INDOOR AND OUTDOOR VARIATION OF RADON CONCENTRATION

By

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This Work is Dedicated to
ALL TRUTH SEEKERS OF THE UNIVERSE!!!

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Abstract

Suction pump was used for air to pass through a glass filter ($>$ 90% filtration efficiency) and aerosols were deposited on it. The sampled filter was placed below a GM tube (with GM nuclear counter) within a time interval of less than one minute after sampling, and gross β counts were registered in successive time interval for more than six to ten hours. Determination of activity concentration of progenies of ^{222}Rn and EEC (equilibrium equivalent concentration) of ^{222}Rn was done by fitting the observed gross β count to a mathematical model.

The indoor and outdoor variation of ^{222}Rn was observed inside and outside of the nuclear physics laboratory (around four meters above the ground).
The average EEC of ^{222}Rn was found to be 23.9 Bq/m^3 and 3.74 Bq/m^3 for indoor and outdoor respectively.

Indoor radon concentration is 4 to 6 times higher than the outdoor. Our result agrees with the results available in other studies.

Introduction

^{222}Rn is part of the natural radioactivity chain which contributes more than 50% of the exposure from the natural radiation environment. The other isotope ^{220}Rn has less significant radiological since it has limited abundance and short half lives of its daughters.

^{222}Rn is available naturally in air wherever uranium laden soil or rocks are available as far as it is the descendant of ^{238}U. Indoor radon concentration exceeds the average permissible limits in some places and seasons depending on construction materials rate of ventilation etc. (Vohra et al., 1981).

Most people spend about 20% of their life time outdoor while the rest is in door. Exposure during this time can not be over looked. Therefore, it is important to compare the indoor and out door radon content of a given place.

In this work the indoor and outdoor radon concentrations are compared in the department of physics building in Addis ababa university.

Air was filtered on a glass fiber filter, of high retention power, and the deposited activity was observed and gross count was registered for long hours ranging from 6 to 10 hours. The gross count was then fitted to a mathematical model to determine the activity concentration of radon daughter products in the sampled air.

Chapter 1

Introduction

1.1 Discovery of Radon

Discovery of radioactivity in (1899) left a bright spot on the birth and progress of nuclear investigations. Great scientists like Becquerel, Rutherford, Friedreich, Curies, . . . are some to be quoted down.

Though the heart of the discovery of radon was by Friedreich Ernest in 1900 which was accompanied by Rutherford in 1991, Marie and Pierre Curies were the first to observe that the emanation from radium is radioactive. Nevertheless, it was not known, to the Curies, the gaseous state of the emanation which was the backbone of the discovery. It was perfectly shown by the discoverers that the emanation stayed for 7.64 days besides to its being gas. Ramsay and Gray in 1908 gave the name niton to this emanation. It was too late to be called radon since 1923.

Brilliant scientists like Friedrich Giessel and Andre-Lousi Debierne followed the footprints of their fathers and showed the existence of another isotope called Actinon. It is known that there are around 17 isotopes of radon in addition to the above two.Some of these isotopes are man made while others are naturally occurring with less than five percent natural abundance.

The first measurement made by Elster and Geitel in 1901 (Nagaratnam, 1994) was basically intended for the study of environmental phenomena like atmospheric electricity, atmospheric transport and exhalation of gases from soil. Serious investigations were followed not for atmospheric studies but to a great

extent due to the health hazards caused by radon.Series of measurements world wide have shown that radon is the ubiquitous part of the atmospheric air.

1.2 Physical properties of radon

Radon is a fascinating type of element in which it is the only massive radioactive inert gas found everywhere in different proportions. This special property of radon makes it to unique. Except the physical effects, radon is colorless (at standard temperature and pressure), odorless and tasteless element. 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 liquifies.

Physical properties of radon	
Name , Symbol , Number	radon , Rn , 86
Chemical series	noble gases
Group , Period , Block	18 , 6 , p
Appearance	colorless
Atomic mass	(222) g / mol
Electron configuration	[Xe] $4f^{14}$ $5d^{10}$ $6s^2$ $6p^6$
Electrons per shell	2, 8, 18, 32, 18, 8
Phase (state)	gas
Melting point	202 °K (-71 °C)
Boiling point	211.3 °K (-61.7 °C)
Heat of fusion	3.247 KJ / mol
Heat of vaporization	18.10 KJ / mol
Heat capacity	(25 °C) 20.786 J / (mol . °k)

Table 1.1: Physical properties of Radon

1.3 Origin 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. Surprisingly, it is the direct radioactive product of radium. Saying it in different words, it is the descendant of Uranium 238. Radon as it has around nineteen isotopes, two of them are thoron and action, are

naturally occurring while the others are artificially found with very small natural abundance. The following are the series showing the family of the radon, thoron and actinon.

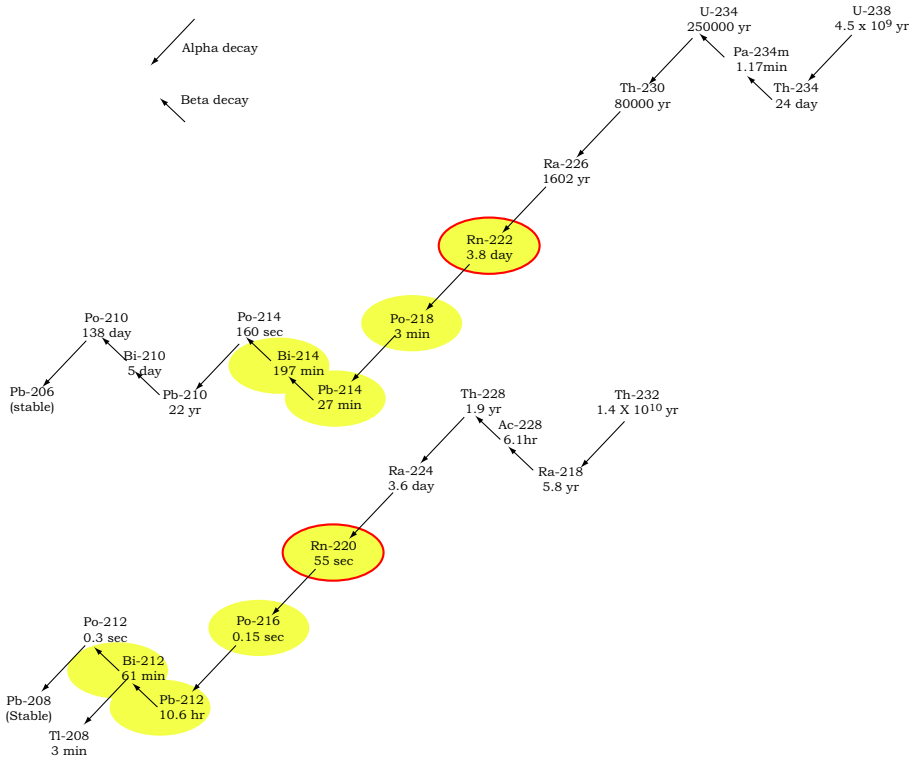

Figure 1.1: Decay series of Radon isotopes

1.3.1 Radon entry into the atmosphere

It is reputedly said that uranium is the basic component of the earth. This fact leads us to say radium which is the progeny of radium is also found 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.

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 μm 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 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.

In addition to the natural mineral composition of a given amount of soil or rock of part of the earth, some other physical events like microscopic fractures and fissures, called nanopores, and pits or openings caused by previous radioactive decays accelerate the emanation probabilities for radon to be released into the air. Specially, in sand-sized and larger grains, nanopores can give to a higher specific surface area of the grain, greatly increasing the emanation by certain orders of magnitude. On the contrary, soil moisture has a recognized effect in decelerating the diffusion or escape of radon and its isotopes. It blocks the journey of recoiled radon which is rushing to join the atmosphere. It does it as it is surrounding the mineral grain in the form of a thin film. This effect is pronounced for low energy recoils.Otherwise it might be challenged perfectly by high energy recoils.

Though limitations exist to go deeper to what happens to radon inside the earth, it is worthy to make a rough investigation. Though the basic strategy for radon to join a certain atmospheric region is molecular diffusion, there might be also some advection caused by wind and changes in barometric pressure.

The concentrations of ^{222}Rn in soils specifically in the upper parts which are near to the atmosphere have variable records with respect to different places and times. The internal dynamics of the earth is basically accountable for it. Evidence is, the great earthquake occurred at Koba, Japan in 1995 (UNSCEAR, 2000) by preceding larger amount of radon concentrations in the atmosphere particularly in outdoor air and groundwater.

Generally speaking, the entry of radon to the atmosphere looks like this. As an atmosphere is layers of gases from the ground to higher altitudes, mines, indoor air, outdoor air and water bodies are in the balm of it. Following this, the succeeding subsections revolve around radon's existence in these parts of atmosphere.

1.3.2 Radon in mines

Radium available as part of the ore is the major source of radon in mines. Production and release into the mine atmosphere depends on the grades, its emanation power, porosity and permeability of host rock to radon and moisture content of the ore. Water coursing through the ore body remains under high pressure which dissolves significant amounts (up to 23%) of radon available in the ore spaces through which it passes; this acts as an efficient medium of transport for radon carrying it from far-off places and discharging it into the mine cavity. The moment radon-laden water enters the mine openings and flows through the mine galleries, dissolved radon is released due to depressurization and constant agitation. (UNSCEAR, 2000)

Radon produced by the decay of radium located in the grains of the ore matrix moves out by recoil into the pore spaces and remains locked up there. Mining operations such as drilling and blasting bring fresh radon into the mine air.

Radon gas, on entering the mine air by various processes remains there till it is carried along in the ventilation current and discharged above ground. Because of its comparatively long half life (3.8 days) compared with the residence time of air in a mine (approx. 40 mins.), radon concentration increases in proportion to its rate of release and travel time along different passages of the mine. (UNSCEAR, 2000).

1.3.3 Radon in outdoor air

It should not be surprising for someone for observing in equal amounts of radon on the outdoor air since the concentration is influenced by many factors. Keeping in mind that exhalation rates play a great role in varying the concentration, the heat induced by solar radiation has also considerable effect meaning turbulence is induced and as a result the radon atoms tend to move upwards. An impressive

phenomena is, this is accompanied by a reverse process in in the absence of the turbulence due to solar energy. In addition to this, radon atoms which are suspending at normal condition might be dissolved and come down to the ground if there is rain. Winds also take great part in transporting radon from place to place though diffusion also has some part. This leads to the conclusion that these effects must be taken into account when interpreting the variable measurements (UNSCEAR, 2000).

1.3.4 Radon in indoor air

According to (Cliff, 1978), Exposure to the short-lived daughters of radon is not confined to the underground miners. Uranium is widely distributed constituent of the earth's crust, typically in 2-4 parts per million and in consequence is found in most materials commonly used by the building industry. Radon, being a noble gas, diffuses from the subsoil below the building into room air, where it and its daughters are available for inhalation by the room occupants

"The early recognition of radon as a carcinogen in the 1920s did not initiate investigation in dwellings until much later. There were two main reasons for the long delay. Firstly, the carcinogenicity of radon miners was not generally accepted and secondly, much lower radon levels were expected in dwellings above ground" (Cliff, 1978).

"Outdoors, where it is diluted to low concentrations in the air, ^{222}Rn poses significantly less risk than indoors. In the indoor environment, however, ^{222}Rn can accumulate to significant levels. The magnitude of ^{222}Rn concentration indoors depends primarily on the type of construction materials of the building and the amount of uranium deposition in the underlying soil. The soil composition under and around a house affects ^{222}Rn levels and the ease with which ^{222}Rn migrate into a house. Normal pressure differences between the house and the soil can create a slight under pressure in the house that can draw ^{222}Rn gas from the soil into the building. ^{222}Rn moves more rapidly through permeable soils, such as coarse sand and gravel, than through impermeable soils, such as clays. Fractures in any soil or rock allow ^{222}Rn to move more quickly. In a very small number of houses ^{222}Rn levels are generally highest in basements and ground floor rooms that are in

contact with the soil. Factors such as design, construction, and ventilation of the house affect the pathways and sources that can draw ^{222}Rn indoors" (Tassos and Haralabos, 2003).

