beta^-$ | 26.8 min | 0.67 | $^{214}Bi$ |
| $^{214}Bi$ | $\beta^-$ | 19.7 min | 3.17 | $^{214}Po$ |
| $^{214}Po$ | $\alpha$ | 164$\mu$s | 7.69 | $^{210}Pb$ |
| $^{210}Pb$ | $\beta^-$ | 22 y | 0.02 | $^{210}Bi$ |
| $^{210}Bi$ | $\beta^-$ | 5 d | 1.161 | $^{210}Po$ |
| $^{210}Po$ | $\alpha$ | 138 d | 5.237 | $^{206}Pb$(stable) |

Because radon is a noble gas with a life-time,which is relatively longer than the breathing time ,most of it that inhaled is exhaled without decaying (Matiullah,2000).Some of the $^{222}Rn$ does of course ,decay while inside the lungs ,although this aspect is often ignored. In contrast, the immediate,promptly decaying daughters of $^{222}Rn$(i.e $^{218}Po$,$^{214}$Pb,$^{214}Bi$, and $^{214}Po$),being chemically more reactive ,may attach to surfaces (attach fraction), typically of aerosols,which can be inhaled and deposited in the nose or the pharynx(3 percent chance of adhering to the lungs lining); the unattached (free ions) have a high probability (50 percent chance) of setting on the surface of bronchi (Connell,2005).

## 1.2.4 Transportation of radon

**Emanation of Radon** : In mineral grain, $^{226}Ra$ decays to $^{222}Rn$ by emitting an $\alpha$-particle. Most of the radon produced remains within the grain. The small fraction of it escapes to the pore spaces either promptly or within a few days before it decays,depending on the grain size and location of its parent in grain (Duenas et al. ,1997). The main mechanism of escape is recoil energy of its atoms during the $\alpha$-decay of $^{226}Ra$ and diffusion through grain. The ratio of the escaped radon to the radon produced in the grain is called emanation coefficient denoted by (E), and is known to be in the order of 0.2 - 0.3 (Durrani and Ilic,1997) for common constituents of building material (eg. sand) (Rehman, 2005).

**Exhalation of Radon** : The term radon-222 exhalation or flux marks the passage of radon-222 from the soil of building material to the indoor environment. A measure of exhalation is given by the exhalation rate, which is the number of atoms leaving the soil per unit surface area per unit time.

Due to emanation or exhalation radon reaches the surface of the earth. Because of its very short half life, $^{219}Rn$ usually disappears soon after its production. $^{220}Rn$ is also not able to travel far (i.e it decays before reaching the earth's surface due to its short half-life of 55.5 seconds).The most important isotope of radon is $^{222}Rn$. Its half life is 3.8 days and can move a substantial distances from its point of origin(Durrani and Ilic,1997). Again, it is being a noble gas (nonreactive), it has greater ability to migrate freely through soil, air,etc.(Matiullah et al ,1993a). In soil and building materials diffusion and advection are responsible for radon transport. Diffusion is the mechanism by which radon transfer from one place to the other due to concentration gradient (Nazaroff and Nero,1998).
And, advection is the movement of radon due to the pressure gradient between the air in pore space and ground surface. This is why only $^{222}Rn$ is generally considerable as a health hazard when estimating risk factors from exposure to radon. There are no sinks for radon, and it is estimated that only negligible quantity escape to the stratosphere (Gingrich,1983).As a result,the ultimate and sole fate of $^{222}Rn$ is transformation or degradation through radioactive decay.
The physical properties, the chemical properties, the radioactivity and the transportation of radon play a great role on the health effects of radon. .

## 1.3 Summary : A chronology of some of the major events in the study of radon

- As early as 1556 : Agricola described high mortality rates from respiritory diseases among underground metal miners at Schneeberg in the Erz mountains of central Europe

- 1879 : Harting and Hesse first linked the high mortality rates at Schneeberg to lung cancer on the basis of autopsy findings

- 1896 : The discovery of the radioactivity of uranium by Bequerel - The base for the discovery of radon

- 1900 : The discovery of Radon-222 by Friedreich Ernest
- 1901 : The invention of the first radon measuring device and its implementation
- 1921 : Margaret Uhling suggested that radium emanation, latter known as Radon-222, may be the cause of the lung cancer
- 1939 : Peller wrote the first review of mining related lung cancers (specially about the ocurrence of lung cancer in Joachimstal miners)
- 1940 - 1960 : The progeny of radon were well recognized as the cause of lung cancer.
- 1950s : Radon was found to be present in indoor air in U.S.A
- In the late 1970s : The potential health implications of radon itself recieved high attention.
- 1979 : WHO drew attention to the health effects from residential radon exposure.
- 1984 : The Watras incident
- 1988 : Radon gas was classified as a human *carcinogen*.
- 2004 : The Chinese pooling indoor radon study (two studies)
- 2005 : The set up of the WHO International Radon Project (IRP)
- 2005 - 2006 : The European indoor radon pooling study (13 studies)
- 2005 - 2006 : the north American indoor radon pooling study (7 studies)
- 2009 : The publishing and releasing of the WHO handbook on Indoor Radon

Chapter 2

# HEALTH EFFECTS OF RADON

In unit one the discovery of health hazards due to radon in mining and residential areas is explored. From these exploration we can understand that, as early as 1556, Agricola described high mortality rates from respiratory diseases among underground metal miners at Schneeberg in the Erz Mountains of Central Europe. Harting and Hesse first linked the high mortality rates at Schneeberg to lung cancer in 1879 on the basis of autopsy findings. In 1921 Margaret Uhlig suggested that radium emanation, later known as $^{222}Rn$, may be the cause of the lung cancers. In 1939 Peller wrote the first review of mining-related cancers, which described the occurrence of lung cancers in Schneeberg and Joachimsthal miners. Finally, in the mid 1950s $^{222}Rn$ progeny inhalation rather than $^{222}Rn$ gas was implicated as the causative agent in the excessive lung cancer deaths noted for miners in both the United States and Europe. In the 1990s, eleven cohort studies were considered, including a total of 60,000 miners in Europe, North America, Asia and Australia among whom 2600 deaths from lung cancer had occurred.
The potential health implications of radon itself received high attention in the late 1970s. Radon gas was classified as a human **carcinogen** in 1988 by the International Agency for Research on Cancer (IARC) the WHO specialized cancer research agency. One study by U.S.A Environmental Protection Agency [EPA,2005] showed that indoor radon is estimated to cause about 21,000 lung cancer deaths per year (See Fig.1.5). Next, let us see the radon studies in relation to epidemiological studies.

## 2.1 Radon Entry into the human Body

Radon is a radioactive gas. So,inhalation is the main route of entry, into human body for radon and its progeny [EPA,2005]. Most of the radon inhaled is also exhaled. However, some of radon's decay products attach to dusts and aerosols in the air, are inhaled and then readily deposited in the lungs. Some of these are also cleared by the lung's natural defense system; and swallowed or coughed out.