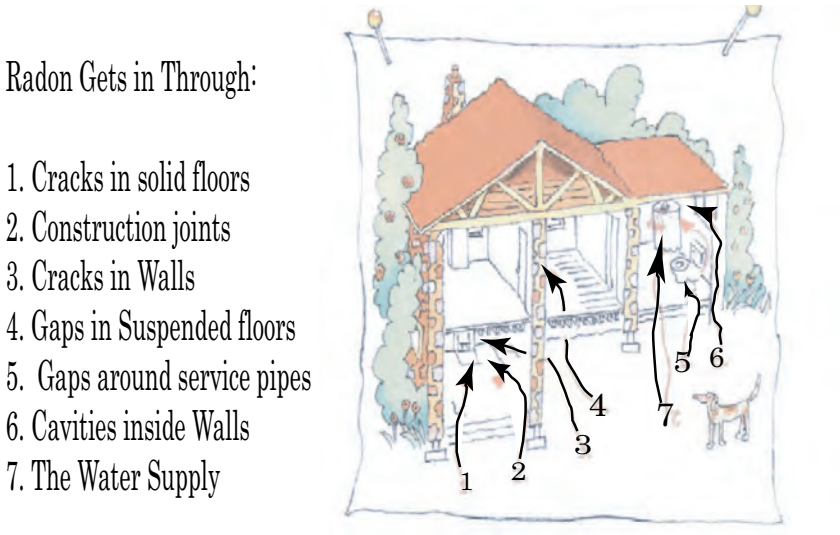

Figure 1.2: Radon entry into the house (EPA, 2005)

"The chances of increased level of indoor radon is higher in areas of higher uranium laden soil. But some houses in areas with lots of uranium in the soil have low levels of indoor ^{222}Rn, and other houses on uranium-poor soils have high levels of indoor ^{222}Rn. Clearly, the amount of ^{222}Rn in a house is affected by other factors in addition to the presence of uranium in the underlying soil. One example is the permeability of the soil" (Tassos and Haralabos, 2003).

Considering all of the factors mentioned above, and especially the design and quality of construction of an individual structure, the factors that determine the entry rate are many, varied, and very site-specific. Successful mitigation strategies, such as identifying and sealing a limited number of entry pathways or effectively ventilating the soil immediately adjacent to the foundation, tend to work because radon entry into structures can be fairly readily prevented, or at least substantially reduced, be redirecting and re-channelling air transport away from building interiors. Radon concentrations are typically reduced by about 30 percent. Other techniques aim at reducing the building/ground pressure differential that drives the advection; the radon convections are typically reduced by 80-90 percent. Improvements in ventilation systems normally change radon concentration by less than 50 percent

(UNSCEAR, 2000).

According to (UNSCEAR, 2000) there are no desired information on the concentration of ^{222}Rn on multistory buildings like apartments offices. Movements are on with single-family houses with or without basements and crawl spaces. The expectation that ground sources would be less important for spaces well above the ground has generally been supported by lower concentrations of ^{222}Rn in higher stories.

Studies show that the concentration of radon gas decreases with the elevation above the ground level i.e. ground floors have higher concentration as compared to higher stories. Similarly, factors like ventilation, room usage, building materials also affect the indoor radon concentration (Al-Sharif and Y.S., 2001).

1.3.5 Radon in water

As radon is found everywhere it is to mean also that it is found in water since water is part of the earth. Basically, radon comes from under ground soil due to different mechanisms. As a matter of fact, radon might successfully come out of the soil but would be stopped by water since it is soluble in it. Practically, it is observed that human activities disturb the water for many purposes. As a result, radon gases escape to the atmospheric air or be used for drinking and consequently intake to the stomach. So people who have private dwellings are at higher risk unless special treatment is made because the intake of the water full of radon is much faster than municipal waters.

1.4 Health risks of radon

1.4.1 Discovery

"G. Agricola (1494 - 1555) working in Joachimsthal (now Jachymov), Czechoslovakia, chronicled unusually high mortality from respiratory disease autopsy findings that documented pulmonary malignancy in miners in that region 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

Table 1.2: Radon concentrations in dwellings (UNSCEAR, 2000)

Region	Country	Population In 1996 (10^6)	Radon concentration (Bqm^{-3}) Arith. mean	Geom. mean	Max. Value	Geom. Standard Deviation
Africa	Algeria	28.78	30		140	
	Egypt	63.27	9		24	
	Ghana	17.83			340	
North America	Canada	29.68	34	14	1720	3.6
	United States	269.4	46	25		3.1
South America	Argentina	35.22	37	26	211	2.2
	Chile	14.42	25		86	
	Paraguay	4.96	28		51	
East Asia	China	1232	24	20	380	2.2
	Honk Kong	6.19	41		140	
	India	944.6	57	42	210	2.2
	Indonesia	200.45	12		120	
	Japan	125.4	16	13	310	1.8
	Malaysia	20.58	14		20	
	Pakistan	140	30		83	
	Thailand	58.7	23	16	480	1.2
West Asia	Armenia	3.64	104		216	1.3
	Iran(Islamic Rep.of)	69.98	82		3070	
	Kuwait	1.69	14	6	120	
	Syria	14.57	44		520	
North Europe	Denmark	5.24	53	29	600	2.2
	Estonia	1.47	120	92	1390	
	Finland	5.13	120	84	20000	2.1
	Lithuania	3.73	55	22	1860	
	Norway	4.35	73	40	50000	
	Sweden	8.82	108	56	85000	
West Europe	Austria	8.11		15	190	
	Belgium	10.16	48	38	12000	2
	France	58.33	62	41	4690	2.7
	Germany	81.92	50	40	>10000	1.9
	Ireland	3.55		37	1700	
	Luxembourg	0.41	110	70	2500	2
	Netherlands	15.58	23	18	380	1.6
	Switzerland	7.22	70	50	10000	
	United Kingdom	58.14	20		10000	
Eastern Europe	Bulgaria	8.47		22	250	
	Czech Republic	10.25	140		20000	
	Hungary	10.05	107	82	1990	2.7
	Poland	38.6	41	32	432	2
	Romania	22.66	45		1025	
	Slovakia	5.35	87		3750	
South Europe	Albania	3.4	120	105	270	2
	Croatia	4.5	35	32	92	
	Greece	10.49	73	52	490	
	Italy	57.23	75	57	1040	2
	Portugal	9.81	62	45	2700	2.2
	Slovenia	1.92	87	60	1330	2.2
	Spain	39.67	86	42	15400	3.7
Oceania	Australia	18.06	11	8	420	2.1
	New Zealand	3.6	20	18	90	
Median			46	37	480	2.2
Pop.-weighted average			39	30	1200	2.3

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 epidemiologic 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 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).

"In 1936 Rajewsky initiated a comprehensive study programme involving radon measurements in Schneeberg mines, measurements of the alpha activity in the tissue samples and histopathological analysis of lung tissues from miners who had died of lung cancer. At that time, the average radon concentration in most mines at Schneeberg was in the range of $70 - 120\,\mathrm{KBqm}^{-3}$. In one time, however, the mean level was $500\,\mathrm{KBqm}^{-3}$, and most workers here died from lung cancer; it was called 'death mine'. On the basis of these studies Rajewsky was able to establish conclusively in 1940 the casual link. However, till 1945, no quantitative dose-response relation could be worked out, nor was the possible role of inhalation of short-lived radon progeny realized" (Nagaratnam, 1994).

"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

Table 1.3: Average worldwide exposure to natural radiations (UNSCEAR, 2000)

Source of exposure	Average effective dose (mSv) Average	Typical range
Cosmic radiation		
Directly ionizing and photon component	0.28	
Neutron component	0.1	
Cosmogenic radionuclides	0.01	
Total cosmic and cosmogenic	**0.39**	**0.3-1.0**
External terrestrial radiation		
Outdoors	0.07	
Indoor	0.41	
Total external terrestrial radiation	**0.48**	**0.3-0.6**
Inhalation exposure		
Uranium and thorium series	0.006	
Radon (^{222}Rn)	1.15	
Thoron (^{220}Rn)	0.1	
Total inhalation exposure	**1.26**	**0.2-10**
Ingestion exposure		
^{40}K	0.17	
Uranium and thorium series	0.12	
Total ingestion exposure	0.29	0.2-0.8
Total	**2.4**	**1-10**

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 $Bqm-3$. 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).

International Agency for Research on Cancer (IARC) has classified radon as a carcinogen to human beings. A study made by U.S. environmental protection agency (EPA, 2005) showed that radon is estimated to cause thousands of lung cancer deaths in the U.S. each year (see figure 1.3).

According to the EPA'S 2003 Assessment of Risks of radon in homes, it is estimated to cause about 21,000 lung cancer deaths per year.

1.4.2 Effects of radon on the body

As mentioned formerly, radon is an alpha emitter radioactive gas element. It enters the lung and might return back to the atmosphere, come out as a by product like urine or come out as sweat (if ingested through the stomach). The source of the problem lies either on the effect produced by the ionizing radiation emitted by radon or the radiations emitted by the progenies of radon which have short half lives compared to the half life of radon. But the effect of radon emitted radiations

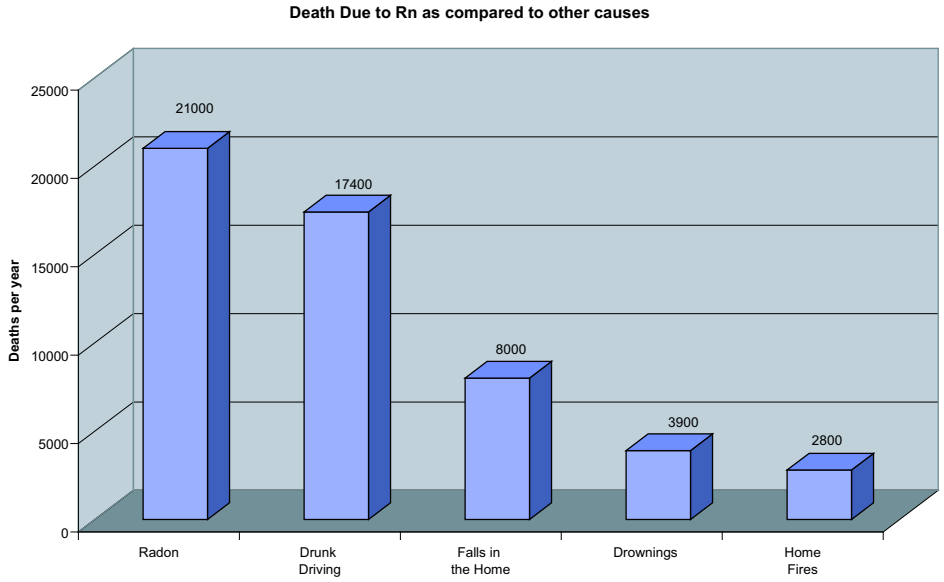

Figure 1.3: Death due to radon as compared to other causes in U.S. (EPA, 2005)

has very small probability since ^{222}Rn has long half life compared to its progenies. Rather, the greatest effect comes from the three progenies of radon 22 (^{218}Po, ^{214}Pb, ^{214}Bi) inhaled simultaneously with the other gases attached with aerosols and finally they might get attached to the digestive organs and as they emit radiations the radiation damages the tissues and organs of our body. Generally speaking, inhalation is the main route of entry, into human body, for radon and its progeny and cause health problems. it is reported that, it is likely that radon decay products contribute significantly to the risk of lung cancer from cigarette smoke(EPA, 2005).

As mentioned above, ingested with water is excreted through the urine over several days. There is some risk from drinking water with elevated radon, because radioactive decay can occur within the the body when tissues, such as the stomach lining, would be exposed. However, particles emitted by radon and its decay product in water prior to drinking quickly lose their energy and are taken up by other compounds in water, and do not themselves pose a health concern (EPA, 2005).

1.5 Treatment of the Problem

Before making best choice of settlements, they have to have the available radon concentration data besides the many considerations they make. If it happened to

make settlements with not taking this measures, there might be many secondary corrections. It is like:take the data of building and if data show some risks in health, make some modification on the building material, which block the entrance of radon from the under ground soils to building, or use ventilation mechanism depending on the financial strength of each individual. To this end, it is important to note down that at least places where many people are in health problems need special treatment.

1.6 Main objective of the study

It is many times written that radon has un ignorable health risk. Once and again it is worth value to say that radon is carcinogenic which directly throws each of us to make heart felt awareness of our environment and as a result to take research based measures. As a matter of fact, we felt responsible in contributing to the future plan of Ethiopian radon gas map. Bemenet broke the ice last year and this year we followed his footsteps. Bemenet's work was function of time but this work is based on place variation.

Chapter 2

Radon Measurement Methods

Many people who were striving to know the concentration of radon and its progenies for different purposes contributed much for the advancement of different techniques for measuring radon concentration since its discovery. The basic principles of these measurements focus on what they emit. Being aware to know the emissions alpha, beta and gamma, they continued their studies on the effects of these radiations on matter which indirectly helps to study the properties of the emitters.

Depending on the duration of time where the sampling is treated, radon measurement techniques are generally classified as *passive* and *active* methods. In the passive methods the measurement is usually accomplished over a long period of time and the result is reported as the average over the measured time interval. In active measurement method, the radon concentration is made as simultaneously as the effects of the radiations are produced.

This chapter lists some commonly used methods from both. Great emphasis should be paid for them because they are standard methods which are described in detail in "indoor radon and radon decay product measurement device protocols" published by U.S. environmental protection agency (EPA, 1992).

2.1 Passive Measuring Methods

There might be as many as number of passive measuring methods but in this section the Solid state nuclear track detector (SSNTD), Activated charcoal (AC), Charcoal liquid scintillation (LS), and Electret ion chamber (EC) will be discussed.

2.1.1 Solid State Nuclear Track Detector

This method amazingly applied as one method of even now days in great research areas. Solid State Nuclear Track Detector (SSNTD) is a small piece of plastic or film enclosed in a container. Then radon diffuses into the container and radon decay products strike the detector and produce submicroscopic damage tracks. At the end of the measurement period, the detectors are returned to the laboratory. Plastic detectors are placed in a caustic solution that accentuates the damaged tracks so they can be counted using an automated counting system. The number of tracks per unit area is correlated to the radon concentration in air. The number of tracks per unit of analyzed detector area produced per unit of time minus the background is proportional to the radon concentration.

SSNTD is mostly made up of detection material and detection chamber. The most popular member of SSNTDs family detection material is CR-39. It has good sensitivity, stability against various environmental factors, and high degree of optical clarity. The detector chamber is a cylindrical cup. Carbon is impregnated in the wall material, polypropylene, to enhance electrical conductivity and to avoid the problem of electrostatic charge. Radon enters the holder with a half-time for entry about 1 minute, which is short compared with the radon half-life of 3.82 days. This means that the radon concentration inside the detector chamber quickly approaches that of outside. It can be shown that the long-term average radon concentration inside the detector chamber is the same as that outside, despite any variations in the outside concentration. But the radon concentration may be overestimated because the short half-time for entry will allow some thoron to enter the detector (Ahn and Jai-Ki, 2005).

The optimal use of any track detector is largely dependent on standardization of various etching parameter. CR-39 samples are irradiated using an alpha source. Irradiated CR-39 samples can be etched in a solution. NaOH solution is most popular etchant and has been extensively studied. Varying concentrations of NaOH solutions can be used at different temperatures and periods. The etched tracks can be observed using an optical microscope. Calibration experiment can be carried out to evaluate the relationship between the track density recorded and the radon concentration (Ahn and Jai-Ki, 2005)

2.1.2 Activated charcoal (AC)

Focusing to the point, AC method is adsorbing radon accompanied by counting the effects produced by gamma radiations emitted from its progenies ^{214}Pb and ^{214}Bi since in this method there is an activated charcoal that has adsorption property not only to radon but also to different gases and vapors. The main point to be remembered is, the above two progenies of radon are chosen because they have short half lives.

Since AC need no power for its functioning and has continuous adsorption property it is mainly applicable in continuous (long period) investigation of radon. One thing that needs critical follow up is during the measurement period some radon nuclide might decay as it is done for long period of time. As a result a leakage to exactness follows. Specially, if it happens that the decay leads to high variation then the deviation might be un ignorable.

Most ACs consists of a circular container filled with activated charcoal in which one side of the container is fitted with a screen that keeps the charcoal allows air to diffuse into the charcoal. In order to keep the uniformity of the response to variations of radon concentration with time, as the measurement made for long time, the charcoal container has a diffusion barrier over the opening and some containers might have desiccant which helps to minimize interference from moisture adsorption. Another variation of the charcoal container has charcoal packaged inside a sealed bag, permitting radon to diffuse through the bag. Over all, all ACs produced properly and legally are sealed with a radon proof cover outer container after preparation.

The first step for the measurement to move is removing the cover for air carrying radon to diffuse into the charcoal bed which is responsible for adsorbing the radons. The measurement is initiated by removing the cover to allow radon-laden air to diffuse into the charcoal bed where the radon is adsorbed onto the charcoal. At the end of measurement period, the device is resealed securely and returned to laboratory for analysis. As the sampling is ended, the device is resealed with a great care and finally to the laboratory for its analysis.

By putting directly sampled activated charcoal, being in its container, on gamma detector then the experiment is pushed forward for investigation of radon

concentration. There might also an error introduced due to simultaneous adsorption of water vapor which decreases the sensitivity of charcoal. One way of paralyzing this error is weighing the detector both before and after sampling. Any weight increase is attributed to water adsorbed on the charcoal. Then finally the net analyzed weight is correlated to a correction factor. This has a great influence in purifying the analytical result found latter.

There might be situations where it is possible to ignore the correction factor if the effect is minimized in some ways like by decreasing the water adsorption power and by running the sampling on the charcoal over wide range of humility.

Great advantages like complete passiveness, low cost, high efficiency and lower detection are some to be risen which are profits of this method.

2.1.3 Charcoal liquid scintillation (LS)

Though not all, frequently used type of LS device is a capped liquid scintillation vial which sometimes contains charcoal having a diffusion barrier with the objective to stabilized its response for variations in radon concentration with time as exposures are for long time intervals. It is advisable to add some few grams of desiccant to reduce interference from moisture adsorption by charcoal as AC. After preparation is ended, the preceding step in all LS devices is to seal it with a radon proof closure.

After preparation and sealing are done the measurement with LS is started by removing the radon proof closure to allow radon-laden air to diffuse into the charcoal where the radon is adsorbed. This exposure runs for some two to three days and finally as in the AC device is resealed with a great care and returned to the laboratory for analysis.

At the laboratory, the devices are prepared for analysis by radon adsorption techniques. This technique transfers reproducibly a major fraction of the radon adsorbed on the charcoal into a vial of liquid scintillation fluid containing the dissolved radon are placed in a liquid scintillation counter and counted for specified number of minutes (e.g. 10 minutes) or until the standard deviation of the count is acceptable (e.g., less than 10 percent)

2.1.4 Electret ion chamber (EC)

The electret ion chamber devices have impressive advantages over the passive such that there are two types of ECs. They are short-term and long-term ECs. They are cost effective, in a sense, they do not need any power supply for their function. In addition to this, they are true integrators to measuring the average concentration over certain measurement period.

The EC devices have special properties unlike the other passives do. It is charged due to its content of a charged electret (an electrostatically charged disk of Teflon) which gathers ions formed in the chamber of the device by radiation emitted from radon and radon decay products. These, radon and its decay products are collected by exposing the EC in to the selected cite since radon can diffuse into the chamber through filtered opening. Then ions which are produced continually by the decay of radon and radon decay products are drawn to the surface of the electret and consequently they reduce its surface voltage which intern this reduced value is related directly to the average radon concentration and the duration of exposure period. ECs can be deployed for exposure periods of two days to 12 months, depending upon the thickness of the electret and the volume of the ion chamber chosen for use.

After making sufficient measurements the electret should be removed from the EC chamber and the final electret voltage is measured with a special surface voltmeter provided that electret voltage was made initially. This method leads to a beautiful determination of the average radon concentration during the exposure period by taking the difference between the initial and final voltages is divided first by a calibration factor and then by the number of exposure days. A background concentration equivalent of ambient gamma radiation is subtracted to compute radon concentration. Electret voltage measurements can be made in a laboratory or in the field.

2.2 Active Measuring Methods

Of the many the following active measurements have drawn the attentions. To call down,they are grab radon sampling method, Pump/collapsible bag method and

Three-day integrating evacuated scintillation cells method. For best explanations the following section will take the part.

2.2.1 Grab radon sampling

This method of measurement revolves around basic techniques. These are Grab radon (scintillation cell) or GS method, Grab radon (activated charcoal) or GC method, Grab radon pump (collapsible bag) or GB method and Grab radon and thoron progeny sampling using Geiger-Muller counter. Following sections contain the details.

Grab radon / scintillation cell (GS) method This method follows the strategy of collecting the sample of the experiment by pumping air through an activated charcoal. After a sample of air is made to pass through it, it is sealed in a flask or cell which contains zinc sulfide phosphor coating on its interior surfaces. To count the scintillations produced by the alpha decays of the collected sample as they interact with the walls of the detector which is made of zinc sulfide, one of the surfaces of the cell should be fitted with a clear window closely attached with a photomultiplier tube. It is obvious that the number of pulses formed is proportional to the radon concentration in the cell. The interval of counting extends for some four hours after filling to allow the short-lived radon decay products to reach equilibrium with the radon. It is worth efficient to take correction factors to the counting results since in the journey from sampling to counting some number of radon atoms are decayed as the time interval describing this physical event is($>$onehour). This contributes an error in the actual investigation of the concentration of radon in the selected cite and time. In a variation of this method, used in some portable instruments, air is pumped continuously through a flow-through-type scintillation cell for just a few minutes. Ineresting part of is alpha particles emitted are counted in this way simultaneously as the radon and its daughters are pass through.

Grab radon/ activted charcoal (GC) method Core of the principle is, charcoal-filled cartridge is placed into a equipment where sampling is to be made.

As this is done,air pumping through the cartridge follows. No matter to the flow of the pump with this cartridge, adjusting the the operation of pump to the limit till equilibrium between the radon collected or sampled to its the environmental (sampling collection) is reached needs a great follow up to wind up the sampling successfully. A sampling duration of one hour has been found to be optimal for most systems.Basic idea that needs focus is,the weight of cartridge should be recorded just before and after sampling to eradicate errors introduced due to adsorbing of water vapor that greatly affects the sensitivity of the charcoal. Then to this end analysis of the cartridges by putting it on sodium iodide gamma scintillation system or germanium detector will be the final step for this method.

collapsible bag (GB) method Unless the time where the bag fills differ that is in this method it is made for short period of time in GB but in PB, all the methods and technologies are same as in the PB to be discussed latter.