A small percentage of the decay products remain unattached; others increase their diameter through chemical and physical processes. The percent attachment depends on numerous factors, including the size and concentration of the airborne particles. The size and density of a particle determine its behavior in the respiratory tract. The unattached particle fraction with a 1-nm diameter is generally removed in the nose and mouth during breathing and has limited penetration of the bronchi. Maximal deposition occurs as the particles with diameters ranging from 3-10 nm increase their rate of penetration through the mouth and nose, ultimately depositing in the bronchial region. The deposition rate decreases for particles as their diameter increases toward 100 nm and larger because the particles are less able to diffuse to the airway surface. However, particle deposition into the respiratory tract through impaction starts to increase again for particles above 500 nm. Larger particles with a diameter exceeding 3.5 m deposit predominantly in the nose and mouth during inhalation and do not reach the sensitive respiratory epithelium.

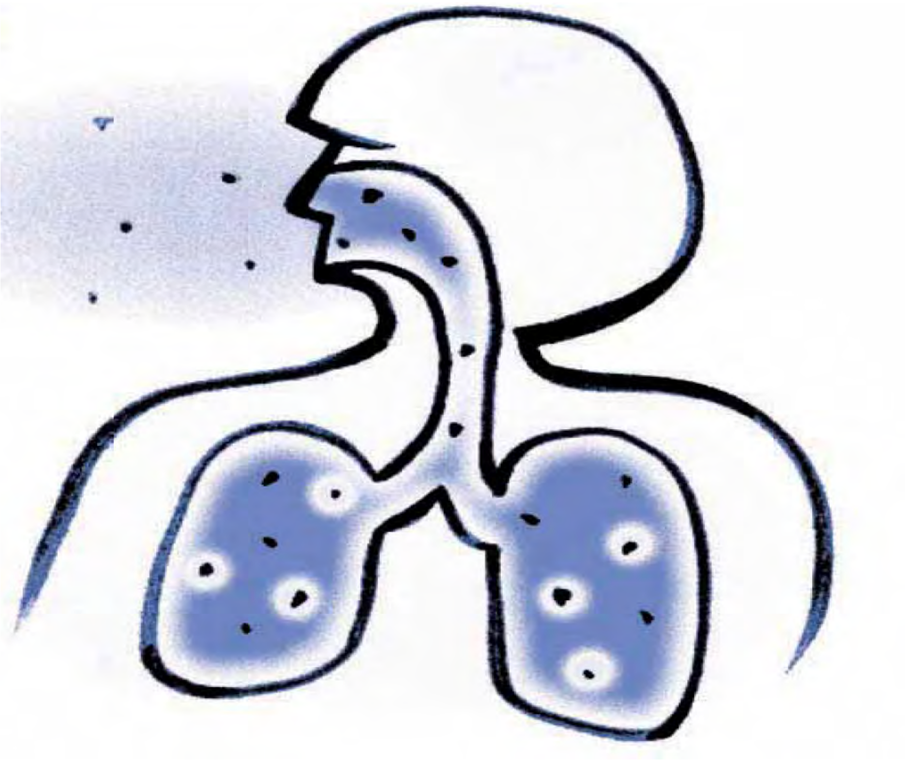

Figure 2.1: Radon entry into the human body

## 2.2 Deposition of alpha Energy in the Lungs

When radon gas is inhaled, densely ionizing alpha particles emitted by radon and its deposited short-lived decay products such as polonium-218 and polonium-214 can interact with biological tissue in the lungs leading to DNA damage. These radon decay products are more dangerous than radon itself. Because they emit high energy alpha particles that can damage fragile lung tissue if they disintegrate while they are inside the lung. From table 1.2 the potential alpha energy of radon atom is 19.2 Mev. It is the energy which could be released in the lung if radon atom underwent the entire decay series after depositing in the lung. Only the alpha energy is considered , since only it is believed to be of radio-biological importance for the $^{222}Rn$ chain. From Table 1.3, we can see that the alpha decay energies of $^{222}Rn$(5.49 Mev) and the short-lived decay products $^{218}Po$(6 Mev) and $^{214}Po$(7.49 Mev) are much greater than the beta decay energies of the short-lived decay products $^{214}Pb$(0.67 Mev) and $^{214}Bi$(3.17 Mev).

The deposition of alpha energy in the lungs increases proportionally with increasing radon exposure and radon concentrations. This also results in the increasing of the radon lung cancer risk.
The physical and biological factors that affect the dose delivered by $^{222}Rn$ progeny to the target cells in the respiratory epithelium should be taken under consideration. For instance aerosol size distribution, respiratory rate, oral vs. nasal inhalation route, etc.

## 2.3 Lung cancer caused by $^{222}Rn$ exposure

$^{222}$Rn progeny exposure induce a primary lung cancer (cancer that started in the lungs). There are several different types of primary lung cancer. Generally, they are classified as small cell lung cancer and non small cell lung cancer. The three types of non small cell lung cancer are squamous cell carcinoma, adenocarcinoma and large cell carcinoma. The North American and European Pooled residential radon studies found an overall increase in all types of primary lung cancer. So a specific primary subtype of lung cancer has not been definitively associated with $^{222}Rn$ progeny exposure.
These results of epidemiological studies have provided convincing evidence of an association between indoor radon exposure and lung cancer, even at the relatively low radon levels commonly found in residential buildings. According to these studies, the lung cancer risk increases proportionally with increasing radon exposure. As many people are exposed to low and moderate radon concentrations,the majority of lung cancers related to radon are caused by these exposure levels rather than high concentrations.

As a result of epidemiological studies, the risk to human health posed by ionizing radiation are well known. Radon gas is by far the most important source of ionizing radiations among those that are of natural origin as shown in Fig.1.4. Most of the radon-induced lung cancer cases occur among smokers due to a strong combined effect of smoking and radon. As a result of this radon is the second cause of cancer in the general population after smoking.

## 2.4 Safe Limits

### 2.4.1 Miners and occupational Safe Limits

The exposure limit varies by regulating agency and type of worker. The Miners Safety and Health Act (MSHA) covers underground miners, whereas the Occupational Safety and Health Act (OSHA) regulates exposure to $^{222}Rn$ gas and $^{222}Rn$ progeny for workers other than miners. The MSHA sets limits so that no employee can be exposed to air containing $^{222}Rn$ progeny in excess of 1.0 WL (100 pCi/L) in active work areas. The MSHA also limits annual exposure to $^{222}Rn$ progeny to less than 4 WLM per year. OSHA limits exposure to either 30 pCi/L or 0.33 WL based on continuous workplace exposure for 40 hours per week, 52 weeks per year.

In Publication 103, the International Commission on Radiological Protection (ICRP) considered that the internationally established value of 1000 $Bq/m^3$ or 27 pCi/L might be used globally in the interest of international harmonization of occupational safety standards (ICRP, 0209).

### 2.4.2 Residential Safe Limit

The EPA recommends that $^{222}Rn$ gas concentrations not exceed a year-long average concentration of 4 pCi/L in any livable area of the home. WHO now suggests that homeowners take action when radon levels exceed 2.7 pCi/L.