Grab radon and thoron progeny sampling using Geiger-Muller counter Formerly few radon concentration measuring methods are introduced and it will precede too. The method in here is nothing but it is based on the betas emitted by radon and its progenies. The beta emitter samples are filtered aerosols from the sampling cite under consideration. Then the filtered sample is placed under an end-window Geiger-Müller nuclear counter. This method enables to investigate simultaneously the concentration of radon as well as thoron's decay products. This is the method applied in the work of the thesis. Further details will be linked soon in the fore going chapter.

2.2.2 Pump / collapsible bag (PB)

It is simple method for the purpose of radon concentration investigation despite its age of introduction. Using this method someone can make integrated measurement of radon over a desired time of interval. The action of collection of the sample of the ambient air in a radon-proof container over the desired sampling time period and measure the resulting radon concentration in the container.

One practical method is to use a small pump with a very low and uniform

flow rate to pump ambient air into an inflatable and collapsible radon proof bag. After the desired sampling period (typically 24 hours), the concentration of radon in the bag can be analyzed by any of the standard methods using the appropriate radon decay correction factors. The main purpose of the collapsible bag is to avoid variation in pump flow rate due to build up of back pressure in a container. Bags that have been measured to have a very low loss of radon by diffusion through the bag have been made of laminated mylar, aluminized laminated mylar, and tedlar. The pump flow rate is not critical as long as it is suitable for the size of the bag and the sample duration, but variation of the flow rate over the collection time period of the sample will affect the accuracy of the measurement.

2.2.3 Three-day integrating evacuated scintillation cells (SC)

In this method collection of air samples is based on certain valve operations of Lucas type scintillation cells. This Locus type of scintillation is outfitted with a restricter valve attached to the main valve. As a result, samples are collected by opening the valve on an evacuated cell. And the restricter valve contributes its help in making the cells fill from a 30-inch mercury (Hg) vacuum to about 80 percent of its capacity over a three day period. As sampling is ended, this valve is closed and analysis in the laboratory heads on. Nodoubt in operating the volume of filtered air for three days sampling or measuring time since the volume of the cell is known and it can be evaluated from the vacuum gauge reading at the end of the sampling period. Handling the sampling in this manner, analyzing it moves using an an alpha scintillation counter. As in the other methods, counting should be made after adjusting the pressure in the cell to be one atmosphere which is accomplished by adding radon-free air so that the sample is analyzed under the same conditions that prevailed during calibration of the cell. For the matter to allow radon and its progeny to be in equilibrium and to allow any radon decay products that may have been collected to decay, the sample should be collected no sooner than four hours after the end of the measurement.

Chapter 3

Materials and Methods

3.1 Materials

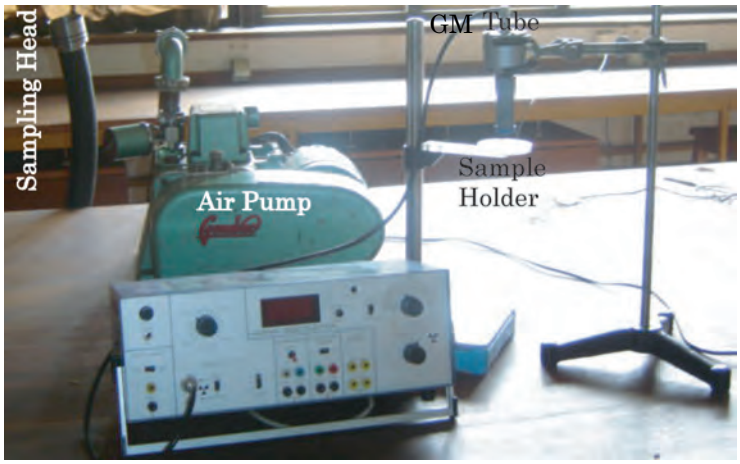

Figure 3.1: The experimental setup

The basic materials used for the experiment are sources of potential difference, pumping machine(air suction pump), sampling head, filtering paper and GM nuclear counter with End-window GM tube

The basic definitions of each equipment is as follows

potential difference: used for functioning of the air suction pump and the GM nuclear counter.

Air suction pump: is an equipment used for driving air to pass through the filter. And its figure is as follows.

Filtering glass paper: used as the screening and absorbing the radon progenies from the air that passes through the filter using the pumping machine. It is put on the sampling head during sampling.

GM nuclear counter: has two parts. The first is GM tube while the second is the counter. The GM tube is filled with argon to be ionized by the the incoming radiation while the counter collects electrons and reports through its window screen.

3.1.1 The sampling head

The sampling head has the following longitudinal crossection view which was also used by Z.Papp.

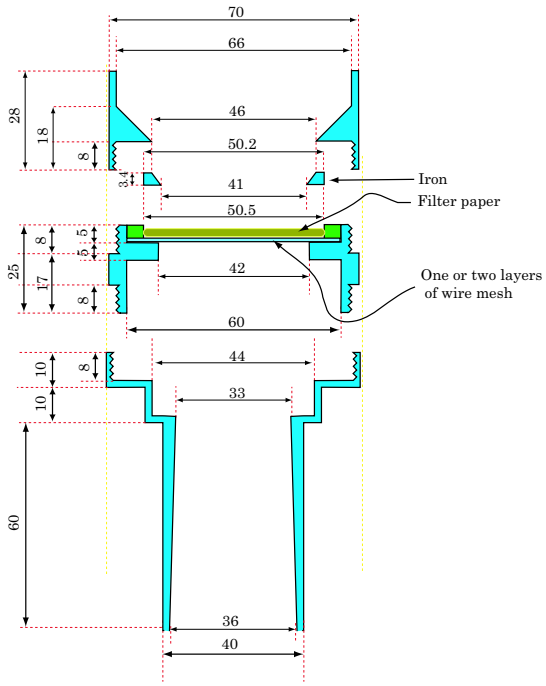

Figure 3.2: Air Sampling Head Blueprint

Figure 3.3: Photograph showing Parts of the Sampling Head

Figure 3.4: The Air Sampling Head assembled

3.1.2 Filtering air

A glass filter of thickness of $0.0095\,\mathrm{gcm}^{-2}$ and with dimensions of $2.9\,\mathrm{cm} \times 2.8\,\mathrm{cm}$ was placed on the sampling head for gathering (sampling) air born radon daughters of radon 22 as well as daughter products of thoron. For pumping Genevo rotary piston vacuum was used. By switching on the air suction pump, air will start flowing through the filter at a rate of 112 litres/minute and as a result progenies of ^{222}Rn and ^{220}Rn are deposited on the filter. This sampling was for twenty minutes.

3.2 Methods

3.2.1 The counting process

The counting process was carried out by GM tube with a nuclear counter. The GM counter has a window thickness of $0.002\,\mathrm{g\,cm}^{-2}$ and a diameter of 1.8 cm. The operating voltage of the GM counter was selected to be 440 V for it was the safest region of counting. Not only this but also the back ground counts using clean

(empty) filter, for the counting time of every mornings (starting from 06:02:00 Am) was found to be 33.75/min.

The sampled filter was placed below the GM tube in a time less than one minute after finishing sampling. It was placed 7 mm below the tube. Then total beta counts over a series of successive time intervals were recorded.

3.2.2 Mathematical model

The computation of activity concentration of airborne radon decay products and thoron decay products (though my basic concern lies on radon) are made similarly as are used by Raabe and Wrenn (Otto G. and McDonald E., 1969) and Papp and Daróczy (Papp and S., 1997)

The computations move as exact as the following:

1. The differential equations which describe the deposition and the decay during sampling of daughters of ^{222}Rn and ^{220}Rnare solved. The differential equation describing its build up due to deposition and decay during sampling is also solved.
2. The differential equations which describe the decay of the daughters of ^{222}Rn and ^{220}Rn on the sample after gathering is completed are also solved. In addition to this, the decay of the unknown beta emitter after sampling is completed is solved.
3. A weighted least-squares regression analysis is performed to mathematically fit the observations of counts during various counting periods to the general decay equation for the sample. This gives the number of nuclei of each progenies present on the sample at the end of sampling from which the concentrations of the daughters in the atmosphere are calculated.

Let the numbers 1 to 7 represent ^{218}Po ,^{214}Pb and ^{214}Bi for ^{222}Rn , ^{212}Pb, ^{212}Bi and ^{208}Tl decay products and U for unknown beta emitter with long half life for the reason, there is along lived beta emitter in the atmosphere which has great effect on the computation.

Constants for this work only:

K = air sampling flow rate same for both doors;
T = air sampling time same for all doors;
t_b = beginning of a counting time interval;
t_c = end of a counting time interval;

C = total beta counts measured over the time interval (t_b , t_c);
M = number of counting time intervals ;
ϵ_j = beta counting efficiencies for the isotopes one by one (j = 2,3,...,7);
λ_j = decay constants, (j = 1,2,...,7) .

Variables of this work:

q_j = numbers of atoms in a unit volume of the sampled air (could be the indoor or outdoor) , (j = 1,2,...7);
a_j = activities of isotopes in a unit volume of the sampled air, (j = 1,2,...7) ;
Q_j = numbers of atoms in the filter, (j = 1,2,...7) ;
Q_{Tj} = numbers of atoms in the filter at the end of sampling , (j= 1,2,...,7);
t = time elapsed since the end of sampling (t = 0 at the end of sampling);
CR = total beta counting rate .

It is possible to assume k and q_j as constants separately for the indoor and outdoor though there might be spatial variation during sampling. The other basic assumption is there are two zero times being the first refereing to starting of sampling while the other is the time at the end of sampling which is zero to the counting process. Under this assumption the probabilistic mathematical equation for each progenies of radon and thoron mathematical follows. And the q_j for the indoor and outdoor is different. Beliving that it is time effective not writing separate equations for the indoor and outdoor, it is not written separately. The basic principle that hardens this action is, since it is easy to substitute indoor and outdoor based on our investigation in hand.

$$dQ_1 = kq_1dt - \lambda_1 Q_1 dt, \qquad Q_1(0) = 0 \tag{3.1a}$$

$$dQ_2 = kq_2dt - \lambda_2 Q_2 dt + \lambda_1 Q_1 dt, \qquad Q_2(0) = 0 \tag{3.1b}$$

$$dQ_3 = kq_3dt - \lambda_3 Q_3 dt + \lambda_2 Q_2 dt, \qquad Q_3(0) = 0 \tag{3.1c}$$

$$dQ_4 = kq_4dt - \lambda_4 Q_4 dt, \qquad Q_4(0) = 0 \tag{3.1d}$$

$$dQ_5 = kq_5dt - \lambda_5 Q_5 dt + \lambda_4 Q_4 dt, \qquad Q_5(0) = 0 \tag{3.1e}$$

$$dQ_6 = kq_6dt - \lambda_6 Q_6 dt + \lambda_5 Q_5 dt, \qquad Q_6(0) = 0 \tag{3.1f}$$

$$dQ_7 = kq_7dt - \lambda_7 Q_7 dt, \qquad Q_7(0) = 0 \tag{3.1g}$$

The general solution for both doors investigation of the above mathematical model of physical phenomena is solved as follows:

$$Q_1 = kq_1\left[\frac{1-e^{-\lambda_1 t}}{\lambda_1}\right] \tag{3.2a}$$

$$Q_2 = kq_1\left[\frac{1-e^{-\lambda_2 t}}{\lambda_2} - \frac{e^{-\lambda_2 t}-e^{-\lambda_1 t}}{\lambda_1-\lambda_2}\right] + kq_2\left[\frac{1-e^{-\lambda_2 t}}{\lambda_2}\right] \tag{3.2b}$$