The high concentrations of indoor radon can be controlled and reduced up to standard international proposed safe limit of indoor radon by means of radon prevention and mitigation as described in unit one.

Chapter 3
# CURRENT STATUS OF RADON STUDIES

## 3.1 *Background*

We explored two separate pathways of radon history over time under 1.3.1 and 1.3.2, an occupational history of radon (mining areas radon) and a residential history of radon (Indoor radon). The occupational story starts much farther back in the $16^{th}$ century and is where we started the story. The residential story is much more recent in time but possibly more widespread than many would have thought. The occupational story starts in a region known as the Erzgebirge, the Ore Mountains. These mountains separate present day Germany from Czechoslovakia. The two principle towns of interest are Schneeberg on the German side of the mountains, about 50 miles due south of Leipzig and Jachymov in Czechoslovakia, about 60 miles northwest of Prague. Mining first started in Schneeberg in the early 1400s and in Jachymov in 1516 after the discovery of rich veins of silver. It seems as though the dawn of the Renaissance (1450-1600) was a real driving force for mining in these two districts due to the increased demand for metals for military purposes and gold and silver to fund trade, expeditions of discovery, and building projects.

I think that we can understand easily from 1.3.2 the indoor radon issue really gaining national attention because of the incident in December of 1984 within the Watras house; however, there is evidence that there was an increasing awareness to the issue prior to 1984. The occupational history of radon starts back in 1470 and continue till now. But the residential history is much more recent in time. The current status of radon studies mainly concerns on residential radon studies. In the previous time radon studies was limited in a very few countries. But, now especially the indoor radon studies is possibly more widespread than the occupational radon studies. The current issue of radon studies mainly concerns on indoor radon as it is described in the following section.

## 3.2 The globalization of Radon Studies

The current issue of the indoor radon studies which get national attention in December 1984 in Watras house continued strongly and in a well an internationally organized form by WHO since 2005. This turn our sight to the human residence. The plac where now about 6 billion of us live. The place that often has four sides, a roof ,and a part in contact with the ground. The place where many of us spent about 70 percent of our time. The place we call it “home”. (K.Lewis, 2006)

”Radon poses an easily reducible health risk to populations all over the world, but has not up to now received widespread attention,” said Dr. Mike Repacholi, coordinator of WHO’s Radiation and Environmental Health Unit.

”Radon is all around us. Radon in our homes is the main source of exposure to ionizing radiation, and accounts for 50 percent of the public’s exposure to naturally occurring sources of radiation in many countries,” Dr. Repacholi said.

To cut the risk of lung cancer for smokers and non-smokers alike, the World Health Organization (WHO) in June 2005 announced that 20 countries have joined with the agency in a new project that will identify effective strategies for reducing the health impact of radon.

The project is initially expected to run for three years (2005 to 2007). As a first step, the WHO International Radon Project (IRP) is setting up a global network of radon scientists, regulators and policy makers to collaborate in the project. Scientists from 20 countries meet to form the WHO International Radon Project in 2005. Later on more than 100 scientists from 30 countries have participated in the WHO International Radon Project (IRP) which has lead to the publishing of the WHO Handbook on Indoor Radon in 2009. (WHO, 2009)

Surveys have been carried out to determine the distribution of residential radon concentrations in most of the 30 member countries of the Organization for Economic Co-operation and Development (OECD). The worldwide average indoor radon concentration has been estimated at 39 Bq/$m^3$. This is shown in table 3.1.

Sources: WHO (2007), UNSCEAR (2000), Billon et al. (2005) and Menzler et al. (2008).

Table 3.1: Indoor radon concentrations in OECD countries

| | | Indoor Radon Levels [Bq/$m^3$] | |
|---|---|---|---|
| Country | Arithmetic mean | Geometric mean | Geometric Standard devia |
| Australia | 11 | 8 | 2.1 |
| Austria | 99 | 15 | NA |
| Belgium | 48 | 38 | 2 |
| Canada | 28 | 11 | 3.9 |
| Czech Republic | 140 | 44 | 2.1 |
| Denmark | 59 | 39 | 2.2 |
| Finland | 120 | 84 | 2.1 |
| France | 89 | 53 | 2.0 |
| Germany | 49 | 37 | 2.0 |
| Greece | 55 | 44 | 2.4 |
| Hungary | 82 | 62 | 2.1 |
| Iceland | 10 | NA | NA |
| Ireland | 89 | 57 | 2.4 |
| Italy | 70 | 52 | 2.4 |
| Japan | 16 | 13 | 1.8 |
| Luxembourg | 110 | 70 | 2 |
| Mexico | 140 | 90 | NA |
| Netherlands | 23 | 18 | 1.6 |
| New zealand | 22 | 20 | NA |
| Norway | 89 | 40 | NA |
| Poland | 49 | 31 | 2.3 |
| Portugal | 62 | 45 | 2.2 |
| Republic of Korea | 53 | 43 | 1.8 |
| Slovakia | 87 | NA | NA |
| Spain | 90 | 46 | 2.9 |
| Sweden | 108 | 56 | NA |
| Switzerland | 78 | 51 | 1.8 |
| United Kingdom | 20 | 14 | 3.2 |
| U.S.A | 46 | 25 | 3.1 |
| Worldwide average | 39 | | |

Brazil, China, Russia, Turkey and Ukrain are also one of the 20 countries participated in the International Radon Project (IRP) in 2005.

Some of radon studies in Africa are :

- Radon emanometry case study in Namibia (on the Spitzkoppe and Tumas Uranium deposites) and presented on the $11^{th}$ SAGA Biennial Technical Meeting and Exhibition in Swaziland,16 - 18 September 2009.
- The influence of meterologicalparameters on indoor radon in selected traditional

Kenya dwellings(2009).

- Domestic radon concentration and childhood cancer study in Cairo, Egypt(2000)
- A study of airborne radon levels in paarl houses-South Africa (2008)
- Radon exhalation rate from building materials used on the Garyounis University campus,Benghazi,Libya(2008)
- Radon soilgas as a geological mapping tool: case study from basement complex of Nigeria(2005) and others.

From the above descriptions we can understand easily that radon study is almost becoming the issue of all continents of the world. At this time, many countries around the world have some idea about the health hazards due to radon. In our country Ethiopia some thesis had done by Addis Abeba University Nuclear Physics Graduate Students on Indoor Radon Concentrations in 2006, 2007 and 2008. Namely, Bemenet Alemayehu(2006), Tsega Berhane(2007) and others. Next,let us see some WHO's current results of studies and researches.

## 3.3 Important Current Information

### 3.3.1 Radon Action Level

The World Health Organization has released their Handbook on Indoor Radon which strongly validates the worldwide threat of exposure to radon gas. WHO now suggests that homeowners take action when radon levels exceed 2.7 pCi/l.

Radon gas has been identified as the leading cause of lung cancer for non-smokers according to recent studies conducted throughout the world. The World Health Organization states that as many as 14 percent of the lung cancer cases in many countries (including the United States) are caused by exposure to radon gas. These recent findings have lead to the establishment of a new standard for action of 2.7 for indoor radon levels.

According to the handbook, WHO has been studying the effects of radon exposure since 1979. Although radon was classified as a human carcinogen in 1988, it took over 20-years of sound research and real-life studies from all over the world to confirm the true magnitude of the risk radon poses. Based on the results of these studies, WHO now suggests that homeowners take action when radon levels exceed strongly validates the worldwide threat of exposure to radon gas. This is a much more conservative figure than the Environmental Protection Agency (EPA's) action level of 4.0 pCi/l, which has been the U.S. standard for over 20-years.

The WHO Handbook on indoor radon is a useful resource for concerned homeowners or anyone who wants to learn more about the toxic carcinogen known as radon. It outlines the years of research and the very conclusive findings that have triggered a push for stricter legislation and construction practices that will reduce the risk of indoor radon exposure to the general population.

The United Nations also broke new ground in the international fight on radon-induced lung cancer earlier in 2009 when they released their acknowledgement of the radon problems throughout the world. They analyzed both residential studies as well as extrapolated data from underground miner studies to confirm the previously understated radon risk. Their findings are documented in The U.N. Assessment for Radon in Homes and Workplaces (UNSCEAR, 2009).

By encouraging people to take action when radon levels exceed 2.7 rather than the previous limit of 4.0, we should see a dramatic increase in the number of homes being tested and mitigated as well as improved enforcement of radon resistant new construction requirements, according to Jamey Gelina, a radon mitigation specialist with Air Quality Control Agency. His firm is one of the largest companies in the U.S. that specializes in installing radon removal equipment.

Most major health organizations (including The American Medical Association, National Cancer Institute, and American Lung Association) for years have known that radon increases lung cancer risk. However recent studies have confirmed that the risk is evident even at levels much lower than earlier studies suggested. Now, the good news is this: Radon testing is becoming easy and inexpensive in developed countries. Today, there is also a technological improvement and invention of radon measuring instruments. Homes with elevated radon levels (even at 2.7) can be fixed using current radon remediation technology.

Radon is naturally occurring, odorless, and colorless gas produced by the breakdown of uranium in soil, rock, and water. Because radon is a gas, it can enter buildings through openings or cracks in the foundation. The radon gas itself decays into radioactive solids, called radon daughters. The radon daughters attach to dust particles in the air, and can be inhaled. The inhalation of radon daughters has been linked to lung cancer. As a result of this, radon has been identified as the second leading cause of lung cancer in the United States (second only to smoking). The Environmental Protection Agency reports that radon causes between 15,000 and 22,000 lung cancer deaths every year in the United States.

Source:WHO, Environmental News Committee, Sep 22, 2009

### 3.3.2 Radon Responsibility

WHO places radon responsibility firmly on professionals. In its recently published Handbook on Indoor Radon, the World Health Organization (WHO) has categorically stated that the responsibility for risks associated with radon gas is placed on designers, contractors and other property professionals.

Since 2005, the World Health Organization has been running the International Radon Project (IRP), an initiative aimed at reducing the worldwide risk of lung cancer associated with exposure to radon gas. In the UK, some 2000 people die every year from lung cancer linked to radon exposure.

The Handbook On Indoor Radon released by WHO stresses that high indoor radon levels are not naturally occurring, rather the result of the human activities of designing and constructing houses as well as the living habits of house occupants.

Prof. William Angell, Chair of the WHO IRP Prevention and Mitigation Working Group highlights that, Indoor radon levels are caused by the way homes are designed and built. They are not naturally occurring.

WHO have specifically stated that they clearly place responsibility for radon risks on architects, builders, real estate professionals and home sellers.

The implications of this declaration are far-reaching, and impose a duty on all those involved in the construction and selling process to ensure adequate steps are taken to construct buildings that are properly protected from radon gas. This includes everyone from the designers and specifiers, contractors on-site and building control officers, right through to the agent selling the property. In the case of leased buildings, the landlord also has a responsibility to ensure his property does not endanger the health of his tenants.

Research carried out in the UK indicates an unacceptably high failure rate in existing radon protection measures. This is likely to be due to a combination of factors, including the use of inappropriate techniques, materials and non-specialist labour.

The WHO Handbook emphasizes the need for trained specialists to be used for radon protection and mitigation work.

Source:WHO, ProTen Services, Sep 28, 2009

In conclusion, we can understand that currently :
(1) the radodn study is globalized by the International Radon Project of WHO inorder to strongly validates the worldwide threat of exposure to radon gas
(2) a new radon action level, which is 2.7 pCi/l, is suggested by WHO
(3) WHO places radon responsibility firmly on professionals.
WHO places radon risk responsibility on professionals such as designers, architects, builders, real estate professionals and home sellers. In addition to this, I suggest that the intellectuals who have the understanding of the health hazards due to radon should have to take the the radon risk responsiblity. If the professionals stated above do not have any information about the health risks of radon, how they can be responsible. So the radon responsibility should be placed on the understood intellectuals and informed professionals. The concerned Ethiopian intellectuals and professionals should think globally and then act locally (that means first they should act in their own country). As I think there is a good and hopeful beginning in the nuclear physics stream of Addis Abeba University. Even this project work is the product of the activity of this stream (nuclear physics).

Chapter 4

# RADON DETECTORS AND MEASURING METHODS

## 4.1 Radiation Detectors - Basic principles

Many specialized varieties of detectors exist and continue to be developed. Detectors technology is highly sophisticated.

Any detector of radiation generates its signals from the results of the interaction of radiation with matter. The fundamental mechanism by which radiations interact and lose their energy in matter are:

- The interaction of charged particles, such as alpha and beta particles, with matter
- The interaction of uncharged particles, such as neutron, with matter
- The interaction of light photons, such as gamma and X-rays, with matter

Nuclear radiation normally consists of energetic particles or photons. Mainly it consists of $\alpha$- and $\beta$-particles and $\gamma$- rays. Radon and its progeny which are radioactive elements that emit energetic particles such as $\alpha$- and $\beta$- particles and $\gamma$ - rays. The basic principles of the most commonly used types of detectors are described as follows. (Knoll, 2000)

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### 4.1.1 Gas Detectors

The radiation interacts with the atoms or molecules of the gas. And, then the gas will be ionized. The charge released by ionization of the gas can be collected and measured. Types of gas detectors are Ionization chamber, Proportional counter , and Geiger muller counter (S.Krane, 1988).

#### *Ionization Chamber*

It is a sealed chamber having two electrodes and a suitable inert gas used for the purpose of detecting nuclear radiations. The geometry of the chamber can be either two parallel plates or cylindrical electrodes.