$$\begin{aligned} Q_3 = {} & kq_1\left[\frac{1-e^{-\lambda_3 t}}{\lambda_3} - \frac{e^{-\lambda_2 t}-e^{-\lambda_3 t}}{\lambda_3-\lambda_2} - \frac{\lambda_2(e^{-\lambda_2 t}-e^{-\lambda_3 t})}{(\lambda_3-\lambda_2)(\lambda_1-\lambda_2)} + \frac{\lambda_2(e^{-\lambda_3 t}-e^{-\lambda_1 t}}{(\lambda_1-\lambda_3)(\lambda_1-\lambda_2)}\right] \\ & + kq_2\left[\frac{1-e^{-\lambda_3 t}}{\lambda_3} - \frac{(e^{-\lambda_2 t}-e^{-\lambda_3 t})}{\lambda_3-\lambda_2}\right] + kq_3\left[\frac{1-e^{-\lambda_3 t}}{\lambda_3}\right] \end{aligned} \tag{3.2c}$$

$$Q_4 = kq_4\left[\frac{1-e^{-\lambda_4 t}}{\lambda_4}\right] \tag{3.2d}$$

$$Q_5 = kq_4\left[\frac{1-e^{-\lambda_5 t}}{\lambda_5} - \frac{e^{-\lambda_5 t}-e^{-\lambda_4 t}}{\lambda_4-\lambda_5}\right] + kq_5\left[\frac{1-e^{-\lambda_5 t}}{\lambda_5}\right] \tag{3.2e}$$

$$\begin{aligned} Q_6 = {} & kq_4\left[\frac{1-e^{-\lambda_6 t}}{\lambda_6} - \frac{e^{-\lambda_5 t}-e^{-\lambda_6 t}}{\lambda_6-\lambda_5} - \frac{\lambda_5(e^{-\lambda_5 t}-e^{-\lambda_6 t})}{(\lambda_6-\lambda_5)(\lambda_5-\lambda_6)} + \frac{\lambda_5(e^{-\lambda_6 t}-e^{-\lambda_4 t})}{(\lambda_4-\lambda_6)(\lambda_4-\lambda_5)}\right] \\ & + kq_5\left[\frac{1-e^{-\lambda_6 t}}{\lambda_6} - \frac{e^{-\lambda_5 t}-e^{-\lambda_6 t}}{\lambda_6-\lambda_5}\right] + kq_6\left[\frac{1-e^{-\lambda_6 t}}{\lambda_6}\right] \end{aligned} \tag{3.2f}$$

$$Q_7 = kq_7\left[\frac{1-e^{-\lambda_7 t}}{\lambda_7}\right] \tag{3.2g}$$

$Q_{Tj}(j = 1, 2, ..., 7)$, which is the number of atoms in the filter at the end of sampling for both doors is easily solved by replacing t by T, because end of sampling time is equal to the air sampling time (T). So $Q_{Tj}(j = 1, 2, ..., 7)$ can be expressed as:

$$Q_{T1} = kq_1\left[\frac{1-e^{-\lambda_1 T}}{\lambda_1}\right] \tag{3.3a}$$

$$Q_{T2} = kq_1\left[\frac{1-e^{-\lambda_2 T}}{\lambda_2} - \frac{e^{-\lambda_2 T}-e^{-\lambda_1 T}}{\lambda_1-\lambda_2}\right] + kq_2\left[\frac{1-e^{-\lambda_2 T}}{\lambda_2}\right] \tag{3.3b}$$

$$Q_{T3} = kq_1\left[\frac{1-e^{-\lambda_3 T}}{\lambda_3} - \frac{e^{-\lambda_2 T}-e^{-\lambda_3 T}}{\lambda_3-\lambda_2} - \frac{\lambda_2(e^{-\lambda_2 T}-e^{-\lambda_3 T})}{(\lambda_3-\lambda_2)(\lambda_1-\lambda_2)} + \frac{\lambda_2(e^{-\lambda_3 T}-e^{-\lambda_1 T})}{(\lambda_1-\lambda_3)(\lambda_1-\lambda_2)}\right] + kq_2\left[\frac{1-e^{-\lambda_3 T}}{\lambda_3} - \frac{(e^{-\lambda_2 T}-e^{-\lambda_3 T})}{\lambda_3-\lambda_2}\right] + kq_3\left[\frac{1-e^{-\lambda_3 T}}{\lambda_3}\right] \tag{3.3c}$$

$$Q_{T4} = kq_4\left[\frac{1-e^{-\lambda_4 T}}{\lambda_4}\right] \tag{3.3d}$$

$$Q_{T5} = kq_4\left[\frac{1-e^{-\lambda_5 T}}{\lambda_5} - \frac{e^{-\lambda_5 T}-e^{-\lambda_4 T}}{\lambda_4-\lambda_5}\right] + kq_5\left[\frac{1-e^{-\lambda_5 T}}{\lambda_5}\right] \tag{3.3e}$$

$$Q_{T6} = kq_4\left[\frac{1-e^{-\lambda_6 T}}{\lambda_6} - \frac{e^{-\lambda_5 T}-e^{-\lambda_6 T}}{\lambda_6-\lambda_5} - \frac{\lambda_5(e^{-\lambda_5 T}-e^{-\lambda_6 T})}{(\lambda_6-\lambda_5)(\lambda_5-\lambda_6)} + \frac{\lambda_5(e^{-\lambda_6 T}-e^{-\lambda_4 T})}{(\lambda_4-\lambda_6)(\lambda_4-\lambda_5)}\right] + kq_5\left[\frac{1-e^{-\lambda_6 T}}{\lambda_6} - \frac{e^{-\lambda_5 T}-e^{-\lambda_6 T}}{\lambda_6-\lambda_5}\right] + kq_6\left[\frac{1-e^{-\lambda_6 T}}{\lambda_6}\right] \tag{3.3f}$$

$$Q_{T7} = kq_7\left[\frac{1-e^{-\lambda_7 T}}{\lambda_7}\right] \tag{3.3g}$$

$q_j (j = 1, 2, ..., 7)$ can be expressed from equations (3.3a) to (3.3g) as follows

$$q_1 = \frac{\lambda_1 Q_{T1}}{k(1-e^{-\lambda_1 T})} \tag{3.4a}$$

$$q_2 = \frac{\lambda_2 Q_{T2}}{k(1-e^{-\lambda_2 T})} - q_1\left[1 - \frac{\lambda_2(e^{-\lambda_2 T}-e^{-\lambda_1 T})}{(\lambda_1-\lambda_2)(1-e^{-\lambda_2 T})}\right] \tag{3.4b}$$

$$q_3 = \frac{\lambda_3 Q_{T3}}{k(1-e^{-\lambda_3 T})} - q_2\left[1 - \frac{\lambda_3(e^{-\lambda_2 T}-e^{-\lambda_3 T})}{(\lambda_3-\lambda_2)(1-e^{-\lambda_3 T})}\right] - q_1\left[1 - \frac{\lambda_3(e^{-\lambda_2 T}-e^{-\lambda_3 T})}{(\lambda_3-\lambda_2)(1-e^{-\lambda_3 T})} - \frac{\lambda_2\lambda_3(e^{-\lambda_2 T}-e^{-\lambda_3 T})}{(\lambda_3-\lambda_2)(\lambda_1-\lambda_2)(1-e^{-\lambda_3 T})} + \frac{\lambda_2\lambda_3(e^{\lambda_3 T}-e^{-\lambda_1 T})}{(\lambda_1-\lambda_3)(\lambda_1-\lambda_2)(1-e^{-\lambda_3 T})}\right] \tag{3.4c}$$

$$q_4 = \frac{\lambda_4 Q_{T4}}{k(1 - e^{-\lambda_4 T})} \tag{3.4d}$$

$$q_5 = \frac{\lambda_5 Q_{T5}}{k(1 - e^{-\lambda_5 T})} - q_4 \left[1 - \frac{\lambda_5 (e^{-\lambda_5 T} - e^{-\lambda_4 T})}{(\lambda_4 - \lambda_5)(1 - e^{-\lambda_5 T})}\right] \tag{3.4e}$$

$$\begin{aligned} q_6 = \frac{\lambda_6 Q_{T6}}{k(1 - e^{-\lambda_6 T})} &- 0.36 n_5 \left[1 - \frac{\lambda_6 (e^{-\lambda_5 T} - e^{-\lambda_6 T})}{(\lambda_6 - \lambda_5)(1 - e^{-\lambda_6 T})}\right] \\ &- 0.36 q_4 \left[1 - \frac{\lambda_6 (e^{-\lambda_5 T} - e^{-\lambda_6 T})}{(\lambda_6 - \lambda_5)(1 - e^{-\lambda_6 T})} - \frac{\lambda_5 \lambda_6 (e^{-\lambda_5 T} - e^{-\lambda_6 T})}{(\lambda_6 - \lambda_5)(\lambda_4 - \lambda_5)(1 - e^{-\lambda_6 T})} \right. \\ &\left. + \frac{\lambda_5 \lambda_6 (e^{-\lambda_6 T} - e^{-\lambda_4 T})}{(\lambda_4 - \lambda_6)(\lambda_4 - \lambda_5)(1 - e^{-\lambda_6 T})}\right] \end{aligned} \tag{3.4f}$$

$$q_7 = \frac{\lambda_7 Q_{T7}}{k(1 - e^{-\lambda_7 T})} \tag{3.4g}$$

The solutions of the equation for the decay after the end of sampling are:

$$Q_1 = Q_{T1} e^{-\lambda_1 t} \tag{3.5a}$$

$$Q_2 = Q_{T1} \left[\lambda_1 \frac{e^{-\lambda_2 t} - e^{-\lambda_1 t}}{\lambda_1 - \lambda_2}\right] + Q_{T2} e^{-\lambda_2 t} \tag{3.5b}$$

$$\begin{aligned} Q_3 = Q_{T1} &\left[\frac{}{\lambda_1 \lambda_2 (e^{-\lambda_2 t} - e^{-\lambda_3 t})} (\lambda_3 - \lambda_2)(\lambda_1 - \lambda_2) - \frac{\lambda_1 \lambda_2 (e^{-\lambda_3 t} - e^{-\lambda_1 t})}{(\lambda_1 - \lambda_3)(\lambda_1 - \lambda_2)}\right] \\ &+ Q_{T2} \left[\frac{\lambda_2 (e^{-\lambda_2 t} - e^{-\lambda_3 t}}{\lambda_3 - \lambda_2}\right] + Q_{T3} e^{-\lambda_3 t} \end{aligned} \tag{3.5c}$$

$$Q_4 = Q_{T4} e^{-\lambda_4 t} \tag{3.5d}$$

$$Q_5 = Q_{T4} \left[\frac{\lambda_4 (e^{-\lambda_5 t} - e^{-\lambda_4 t}}{\lambda_4 - \lambda_5}\right] + Q_{T5} e^{-\lambda_5 t} \tag{3.5e}$$

$$\begin{aligned} Q_6 = 0.36 Q_{T4} &\left[\frac{\lambda_4 \lambda_5 (e^{-\lambda_5 t} - e^{-\lambda_6 t})}{(\lambda_6 - \lambda_5)(\lambda_4 - \lambda_5)} - \frac{\lambda_4 \lambda_5 (e^{-\lambda_6 t} - e^{-\lambda_4 t})}{(\lambda_4 - \lambda_6)(\lambda_4 - \lambda_5)}\right] \\ &+ .36 Q_{T5} \left[\frac{\lambda_5 (e^{-\lambda_5 t} - e^{-\lambda_6 t}}{\lambda_6 - \lambda_5}\right] + Q_{T6} e^{-\lambda_6 t} \end{aligned} \tag{3.5f}$$

$$Q_7 = Q_{T7} e^{-\lambda_7 t} \tag{3.5g}$$

Then the count rate (CR) is given as:

$$CR = \sum_{j=2}^{7} \epsilon_j \lambda_j Q_j, Whereepisilonistheeffeciencyofcountingofthe"j"thnuclie. \quad (3.6)$$

Since it is physically incorrect to consider ^{218}Po as it is an alpha emitter, it is ignored in the above manipulation.