As a result of the interaction of the incident radiation with the gas, a neutral atom or molecule is ionized. That is ion pair (positive ion and a free electron) is produced in the process of ionization (energy loss of radiation) in the filled gas.
If an electric field (voltage) is applied to the region in which ion pair exist in the gas, the electrostatic force will tend to move the charges (separated ion pairs) away from their point of origin towards the electrodes. This serves as the basic constituent of the electrical signal developed by the ion chamber. If a suitable voltage is applied, the total recombination of the ion pairs is over and the total primary charge produced by the ionizing radiation is collected and measured by the measuring external circuit. As a result of this, the pulse height depends upon the primary ionization and hence the energy of the radiation (particle) can be measured or the particle can be idetified.
One of the application of DC ion chamber is in the measurement of radioactive gas such as radon gas. Radioactive gases can be conveniently be measured by incorporating them as constituent of the fill gas (the gas to be sampled) of an ionization chamber.
ELECTRET : It is a sample of dielectric material that carries of quasi-permanent electrical charge. It is placed inside an ion chamber. A voltage $v_o$ of 1000v may then appear between the opposite surfaces of the electret. Any ion pairs created by radiation with the chamber will be separated and collected by an electric field, serving to partially neutralize the charge carried by the electret. This results in the drop in surface voltage on an electret.
$\Delta V = v_o$ - v
$\Delta Q = Q_o$ - Q
$\Delta v = \frac{Q_o}{c}$ - $\frac{Q}{c}$
$v_o$ and v are the original and the new voltage of the eletret.
$\Delta Q$ is the total ionization charge produced in the ionization chamber.

## *Proportional Counter*

Its preferable geometry is the cylindrical electrodes. The proportional counter rely on the phenomenon of **gas multiplication** to amplify the charge represented by the original ion pairs created within the gas. Each original electron leads to an avalanche that is basically independent of all other avalanches formed from other electrons associated with the original ionizing event. Pulses are considerably larger than those from ion chambers used under the same conditions, and proportional counters can be applied to situations in which the number of ion pairs generated by the radiation is too small to permit satisfactory operation in pulse-type ion chambers. In proportional counter the pulse height is directly proportional to the voltage applied. It also depends on the primary ionization. That is the collected charge is proportional to the number of original ion pairs created by the incident radiation. This counter is better to identify the particles than ionization chamber since it has a larger pulse height.

### *Geiger Muller (G-M) Counter*

As a complement to the ion chambers and proportional counters, G-M counters comprises the third general category of gas filled detectors based on ionization. In common with proportional counters, they employ **gas multiplication** (secondary electrons) to greatly increase the charge represented by the original ion pairs formed along the radiation track, but in a fundamentally different manner. In G-M counter, at a critical value of the electric field each avalanche formed in it can create, on the average, at least one more avalanche. In principle, an exponentially growing number of avalanches could be created within a very short time if still the values of the electric field is greatly increased. The electrons (charge) spreads throghout the central wire (anode) which produces huge voltage in the external measuring circuit. All pulses from a Geiger tube are of the same amplitude regardless of the number of original ion pairs that initiated the process. That is the pulse height is independent of the primary ionization. It function only as a simple counter of radiation-induced events and can not be applied to identify particles. It is only a detector.

## 4.1.2 Scintillation Detectors

The radiation interacting with the scintillation materials transfer its energy to the electrons in the scintillator. The kinetic energy of these mono energetic electrons again transfers to the valence electrons. Then these valence electrons will excite. And, when de-excitation of these excited electrons takes place in a scintillation material the emission of fluorescent photons (luminescence) will be observed.

The modern scintillation detector followed from the production of materials that are transparent to their own fluorescent light and the development of the photomultiplier tube (PMT) as an extremely sensitive detector of this fluorescent photons. The photo-cathode which is one of the major components inside the PMT converts these light photons into photoelectrons or electrical pulse or signal. Finally, these pulses can be counted by the electronic devices. The final counted results depend on the intensity or the energy of the incident radiation. There are two basic types of scintillator material. These are organic and inorganic scintillator materials (Chaubey, 2010).

## 4.1.3 Semiconductor Detectors

In this case the radiation interacts with semiconductor materials. As a result of this, excitation of electrons occur. Semiconductor detectors are widely used in research and industry where an accurate measurement of energy is needed. This detector consists of a single crystal of semiconductor, usually either silicon or germanium, across which a voltage is applied between two attached electrodes. The device operates like a solid ionization chamber. The transfer of ionization energy to the crystal creates electron - hole pair. The two types of semiconductors in common use are a p-n junction detector and an intrinsic detector (Lilley, 2001). Next, let us see Radon Detection and Measuring Methods

## 4.2 Radon Detecting Devices

After reviewing historical perspectives, origin, properties, health effects and current status of radon, the next step is to review the studies on the radon measurement techniques and how to monitor it. Many techniques have been developed over the years for measuring radon and its progeny based on detecting alpha and beta particles and gamma rays, independently or in some combination. A variety of types of testing devices are used to test radon or radon decay products. Devices used by EPA to measure radon gas are listed here.

1. Activated Charcoal Absorption
2. Grab Radon/Activated Charcoal
3. Alpha Track Detection
4. Grab Radon/Pump
5. Continuous Radon Monitoring
6. Grab Radon/Scintillation Cell
7. Electret Ion Chamber-Long Term
8. 3-Day Integrating Scintillation Cell
9. Electret Ion Chamber-Short Term
10. Pump-Collapsible Bag
11. Unfiltered Track Detection
12. Continuous Working Level Monitoring
13. Charcoal Liquid Scintillation
14. Grab Working Level
15. Radon Progeny Integrating

SOURCE : NC Radon Program - www.ncradon.org

Alpha-Track Detector(ATD), Activated Charcoal Detector(ACD), Electret Ion Chamber(EIC), Electronic Integrating Device(EID) and Continuous Radon Monitor(CRM) are the type of radon gas measuring devices used by the WHO International Radon Project(IRP). They are briefly described as follows.

### 4.2.1 General classification and characteristic of radon measuring devices

Generally,radon gas measuring devices can be classified as *Passive* (time integrated) and *Active* (instantaneous) devices. Passive devices do not require electrical power or a pump to work in the sampling setting, whereas active devices require electricity and include the ability to chart the concentration and fluctuations of radon gas during the measurement period. The characteristics of radon measuring devices used by the international Radon

Project of WHO from 2005 to 2007 are described as follows.

Table 4.1: Radon gas measurement devices and their characteristics

| Detector type (Abbreviation) | Passive/Active | Typical Uncertainty (in percentage) | Typical Sampling Period | Cost |
|---|---|---|---|---|
| Alpha-Track Detector (ATD) | Passive | 10 - 25 | 1 - 12 months | low |
| Activated Charcoal Detector (ACD) | Passive | 10 - 30 | 2 - 7 days | low |
| Electret Ion Chamber (EIC) | Passive | 8 - 15 | 5 days - 1 year | medium |
| Electronic Integrating Device (EID) | Active | $\sim$ 25 | 2 days - year(s) | medium |
| Continuous Radon Monitor (CRM) | Active | $\sim$ 10 | 1 hour - year(s) | high |

Uncertainty expressed for optimal exposure durations and for exposures 200 Bq/m3. The most popular radon measuring devices used by countries surveyed within the WHO International Radon Project (WHO 2007) were alpha-track detectors (ATDs), electret ion chambers (EICs), and activated charcoal detectors (ACDs). Active devices in use by many countries included electronic integrating devices (EIDs) and continuous radon monitors (CRMs). For homes, ATDs are a popular choice to obtain a long-term radon measurement and are often deployed for a one-year period, while EICs are often used for short (e.g. several days) to intermediate (e.g. weeks to months) measurement periods. EICs also have the ability to integrate the radon concentration over time (e.g. 8-hour home occupancy period), using an open-and- close feature of the detector. The use of CRMs has become more prevalent as the price of these detectors has slowly declined. CRMs can automatically provide time- resolved information.

1) Alpha-track Detectors(ATDs)

An ATD is a small piece of specially produced plastic substrate enclosed within a filter-covered diffusion chamber that excludes the entry of radon decay products as shown in Figure 4.1.

The plastic is generally a polyallyl diglycol carbonate (PADC or CR-39), cellulose nitrate (LR-115), polycarbonate (Makrofol) material. When alpha particles are generated by radon or radon decay products in proximity to the detecting material, they can strike the detecting material, producing microscopic areas of damage called latent alpha tracks. Chemical or electro-chemical etching of the plastic detector material enlarges the size

Figure 4.1: Example of Radon Detector.

of the alpha tracks, making them observable by light microscopy so that they can be counted either manually or by an automated counting device. The number of tracks per unit surface area, after subtracting background counts, is directly proportional to the integrated radon concentration in Bqh/$m^3$. A conversion factor obtained by controlled exposures at a calibration facility allows conversion from track density to radon concentration. Alpha-track detectors are generally deployed for an exposure period ranging from 1 month to 1 year. Alpha-track detectors are insensitive to humidity, temperature, and background beta and gamma radiation, but measurements performed at very high altitudes (e.g. above 2 000 m) may require slight adjustments due to differences in air density that can affect the distance alpha particles can travel (Vasudevan et al. 1994). Cross-sensitivity to thoron can be avoided by using a diffusion chamber with a large diffusion resistance to gas entering the chamber. A minimum detectable concentration (MDC) of 30 Bq/$m^3$,calculated by methods discussed elsewhere (Currie 1968, Alshuler and Pasternack 1963, Strom and MacLellan 2001), for a 1 month exposure is generally achievable for ATDs. Even lower MDCs can be obtained as prescribed by Durrani and Ilic (1997) and Field et al. (1998).

2) Activated charcoal adsorption detectors

ACDs are passive devices deployed for 1-7 days to measure indoor radon. The principle of detection is radon adsorption on the active sites of the activated carbon. After sampling, the detector is sealed and the radon decay products equilibrate with the collected radon. After a 3-hour waiting period, the collectors can be directly gamma counted, or analytically prepared for liquid scintillation counting techniques. In the gamma counting method, the charcoal canisters or bags contain 25-90 g of activated carbon. In the alpha counting method, 20 ml liquid scintillation vials containing 2-3 g of activated carbon are used. The canisters can be open-faced or equipped with a diffusion barrier to extend the measurement period to 7 days. Because the response of ACD devices is affected by humidity, they must be calibrated under various levels of humidity. The devices should also be calibrated over the range of exposure durations and temperatures likely to be encountered in the field. If different types of carbon are mixed, the calibration may not remain constant. Because charcoal allows continuous adsorption and desorption of radon, the method only provides a good estimate of the average radon concentration over the exposure time if changes in radon concentration are small. The use of a diffusion barrier reduces the effects of drafts and high humidity. Since radon decays with a half-life of 3.8 days, detectors must be returned for analysis as soon as possible after the exposure period. For example, some laboratories require that detectors be returned to the laboratory within 8 days. An MDC of 20 Bq/m3, calculated by methods described by Altshuler and Pasternack (1963), for a 2 to 7 day exposure period, is generally achievable for standard ACDs. Further details are given by George (1984) and USEPA (1987).

3) Electret ion chambers

EICs are passive devices that function as integrating detectors for measuring the average radon gas concentration during the measurement period. The electret serves both as the source of an electric field and as a sensor in the ion chamber. Radon gas, but not decay products, enters the chamber by passive diffusion through a filtered inlet. Radiation emitted by radon and its decay products formed inside the chamber ionizes the air within the chamber volume. The negative ions are collected by the positive electret located at the bottom of the chamber. The discharge of the electret over a known time interval is a measure of time-integrated ionization during the interval. This in turn is related to the radon concentration. The electret discharge in volts is measured using a noncontact battery-operated electret reader. This value, in conjunction with a duration and calibration factor, yields the radon concentration in desired units. Typical short-term EICs are designed to measure radon for 2 to 15 days at a concentration of 150 Bq/m3. The long-term EICs measure radon over 3 to 12 months at a concentration of 150 Bq/m3. EICs have been described previously (Kotrappa et al. 1990). These devices have been used in various countries and have displayed excellent accuracy and precision if standard operating procedures (routine correction for background gamma radiation, assuring the electrets are free of dust, etc.) are followed (Sun et al. 2006).

4) Electronic integrating devices

Most EIDs use a solid-state silicon detector within a diffusion chamber for counting the alpha particles emitted by the radon decay products. Due to the small dimensions of the diffusion chamber, long integration times (¿ 2 days) are often necessary for a statistically stable reading at moderate radon concentrations. Higher sensitivities can be achieved by applying high voltage to collect the charged radon decay products electrostatically by direct contact to the detector. High air humidity may affect the measurement. An MDC of 20 Bq/m3 is typical for a 7-day exposure period. For several popular EIDs, the ability to routinely calibrate these detectors is lacking.
5) Continuous radon monitors

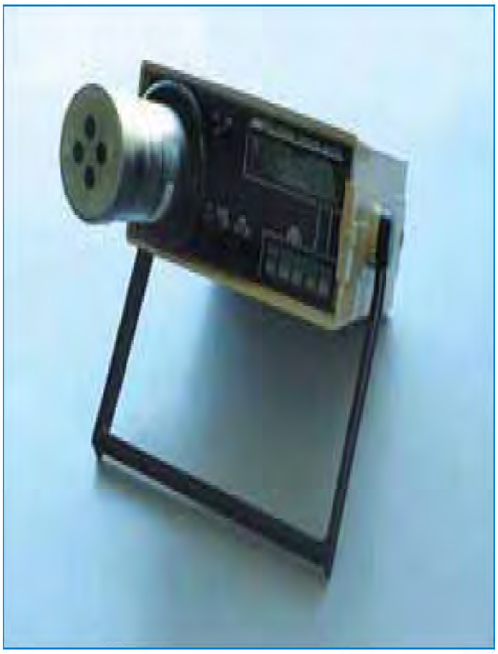

Figure 4.2: An Example of an Electronic Radon Measurement Device.