Replacing Q_j by substituting (3.5a) to (3.5g) and integrating with respect to t between t_b and t_c, it follows

$$C = \sum_{j=1}^{7} Q_{Tj} Y_j \quad (3.7)$$

where

$$\begin{aligned} Y_1 = {} & \frac{\epsilon_2\lambda_2(e^{-\lambda_1 b} - e^{-\lambda_1 c})}{\lambda_2 - \lambda_1} - \frac{\epsilon_2\lambda_1(e^{-\lambda_2 b} - e^{-\lambda_2 c})}{\lambda_2 - \lambda_1} + \frac{\epsilon_3\lambda_2\lambda_3(e^{-\lambda_1 b} - e^{-\lambda_1 c})}{(\lambda_2 - \lambda_1)(\lambda_3 - \lambda_1)} \\ & - \frac{\epsilon_3\lambda_1\lambda_3(e^{-\lambda_2 b} - e^{-\lambda_2 c})}{(\lambda_2 - \lambda_1)(\lambda_3 - \lambda_2)} + \frac{\epsilon_3\lambda_1\lambda_2(e^{-\lambda_3 b} - e^{-\lambda_3 c})}{(\lambda_3 - \lambda_2)(\lambda_3 - \lambda_1)} \end{aligned} \quad (3.8a)$$

$$Y_2 = \epsilon_2(e^{-\lambda_2 b} - e^{-\lambda_2 c}) + \frac{\epsilon_3\lambda_3(e^{-\lambda_2 b} - e^{-\lambda_2 c})}{\lambda_3 - \lambda_2} - \frac{\epsilon_3\lambda_2(e^{-\lambda_3 b} - e^{-\lambda_3 c})}{(\lambda_3 - \lambda_2)} \quad (3.8b)$$

$$Y_3 = \epsilon_3(e^{-\lambda_3 b} - e^{-\lambda_3 c}) \quad (3.8c)$$

$$\begin{aligned} Y_4 = {} & \epsilon_4(e^{-\lambda_4 b} - e^{-\lambda_4 c}) + \frac{\epsilon_5\lambda_5(e^{-\lambda_4 b} - e^{-\lambda_4 c})}{\lambda_5 - \lambda_4} - \frac{\epsilon_5\lambda_4(e^{-\lambda_5 b} - e^{-\lambda_5 c})}{(\lambda_5 - \lambda_4)} \\ & + \frac{0.36\epsilon_6\lambda_5\lambda_6(e^{-\lambda_4 b} - e^{-\lambda_4 c})}{(\lambda_5 - \lambda_4)(\lambda_6 - \lambda_4)} - \frac{0.36\epsilon_6\lambda_4\lambda_6(e^{-\lambda_5 b} - e^{-\lambda_5 c})}{(\lambda_5 - \lambda_4)(\lambda_6 - \lambda_5)} \\ & + \frac{0.36\epsilon_6\lambda_4\lambda_5(e^{-\lambda_6 b} - e^{-\lambda_6 c})}{(\lambda_6 - \lambda_5)(\lambda_6 - \lambda_4)} \end{aligned} \quad (3.8d)$$

$$Y_5 = \epsilon_5(e^{-\lambda_5 b} - e^{-\lambda_5 c}) + \frac{0.36\epsilon_6\lambda_6(e^{-\lambda_5 b} - e^{-\lambda_5 c})}{(\lambda_6 - \lambda_5)} - \frac{0.36\epsilon_6\lambda_5(e^{-\lambda_6 b} - e^{-\lambda_6 c})}{(\lambda_6 - \lambda_5)} \quad (3.8e)$$

$$Y_6 = \epsilon_6(e^{-\lambda_6 b} - e^{-\lambda_6 c}) \quad (3.8f)$$

$$Y_7 = \epsilon_7(e^{-\lambda_7 b} - e^{-\lambda_7 c}) \quad (3.8g)$$

Keeping the assumption that the total beta counts were measured over M

successive time intervals. Then these consecutive of measurements can be described by a series of linear equations as

$$C_m = \sum_{j=1}^{7} Q_{Tj} Y_{mj}, (m = 1, 2, ..., M) \tag{3.9}$$

C_m are the measured total beta counts, and Y_{mj} are the values of Y_j for different time intervals, respectively.

Q_{Tj} could be estimated from (3.9) using the least square fitting method. q_j could be computed according to (3.4a) to (3.4g).

Having the above concentrations, the Equivalent Equilibrium Concentration (EEC) of ^{222}Rn and ^{220}Rn can be obtained. EEC can be given in terms of the individual decay product concentrations of ^{222}Rn and ^{220}Rn as

$$EEC_{Rn} = 0.105\, C_1 + .515\, C_2 + 0.380\, C_3$$

since it is impossible to findout directly the concentration of radon in the atmosphere it is possible to have the equivalent concentration interms of its daughter products where C_1, C_2, and C_3 represent concentrations of ^{218}Po, ^{214}Pb and ^{214}Bi respectively.

$$EEC_{Th} = 0.913\, C_1 + 0.087\, C_2$$

where C_1, C_2 represent ^{212}Pb and ^{212}Bi respectively.

The Defined Solid Angle Absolute Beta Counting (DSAABC) method was used to determine the counting efficiencies ϵ_is in (3.8a) to (3.8g), one by one. This method will be explained briefly in the next section.

3.2.3 Defined Solid Angle Absolute Beta Counting Method

Introduction

In 1950s B.P.Burtt and some others were digging to get ways to determine the methods and efficiencies for β-counting (Burtt, 1949). As a result they developed a method called Defined solid angle absolute β-counting (DSAABC) where it is one of

the oldest methods for the determination of the activity of β-emitting radionuclides.

The basic principles in this method is counting rate of a beta emitter relative to the activity rate (efficiency for counting) depends upon the geometry, the percent of solid angle about the source subtended by the sensitive volume of the counter, and absorption of the radiations by the air and window of the counter and scattering from the source support and assembly.

Applying the (DSAABC) method it is possible to solve the efficiencies of ^{222}Rn progenies and that of the unknown long lived β-emitter.

However, several problems may arise if someone wants to apply this method in the field of environmental radio analysis. The most difficult one is that the counting rate is influenced by numerous effects which have to be precisely considered if accurate activity results are needed.

It is often said that it is not worth the trouble to deal with the problems of this method because

1. High accuracy cannot be reached
2. β emitters cannot be easily identified
3. relative counting using certified reference samples is simpler and more accurate
4. more suitable methods are available

The first of the above arguments is indisputable but high accuracy is not necessarily needed in all fields of environmental radioanalysis. As to the second argument, identification of the emitters are exactly known. It has to be emphasized that relative counting as against absolute one may be more accurate only if the reference sample contains the same radionuclide(s) and has exactly the same dimensions, elemental composition and inner distribution of activity as those of the sample to be measured. The complete fulfilment of the above requirements is not easy in most cases, so the relative method may be either simpler or more accurate than the absolute one, but seldom may be both at the same time. It is true that modern methods for the detection of β particles or γ-rays, such as liquid scintillation counting (LSC) or semiconductor γ-spectrometry, are better choices in most cases. But there are special cases when the DSAABC method using an end-window Geiger-Müller (GM) can compete with the above methods or may be even more suitable. Samples have to be liquefied and in most cases also some

chemical separations are needed for LSC. Semiconductor γ- spectrometers have low efficiency and cannot be used for the determination of of pure β-emitters. If, for example, low activities, have to be measured or the chemical treatment of the sample should be avoided for some reason then the DSAABC method be priory chosen. The other importance is that it is cheap and technically simple one. (Papp, 1997)

Counting efficiency determination

Assume that the β-radiation of a thin sample containing one β-emitting radionuclide is measured by an end-window GM counter through a thin absorber in a fixed geometry. The nuclide has n different β-transitions with energies, $E_{\beta i}$ and intensities, $I_{\beta i}$ (i= 1,2,...,n ; $\sum_{i=1}^{n} I_{\beta i} \leqslant 1$), emits conversion electrons with p different energies, E_{cj} and intensities, I_{cj} (j=1,2,...,p) and γ-quanta and X-rays with q different energies, $E_{\gamma k}$ and intensities, $I_{\gamma k}$ (k= 1,2,...,q). According to Papp (Papp, 1997), the counting rate, CR, is related to the activity A, by

$$CR = A f_m f_c f_g \left[f_{se} \left(\sum_{i=1}^{n} I_{\beta i} f_{Wi} f_{Si} f_{Ai} f_{Bi} f_{Hi} + \sum_{j=1}^{p} I_{cj} f_{Ccj} f_{acj} \right) + \sum_{k=1}^{q} I_{\gamma k} f_{c\gamma k} f_{s\gamma k} f_{a\gamma k} \right] \tag{3.10}$$

where

f_m is for multiple counting

f_c is for loss due to random coincidence

f_g is for the solid angle geometry

f_{se} is for the intrinsic sensitivity of the counter for electrons

f_{Wi} are for the absorption of β-particles by the window and further absorbers

f_{Si} are for the effect of the sample in scattering and absorption of β-particles

f_{Ai} are for air scattering

f_{Bi} are for backscattering

f_{Hi} are for the effect of the housing in scattering β-particles into the counter

f_{Ccj} are for the true coincidences of conversion electrons with β-particles

f_{acj} are for the absorption of conversion electrons

$f_{c\gamma k}$ are for the true coincidences of γ-quanta and X-rays with β-particles and conversion electrons

$f_{s\gamma k}$ are for the intrinsic sensitivity of the detector for γ-quanta and X-rays

$f_{a\gamma k}$ are for the absorption of γ-quanta and X-rays

A can be determined from CR if the correction factors in (3.10) are measured, computed, estimated or eliminated in some way. Errors are introduced in this way into the final activity result. So it is recommended to choose the detector, the counting geometry and the structural materials like that the values of the factors be as near unity and their errors be as low as possible. The counting efficiency ϵ can be computed as $\epsilon = CR/A$.

In order to determine the factors one by one papp (Papp, 1997), tried to attain the highest accuracy obtainable with reasonable effort. The less important factors and the errors of the evaluations have not been examined intensively.

f_{se} and f_m are assumed to be close to unity for good GM tubes if the high voltage is chosen at the beginning of the plateau.

f_A and f_H are close to unity if small sample-detector distance and spacious housing covered from inside by low atomic number material are used.

f_{Ccj} is equal to the probability of not detecting β-particle emitted simultaneously with the conversion electron. It can be estimated by the formula

$$f_{Ccj} = 1 - f_g(I_{\beta i} f_{Wi} f_{Si} f_{Bi}) \tag{3.11}$$

f_{acj} can be estimated using experimental data on the transmission of monoenenergetic electron beams.

$f_{s\gamma}$ can be measured by using ^{54}Mn and ^{57}Co reference point sources and by analyzing the γ-background in absorption curves measured by ^{134}Cs and ^{137}Cs point sources.

$f_{c\gamma k}$ can be estimated as

$$f_{C\gamma k} = 1 - f_g(I_{\beta i} f_{Wi} f_{Si} f_{Bi} + I_{cj} f_{Ccj} f_{acj}) \tag{3.12}$$

where i and j are the indexes of the corresponding β transition and conversion electron.

$f_{a\gamma}$ differs from unity only for X-rays. It can be estimated as

$$f_{a\gamma} = \exp(-\mu_\gamma W)$$

where W is the total thickness of the absorbers (detector window, air, added absorber) and μ_γ is the mass absorption coefficient which can be evaluated from literatures.

f_c becomes an important factor only in case of high values of CR (above 100-200 sec^{-1}). It can be computed for GM counters as $f_c = 1 - CR\tau$, where τ is the resolving time of the counter

f_g can be determined from the solid angle subtended by a circular aperture of radius R at a circular source of radius r, coaxial with the aperture, the distance of which from the aperture is equal to Z, in case of $r < R$ which is

$$G = \frac{1}{2}\left[1 - \frac{Z}{D}\right] - \frac{3r^2R^2Z}{16D^5} + \frac{5r^4R^2Z}{32D^9}\left[Z^2 - \frac{3}{4}R^2\right] - \frac{35r^6R^2Z}{256D^{13}\left[Z^4 - \frac{5}{2}R^2Z^2 + \frac{5}{8}R^4\right]} \tag{3.13}$$

where $D = (Z^2 + R^2)^{1/2}$ if R and Z are equal to the radius of the sensitive volume of the detector and the distance from the sample to the bottom surface of the sensitive volume, respectively. It can be assumed that the sensitive volume is cylindrical and its diameter is equal to that of the window.

f_W can be evaluated by the expression

$$f_W = \exp(-\mu_a W)$$

where μ_a is the mass-absorption coefficient and W is the summed thickness of the absorbers(window, absorber sheet and air) μ_a in function of E_β can be determined experimentally from the results of absorption measurements.

f_s is the most difficult factor that has complex character. It is reasonable to treat

the different effects contributing in f_s separately. They are: self-absorption (f_{sa}), self-scattering (f_{ss}) and internal backscattering (f_{ib}). Thus f_s is written as the product of three factors, which are for the above effects:

$$f_s = f_{sa} f_{ss} f_{ib}$$

f_{ss} is close to unity if

1. near 2π-type geometry is used;
2. sample is made from low Z material;
3. most of the activity is on or close to the upper surface of the sample

f_{sa} = $[1 - \exp(-\mu_s d)]/(\mu_s d)$, where μ_s is the self absorption coefficient and d is the thickness of the sample.

f_{ib} is generally a phenomenon of second order but it becomes more significant in case of strongly decreasing exponential activity distribution.

using this method efficiencies 0.14313, 0.123516, 0.11697, 0.0774 and 0.1319 were obtained for ^{214}Pb, ^{214}Bi, ^{212}Pb, ^{212}Bi, ^{208}Tl respectively taken from Bemenet's results since we have similar conditions.

Chapter 4

Data Analysis and Discussion

4.1 Results

Measurements were carried on in the first floor of physics department specifically in the nuclear laboratory around four meters above the ground. Air sampling was taken in the morning hours starting from 6:00 A.M.

A total of 34 (17 indoor and 17 outdoor) measurements were made and each was recorded for more than 8 hrs in successively increasing intervals of time. Typical measurement procedure is indicated in table 4.1. The first and the second columns in table 4.1 were recorded from the Geiger counter screen. The third term indicates the serial of the intervals of measurement and the fourth and the fifth columns indicate the beginning and end of diurnal time for the corresponding interval. The sixth column indicates the age of the filtered starting from point sampling till counting is ended (time as measured from the end of sampling as origin. i.e. the time in the six column thus indicate the age of the filtered air sample as measured from the end of sampling.

The seventh column contains the width of measurement of each time interval whereas the eighth column is the gross count in the interval.

The age of the filter, the length of the measuring time interval and the gross count obtained were fed in a computer programme, that computes the concentration of progeny and the equilibrium equivalent concentration for the two isotopes, from the observed decline in the observed count rates.

Table 4.1: Measurement Procedure in DSAABC Method

Label:	**JUL19ID**	0:03	0:00:30					
Samp Sta.	6:02:00	0:12	0:01:00					
Samp Sto.	6:22:00	0:16	0:02:00					
Samp t (min)	0:20:00	0:20	0:04:00					
Samp. Date	19/07/2007	0:04	0:08:00	Back g.	33.75	Tube 3 ,OP.V=440V		

observe t	**disply cnt**	**m**	**tb**	**te**	**time (min)**	**Dt**	**count**	**Count rate**
6:23:00	0	1	6:23:00	6:24:00	1	1	1246	1246
6:24:00	1246	2	6:24:00	6:25:00	2	1	1277	1277
6:25:00	2523	3	6:25:00	6:26:00	3	1	1165	1165
6:26:00	3688	4	6:26:00	6:27:00	4	1	1220	1220
6:27:00	4908	5	6:27:00	6:28:00	5	1	1198	1198
6:28:00	6106	6	6:28:00	6:29:00	6	1	1109	1109
6:29:00	7215	7	6:29:00	6:30:00	7	1	1148	1148
6:30:00	8363	8	6:30:00	6:31:00	8	1	1133	1133
6:31:00	9496	9	6:31:00	6:32:00	9	1	1107	1107
6:32:00	10603	10	6:32:00	6:33:00	10	1	1150	1150
6:33:00	11753	11	6:33:00	6:34:00	11	1	1121	1121
6:34:00	12874	12	6:34:00	6:35:00	12	1	1054	1054
6:35:00	13928	13	6:35:00	6:36:00	13	1	1039	1039
6:36:00	14967	14	6:36:00	6:37:00	14	1	1111	1111
6:37:00	16078	15	6:37:00	6:38:00	15	1	1010	1010
6:38:00	17088	16	6:38:00	6:39:00	16	1	1002	1002
6:39:00	18090	17	6:39:00	6:40:00	17	1	1013	1013
6:40:00	19103	18	6:40:00	6:41:00	18	1	1039	1039
6:41:00	20142	19	6:41:00	6:42:00	19	1	933	933
6:42:00	21075	20	6:42:00	6:43:00	20	1	1004	1004
6:43:00	22079	21	6:43:00	6:44:00	21	1	947	947
6:44:00	23026	22	6:44:00	6:45:00	22	1	996	996
6:45:00	24022	23	6:45:00	6:46:00	23	1	922	922
6:46:00	24944	24	6:46:00	6:47:00	24	1	946	946
6:47:00	25890	25	6:47:00	6:48:00	25	1	915	915
6:48:00	26805	26	6:48:00	6:49:00	26	1	817	817
6:49:00	27622	27	6:49:00	6:50:00	27	1	914	914
6:50:00	28536	28	6:50:00	6:51:00	28	1	886	886
6:51:00	29422	29	6:51:00	6:52:00	29	1	874	874
6:52:00	30296	30	6:52:00	6:53:00	30	1	873	873
6:53:00	31169	31	6:53:00	6:54:00	31	1	886	886
6:54:00	32055	32	6:54:00	6:55:00	32	1	827	827
6:55:00	32882	33	6:55:00	6:56:00	33	1	851	851
6:56:00	33733	34	6:56:00	6:57:00	34	1	812	812
6:57:00	34545	35	6:57:00	6:58:00	35	1	773	773
6:58:00	35318	36	6:58:00	6:59:00	36	1	754	754
6:59:00	36072	37	6:59:00	7:00:00	37	1	780	780
7:00:00	36852	38	7:00:00	7:01:00	38	1	731	731
7:01:00	37583	39	7:01:00	7:02:00	39	1	772	772
7:02:00	38355	40	7:02:00	7:03:00	40	1	741	741
7:03:00	39096	41	7:03:00	7:04:00	41	1	742	742
7:04:00	39838	42	7:04:00	7:05:00	42	1	747	747
7:05:00	40585	43	7:05:00	7:06:10	43	1.17	824	706
7:06:10	41409	44	7:06:10	7:07:00	44.17	0.833	599	719
7:07:00	42008	45	7:07:00	7:08:00	45	1	682	682
7:08:00	42690	46	7:08:00	7:09:00	46	1	713	713
7:09:00	43403	47	7:09:00	7:10:00	47	1	670	670
7:10:00	44073	48	7:10:00	7:11:00	48	1	692	692
7:11:00	44765	49	7:11:00	7:12:00	49	1	660	660
7:12:00	45425	50	7:12:00	7:13:00	50	1	634	634
7:13:00	46059	51	7:13:00	7:14:00	51	1	614	614
7:14:00	46673	52	7:14:00	7:15:00	52	1	840	840
7:15:00	47513	53	7:15:00	7:16:00	53	1	441	441
7:16:00	47954	54	7:16:00	7:17:00	54	1	587	587
7:17:00	48541	55	7:17:00	7:18:00	55	1	597	597
7:18:00	49138	56	7:18:00	7:19:00	56	1	620	620
7:19:00	49758	57	7:19:00	7:20:00	57	1	652	652
7:20:00	50410	58	7:20:00	7:21:00	58	1	597	597

Table 4.1: Continued

7:21:00	51007	59	7:21:00	7:22:00	59	1	561	561
7:22:00	51568	60	7:22:00	7:23:00	60	1	616	616
7:23:00	52184	61	7:23:00	7:24:00	61	1	548	548
7:24:00	52732	62	7:24:00	7:26:00	62	2	1047	524
7:26:00	53779	63	7:26:00	7:28:00	64	2	1064	532
7:28:00	54843	64	7:28:00	7:30:00	66	2	1051	526
7:30:00	55894	65	7:30:00	7:32:00	68	2	1042	521
7:32:00	56936	66	7:32:00	7:34:00	70	2	1017	509
7:34:00	57953	67	7:34:00	7:36:00	72	2	969	485
7:36:00	58922	68	7:36:00	7:38:00	74	2	934	467
7:38:00	59856	69	7:38:00	7:40:00	76	2	911	456
7:40:00	60767	70	7:40:00	7:42:00	78	2	890	445
7:42:00	61657	71	7:42:00	7:44:00	80	2	859	430
7:44:00	62516	72	7:44:00	7:46:00	82	2	883	442
7:46:00	63399	73	7:46:00	7:48:00	84	2	817	409
7:48:00	64216	74	7:48:00	7:50:00	86	2	836	418
7:50:00	65052	75	7:50:00	7:52:00	88	2	783	392
7:52:00	65835	76	7:52:00	7:54:00	90	2	774	387
7:54:00	66609	77	7:54:00	7:56:00	92	2	729	365
7:56:00	67338	78	7:56:00	7:58:00	94	2	772	386
7:58:00	68110	79	7:58:00	8:00:00	96	2	770	385
8:00:00	68880	80	8:00:00	8:02:00	98	2	720	360
8:02:00	69600	81	8:02:00	8:04:00	100	2	736	368
8:04:00	70336	82	8:04:00	8:06:00	102	2	693	347
8:06:00	71029	83	8:06:00	8:08:00	104	2	688	344
8:08:00	71717	84	8:08:00	8:10:00	106	2	672	336
8:10:00	72389	85	8:10:00	8:12:00	108	2	626	313
8:12:00	73015	86	8:12:00	8:14:00	110	2	615	308
8:14:00	73630	87	8:14:00	8:16:00	112	2	616	308
8:16:00	74246	88	8:16:00	8:18:00	114	2	584	292
8:18:00	74830	89	8:18:00	8:20:00	116	2	625	313
8:20:00	75455	90	8:20:00	8:22:00	118	2	614	307
8:22:00	76069	91	8:22:00	8:24:00	120	2	549	275
8:24:00	76618	92	8:24:00	8:28:00	122	4	1114	279
8:28:00	77732	93	8:28:00	8:32:00	126	4	1087	272
8:32:00	78819	94	8:32:00	8:36:00	130	4	1078	270
8:36:00	79897	95	8:36:00	8:40:00	134	4	1062	266
8:40:00	80959	96	8:40:00	8:44:00	138	4	972	243
8:44:00	81931	97	8:44:00	8:48:00	142	4	977	244
8:48:00	82908	98	8:48:00	8:52:00	146	4	957	239
8:52:00	83865	99	8:52:00	8:56:00	150	4	1134	284
8:56:00	84999	100	8:56:00	9:00:00	154	4	698	175
9:00:00	85697	101	9:00:00	9:04:00	158	4	919	230
9:04:00	86616	102	9:04:00	9:08:00	162	4	842	211
9:08:00	87458	103	9:08:00	9:12:00	166	4	875	219
9:12:00	88333	104	9:12:00	9:16:00	170	4	837	209
9:16:00	89170	105	9:16:00	9:20:00	174	4	853	213
9:20:00	90023	106	9:20:00	9:24:00	178	4	814	204
9:24:00	90837	107	9:24:00	9:32:00	182	8	1594	199
9:32:00	92431	108	9:32:00	9:40:00	190	8	1548	194
9:40:00	93979	109	9:40:00	9:48:00	198	8	1560	195
9:48:00	95539	110	9:48:00	9:56:04	206	8.067	1470	182
9:56:04	97009	111	9:56:00	10:04:10	214	8.167	1522	186
10:04:10	98531	112	10:04:00	10:12:00	222	8	1434	179
10:12:00	99965	113	10:12:00	10:20:00	230	8	1502	188
10:20:00	101467	114	10:20:00	10:28:00	238	8	1422	178
10:28:00	102889	115	10:28:00	10:40:20	246	12.33	2178	177
10:40:20	105067	116	10:40:00	10:52:20	258	12.33	2053	166
10:52:20	107120	117	10:52:00	11:04:00	270	12	1985	165
11:04:00	109105	118	11:04:00	11:16:00	282	12	1939	162
11:16:00	111044	119	11:16:00	11:28:00	294	12	1937	161
11:28:00	112981	120	11:28:00	11:44:00	306	16	2524	158
11:44:00	115505	121	11:44:00	12:00:00	322	16	2546	159
12:00:00	118051	122	12:00:00	12:30:00	338	30	4799	160
12:30:00	122850	123	12:30:00	13:11:20	368	41.33	6352	154
13:11:20	129202	124	13:11:20	13:50:20	409.33333	39	5931	152
13:50:20	135133	125	13:50:20	14:57:00	448.33333	66.67	9508	143
14:57:00	144641	126	16:25:20	17:10:20	603.33333	45	5784	129
16:25:20	0	127	18:16:01	19:15:00	714.01667	58.98	7025	119
17:10:20	5784	128	21:39:10	22:09:02	917.16667	29.87	3092	104
18:16:01	3950	129	22:09:02	22:43:00	947.03333	33.97	3501	103
19:15:00	10975							