There are several types of commercially available CRMs using various types of sensors including scintillation cells, current or pulse ionization chambers, and solidstate silicon detectors. CRMs either collect air for analysis using a small pump or by allowing air to diffuse into a sensor chamber. All CRMs have electrical circuitry that provide a summary report, and often a time-resolved recording, which allows the calculation of the integrated radon concentration for specified periods. The different types have their specific advantages. For example, when using solid-state silicon detectors, alpha spectrometry is possible (Tokonami et al. 1996, Iimoto et al. 1998a), allowing discrimination between radon and thoron. Some devices eliminate the cross-sensitivity to air humidity by drying the incoming air. Generally, the MDC of these devices is about 5 Bq/m3 calculated using standard methods. CRMs require routine calibrations to assure proper functioning and reliable results. Figure 4.2 shows an example of an electronic radon measurement device.

## 4.3 Radon Measuring Methods

From the devices listed under 4.2 we can understand that there are fifteen (15) different radon measurement methods. There are methods appropriate for measuring radon gas and radon decay products, respectively. Radon measurements are often discussed in terms of either a short-term or long-term test (Quindos et al. 1991). A short-term test for radon, using an activated charcoal detector or another type of detector such as an electret ion chamber, can provide a first indication of the mean long-term radon concentration in a home. However, diurnal and seasonal radon variations should be taken into account when performing short-term radon measurements. Since high radon concentrations commonly occur during periods when homes are closed up (i.e. windows closed), a short-term measurement performed during this period, or season, can overestimate the yearly mean radon concentration. Alternatively, a short-term radon measurement performed during a period when the house has increased ventilation (e.g. windows open) can substantially underestimate the mean annual radon concentration. Therefore, in order to assess the annual average radon concentration within a home, devices that provide a long-term integrated radon measurement are preferred. However, it should be noted that even yearly radon concentrations in the same home can vary (Zhang et al. 2007).

The following table provides a general guide for the selection of measurement methods and detectors for various measurement scenarios.

Table 4.2: Primary methods and devices for residential radon measurements

| Method | Measurement Type | Device |
|---|---|---|
| Preliminary Test for Radon | Short-term Sampling | CRM, EIC, ACD |
| Assessment of Exposure | Time Integrating | ATD, EIC, CRM, EID |
| Remediation Testing | Continuous Monitoring | CRM |

In situations where a more precise assessment of the radiation exposure is needed (e.g. in a situation where the equilibrium factor F between radon and its decay products differs significantly from the usually assumed value of F = 0.4), the direct determination of the radon decay products can be performed in terms of the equilibrium equivalent radon concentration, the total PAEC, or the activities of each single decay product. All available methods are based on the collection of the radon decay products on filters and a subsequent activity measurement on the filter. Depending on the analyzing technique, different filter material is used, e.g. for alpha measurement, membrane filters on which the sample is deposited at the surface (Iimoto et al. 1998b). Examples of radon and thoron decay product measurement devices include gross alpha counters, integrating alpha-track decay product detectors, alpha-spectrometric devices with surface barrier detectors, and attached-unattached samplers (NCRP 1988, Cheng et al. 1992).

### 4.3.1 Important Terms related to Radon Measurement

**Potential Alpha Energy of Radon:**

The quantity potential alpha energy is the total alpha energy emitted by radon atom as it decays through its entire radioactive series. The term potential then refers to the fact that a given radon atom has a potential to produce a certain amount of energy,if it decays through the rest of the decay chain. In other words, potential alpha energy is the energy which could be released in the lung if radon underwent the entire decay series after depositing in the lung. Only the alpha energy is considered in this definition, since only it is believed to be of radiobiological importance for the $^{222}Rn$ chain. You can see the potential alpha energy in Mev per atom for the three naturally occurring isotopes of radon in table 2.2 (Cothern & Jr., 1987).

**Radon Concentration:**

It is the activity of radon gas in terms of decays per unit time in a volume of air. The unit of radioactivity concentration is Bq/$m^3$. Bq is the unit of radioactivity.

**Equilibrium Equivalent Concentration of Radon (EEC):**

It is the activity concentration of the combined short-lived radon decay products ($C_{EEC}$) which may be in Equilibrium or in Disequilibrium to that of radon activity concentration ($C_{Rn}$). Radon is constantly decaying and giving rise to radon progeny as shown in the following decay chain.

$^{222}\mathrm{Rn} \longrightarrow {}^{218}\mathrm{Po} \longrightarrow {}^{214}\mathrm{Pb} \longrightarrow {}^{214}\mathrm{Bi} \longrightarrow {}^{214}\mathrm{Po}$

These are short-lived radon progenies and decay until reaching a long-lived isotope of lead. Rn-222 and Po-218 emit $\alpha$-radiations. And Pb-214 and Bi-214 emit $\beta$-radiations.

$C_{EEC}$=The Equilibrium Equivalent concentration of radon in Bq/$m^3$

$C_{Rn}$=Radon activity concentration in Bq/$m^3$

Although the exposure to radon is mainly from the inhalation of the short-lived radon decay products and not the radon gas itself, most large surveys are of radon gas concentration $C_{Rn}$. Direct measurements of the concentration of all short-lived radon decay products are difficult and limited. Thy are estimated from the consideration of Equilibrium or (Disequilibrium) between radon and the decay products. The parameter of interest is the

Equilibrium Equivalent concentration of radon, $C_{EEC}$.

**Equilibrium Factor (F-Factor)**:

It is used to describe the ratio between its progeny and radon concentrations. That is, F=$\frac{C_{EEC}}{C_{Rn}}$

Where F = The Equilibrium factor (F-factor)

**Working Level(WL):** It is any combination of short-lived radon decay products in one liter of air that will result in the ultimate emission of 1.3 x $10^5$ Mev of potential alpha energy. This number was chosen because it is approximately the alpha energy released from the decay products in equilibrium with 100 pci of Rn-222. That is 1.3 x $10^5$ of alpha potential enrgy is emitted during radon decay to Lead-210(which is stable) in one liter of air.

1 WL = 1.3 x $10^5$ Mev/lit = 130 Mev/$cm^3$ = 20.83 $\mu$J/$m^3$

F-factor can be defined in terms of WL as follows:

F = 100 x $\frac{WL}{C_{Rn}}$

WL = Radon decay product measurement in WL

$C_{Rn}$ = Radon activity concentration in pci/lit

F = Equilibrium factor,which is a decimal fraction

**Working Level Month (WLM):** It is used to measure the exposures to radon concentrations. The cumulative exposure to an individual exposed at the short-lived radon progeny concentration of a "working level (WL)" over a "working month" of 170 hours is defined as a "working level month (WLM)".

### 4.3.2 Radiation units

Radon and its progeny emit radiations such as $\alpha$-, $\beta$- and $\gamma$-radiations in different proportion. There are four measures of radiation that radiographers will commonly encounter. These are : Activity, exposure, Absorbed dose and Dose equivalent.

1. Activity : Its SI unit is Bequerel (Bq).
2. Exposure : Its most commonly used unit is the roentgen (R).
3. Absorbed Dose : It specifies the amount of radiation energy absorbed per unit mass of material.

   Its SI unit is the gray (Gy). But the "rad" (or radiation absorbed dose) is the commonly used unit of the absorbed dose.

1 rad = 0.01 Gy = 100 ergs/g
or 1 Gy = 100 rad = 1 J/Kg

4. Dose Equivalent : The dose equivalent relates the absorbed dose to the biological effect of that dose. The absorbed dose of specific types of radiation is multiplied by a weight factor or a "quality factor" Q to arrive at the dose equivalent.

   Its SI unit is the Sievert (sv). But the rem (or roentgen equivalent in man) is the commonly used unit of dose equivalent.

   1 rem = 0.01 sv

Table 4.3: The dose equivalent of different radiations

| Type of radiation | Rad | Q factor | Rem |
|---|---|---|---|
| X-ray | 1 | 1 | 1 |
| $\gamma$-ray | 1 | 1 | 1 |
| $\beta$-particles | 1 | 1 | 1 |
| Thermal neutrons | 1 | 5 | 5 |
| Fast neutrons | 1 | 10 | 10 |
| $\alpha$-particles | 1 | 20 | 20 |

Radiation with higher Q factors will cause greater damage to tissue. The above radiation types have equal absorbed dose but different biological effects. For instance; $\alpha$-particles may be 20 times as damaging as beta particles. When describing human health risks from radiation exposure,the quantity called "dose equivalent" is used. The factors (Q factors) are indicative of the relative biological-damage potential of the particular type of radiation.

Chapter 5

# Summary,Conclusion and Recommendation

## 5.1 Summary

The following results are achieved from the long time study of radon in some countries around the world and from the radon study of the international or national organizations. EPA of North America, the North America pooling study, the Eurpean pooling study and WHO are considerable.

Radon was discovered by Friedreich Ernest in 1900; after the discovery of the radioactivity of uranium by Bequerel in 1896. Radon is produced by the radioactive decay of radium which is a member of the naturally occurring uranium decay series. Scientifically, radon is known to be $^{222}Rn$. The most abundant isotope $^{222}$Rn half-life of 3.8 days is a descendant of $^{238}$U while $^{220}$Rn(thoron) haf-life of 55s and $^{219}$Rn(actinon) half-life of 4s are the descendant of $^{232}$Th and $^{235}$U respectively(see Fig.1.1,1.2 and 1.3). Now, radon is known to be a naturally occurring, odorless, tasteless, and colorless radioactive noble (inert) gas produced by the natural breakdown of uranium in soil,rock and rarely in water.

From occupational (miner's environment) history of radon studies we can understand that the health hazards due to radon was occurred among underground miners (even if it was not known at that time) farther back in the 16th century . And from residential history of radon studies we understood that the indoor radon health risks evidentially occurred since 1950 and specially the considerable event occurred in Watras house during December 1984.

Both radon measurements and epidemiological studies in miners' and dwellings' environments, which started early in the 20th century and continued till now, confirmed that there is connection between inhaling radon and the lung cancer. Radon gas was classified as a human **carcinogen** in 1988 by the International Agency for Research on Cancer (IARC) the WHO specialized cancer research agency. More than 100 scientists from 30 countries have participated in the WHO International Radon Project (IRP) since 2005 until 2007 to study the worldwide health hazards due to radon. This has lead to the publishing of the WHO Handbook on Indoor Radon in 2009. The results of radon studies by different international and national organizations and different countries around the world show that radon is considerable to have no immediate health effects but its short-lived solid particulate daughter products ($^{218}Po$ ,$^{214}Pb$,$^{214}Bi$, and $^{214}Po$) are responsible for the main health risks. These daughter products being chemically more reactive ,may attach to surfaces (atach fraction) ,typically of aerosols,which can be inhaled and deposited in the nose or the pharynx(3 percent chance of adhering to the lungs lining); the unattached (free ions) have a high probablity (50 percent chance) of setting on the surface of bronchi (Connell,2005).

Currently, WHO suggests that homeowners take action when radon levels exceed 2.7 pCi/l. The World Health Organization states that as many as 14 percent of the lung cancer cases in many countries (including the United States) are caused by exposure to radon gas. Radon gas has been identified as the leading cause of lung cancer for non-smokers according to recent studies conducted throughout the world. In its recently published Handbook on Indoor Radon, the World Health Organisation (WHO) has categorically stated that the responsibility for risks associated with radon gas is placed on designers, contractors and other property professionals. "Radon poses an easily reducible health risk to populations all over the world, but has not up to now received widespread attention," said Dr. Mike Repacholi, coordinator of WHO's Radiation and Environmental Health Unit.

Many specialized varieties of radon detectors and measurement devices exist and continue to be developed. Detectors technology is highly sophisticated. Radon gas measurement devices can be classified as Passive and Active devices. Passive devices do not require electrical power or a pump to work in the sampling setting, whereas active devices require electricity and include the ability to chart the concentration and fluctuations of radon gas during the measurement period. Some of the radon measurement devices suggested by WHO are Alpha-track Detector (ATD), Activated Charcoal Detector (ACD), Electret Ion Chamber (EIC), Electronic Integrating Device (EID) and Continuous Radon Monitor (CRM). The most popular radon measuring devices used by countries surveyed within the WHO International Radon Project (WHO 2007) were alpha-track detectors (ATDs), electret ion chambers (EICs), and activated charcoal detectors (ACDs).

## 5.2 Conclusion

Now a days the interest of radon study which were started in the laboratory by scientists is increased around the world because of its health effect. The radon study in relation to its health hazards established in the early $20^{th}$ century in Europe in Schneeberg (in Germany) and Joachimstal (in Czechoslovakia) regions after the invention of radon measuring instrument in 1901 as described in unit one. Then, the radon study is continued in many countries of Europe, in U.S.A, in Russia, China, Brazil, Ukraine, Turkey, in South Africa, Namibia, Kenya, Egypt, Libya, Nigeria, etc. At this time, the interest of radon study is highly increased in many countries of the world including our country Ethiopia. No controversy on the health hazards due to radon. The radon action level 4.0 pCi/l which is recommended by EPA of U.S.A is changed to 2.7pCi/l which is recommended by WHO in 2009.

## 5.3 Recommendation

Now, the health effect of radon is becoming a global issue. So, many countries of the world, the international organizations and the national organizations started to take measures. Some M. Sc thesis were performed to measure the radon concentrations, by some nuclear physics graduate students, in nuclear laboratory and in the floors of the graduate building, in A.A.U in 2006, 2007 and 2008. This is an appreciable beginning. But, I recommend that it should be continued in the relevant areas of our country. That is, in the mining region such as Adola, in occupational places such as schools, hospitals and in the residential such as the apartment, the condominium and the individual homes. If the measured radon concentrations is greater than the action level of 2.7 pCi/l, which is recommended by WHO in 2009, the appropriate remedial measures must be taken. Finally, I recommend that it is preferable if our country have a national program of radon measurement.

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## DECLARATION

I the under signed declare that the project is my original work, has not been presented for a degree in any other university and that all sources of material used for the project have been duly acknowledged.

Name: ______________________________

Signature: ______________________________

This project has been submitted for examination with my approval as university advisor.

Name: ______________________________

Signature: ______________________________