4.2 Analysis

In the computation the program assumes the following points

- The assumption of the existence of air born long lived β- emitter in the sampled air has given a mathematically correct result but physically meaningless EEC and progenies of ^{222}Rnconcentrations of that fit to the observed gross count. Due to this the the existence of an unknown long lived β-emitter was assumed to be zero.

From the plot using the program the following results were observed

- The beta count rate measured over the time interval specified for all the counting intervals as a function of time
- Contribution of the individual decay products for all the counting intervals, as a function of time.
- Sum of the individual contributions for some counting intervals
- The Equilibrium Equivalent Concentration (EEC) of ^{222}Rn
- standard deviation which can be regarded as a random error

Based on the data of table 4.1 analysis was made by fitting the experimental data to the mathematical model that best fits with the time variation of the gross count rate. One instance of such procedure is shown in figure 4.1.

Using the same procedure the computation was done for the rest of the datas. The computed activities of Radon daughters and the equilibrium equivalent concentration ^{222}Rn is shown in table 4.2.

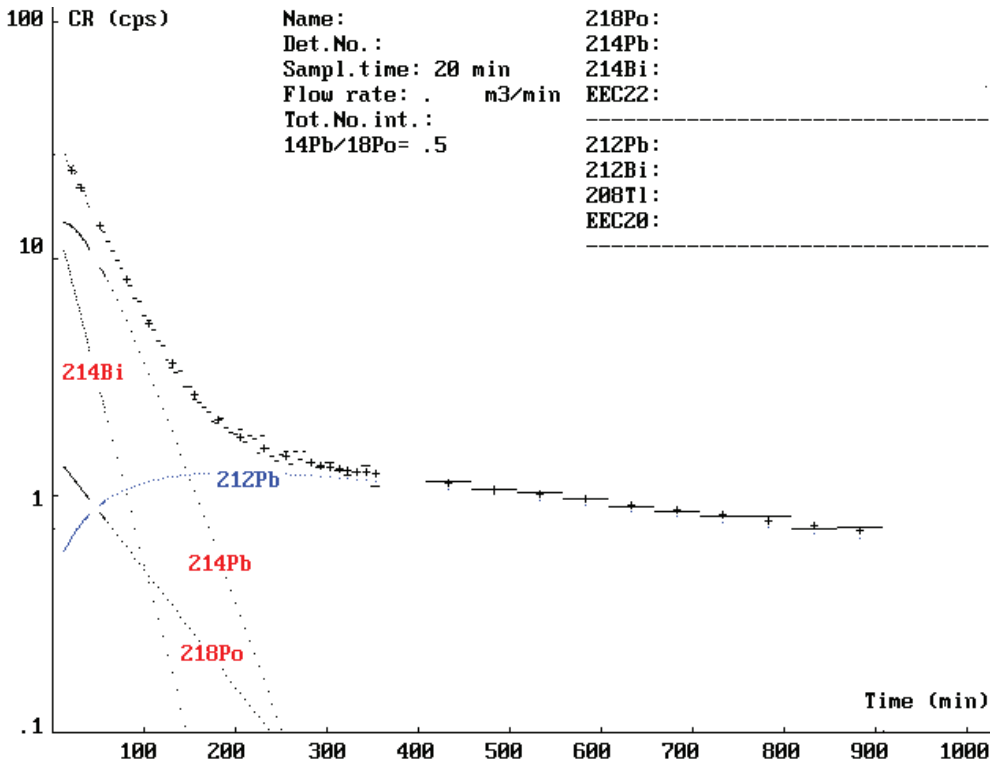

Figure 4.1: Concentration of daughters determined from gross β count

The naming of the data files and hence the experiment consists of the first three letters of the month (some times four) of the date of measurement and a suffix ID if it is indoor and a suffix OD if the measurement is made outdoor. Again pm is for plus or minus.

Table 4.2: Computed activity concentration of Radon Progeny and Equilibrium Activity Concentrations

	Radon Daughters and EEC															
Label	**INDOOR MEASUREMENTS**								**OUTDOOR MEASUREMENTS**							
	Po-218		**Pb-214**		**Bi-214**		**Rn-EEC**		**Po-218**		**Pb-214**		**Bi-214**		**Rn-EEC**	
	Value	**Pm**	**Value**	**Pm**	**Value**	**Pm**	**Value**	**Pm**	**Value**	**Pm**	**Value**	**Pm**	**Value**	**Pm**	**Value**	**Pm**
JUNE5ID	3.09	0.62	2.32	0.46	1.69	0.39	2.16	0.29								
JUNE7OD									30.3	3.46	15.15	1.73	11.01	4.69	15.17	2.02
JUNE9ID	30.3	3.46	15.15	1.73	11.01	4.69	15.17	2.02								
JUNE10OD									8.41	0.51	4.21	0.26	2.24	0.66	3.9	0.29
JUNE11ID	37.7	4.12	18.85	2.06	12.36	1.62	18.37	1.3								
JUNE12OD									14.35	0.79	7.17	0.4	1.01	1.03	5.59	0.45
JUNE13ID	9.93	0.5	4.97	0.25	0.78	0.64	3.9	0.28								
JUNE15ID	30.16	2.24	15.08	1.12	11.93	1.1	15.47	0.78								
JUNE16OD									11.37	0.4	5.68	0.2	4.76	0.53	5.93	0.23
JUNE18ID	29.52	2	14.76	1	16.08	0.98	16.81	0.67								
JUNE19OD									9.32	0.5	4.66	0.25	3.91	0.66	4.87	0.29
JUNE20ID	39.56	3.67	19.78	1.83	19.35	1.83	21.69	1.24								
JUNE21OD									2.04	0.21	1.02	0.1	1.25	0.26	1.22	0.11
JUNE22ID	35.13	2.62	17.56	1.31	12.99	1.28	17.66	0.88								
JUNE23OD									5.31	0.38	2.66	0.19	2.38	0.49	2.83	0.22
JUNE25ID	150.46	15.28	0	0	25.18	4.24	25.34	2.27								
JUNE27OD									3.58	0.31	1.79	0.16	1.1	0.4	1.71	0.17
JUNE28ID	46.2	2.45	27.72	1.47	14.87	3.88	24.79	1.67								
JUNE29OD									4.56	0.31	3.65	0.25	0.15	0.6	2.42	0.26
JUNE30ID	37.16	8.91	18.58	4.45	20.17	4.66	21.13	3.05								
JULY05OD									5.06	0.41	2.53	0.2	1.11	0.56	2.25	0.24
JULY06ID	33.74	5.6	16.87	2.8	13.98	2.77	17.55	1.88								
JULYO7OD									6.61	0.91	3.31	0.45	3.63	1.23	3.78	0.53
JULY08ID	28.54	2.16	14.27	1.08	15.99	1.07	16.42	0.73								
JULY10OD									3.14	0.24	1.71	0.12	1.73	0.31	1.9	0.14
JULY11ID	70.5	6.23	35.25	3.12	24.33	3.18	34.82	2.11								
JULY12OD									3.89	0.28	1.94	0.14	0.64	0.35	1.65	0.15
JULY14ID	47.47	2.79	23.73	1.4	18.58	1.62	24.27	0.99								
JULY16OD									2.33	0.21	1.16	0.11	0.9	0.28	1.19	0.12
JUL18OD									7.92	0.34	3.96	0.17	2.59	0.45	3.86	0.19
JUL19ID	46.16	2.66	23.08	1.33	19.98	1.67	24.33	0.97								
JUL20OD									3.2	0.25	1.6	1.3	1.16	0.33	1.6	0.14
JUL21ID	47.89	5.05	23.95	2.53	20.74	3.43	25.24	1.92								

4.3 Comparison With Other Areas of the World

The indoor radon concentration determined in our lab in average is 19.12 Bq/m^3. Bemenet (Bemenet, 2006) found that the average radon concentration in the same place is 23.9 Bq/m^3. The decrease observed in this measurement may be explained by wet wash out of radon and less emanation from the ground. It is about 50% less than the global average 39 Bq/m^3 reported by WHO (WHO, 2005). This is due high diffusion from indoor air to outdoor air since in the outdoor air there is heavy rain which dissolves the outdoor radon atoms. The average outdoor concentration of ^{222}Rn is 3.74 Bq/m^3.

Table 4.3: Comparison of Indoor Radon Concentrations

Region	Country	Population In 1996 (10^6)	Mean Radon concentration (Bqm^{-3})
Africa	Algeria	28.78	30
	Egypt	63.27	9
America	Canada	29.68	34
	United States	269.4	46
	Argentina	35.22	37
Asia	China	1232	24
	India	944.6	57
	Indonesia	200.45	12
	Kuwait	1.69	14
	Syria	14.57	44
Europe	Denmark	5.24	53
	Finland	5.13	120
	Belgium	10.16	48
	France	58.33	62
	Czech Republic	10.25	140
	Poland	38.6	41
	Romania	22.66	45
	Slovakia	5.35	87
	Albania	3.4	120
	Cyprus	0.76	7
	Spain	39.67	86

4.4 Indoor and Outdoor variation of EEC of ^{222}Rn

The indoor and outdoor variation of EEC ^{222}Rn and its progenies lies; in the outdoor air there is free movement of radon depending on the many environmental parameters. For instance there might be transportation, diffusion,as there is rain the considerable radon atoms are dissolved, Unlike in the indoor where there is confinement.

From the data collected in this experiment, the EEC variation of ^{222}Rn and its progenies was analyzed. The results obtained are shown in table 4.2 and the corresponding plot is shown in fig. 4.2 and fig. 4.3.

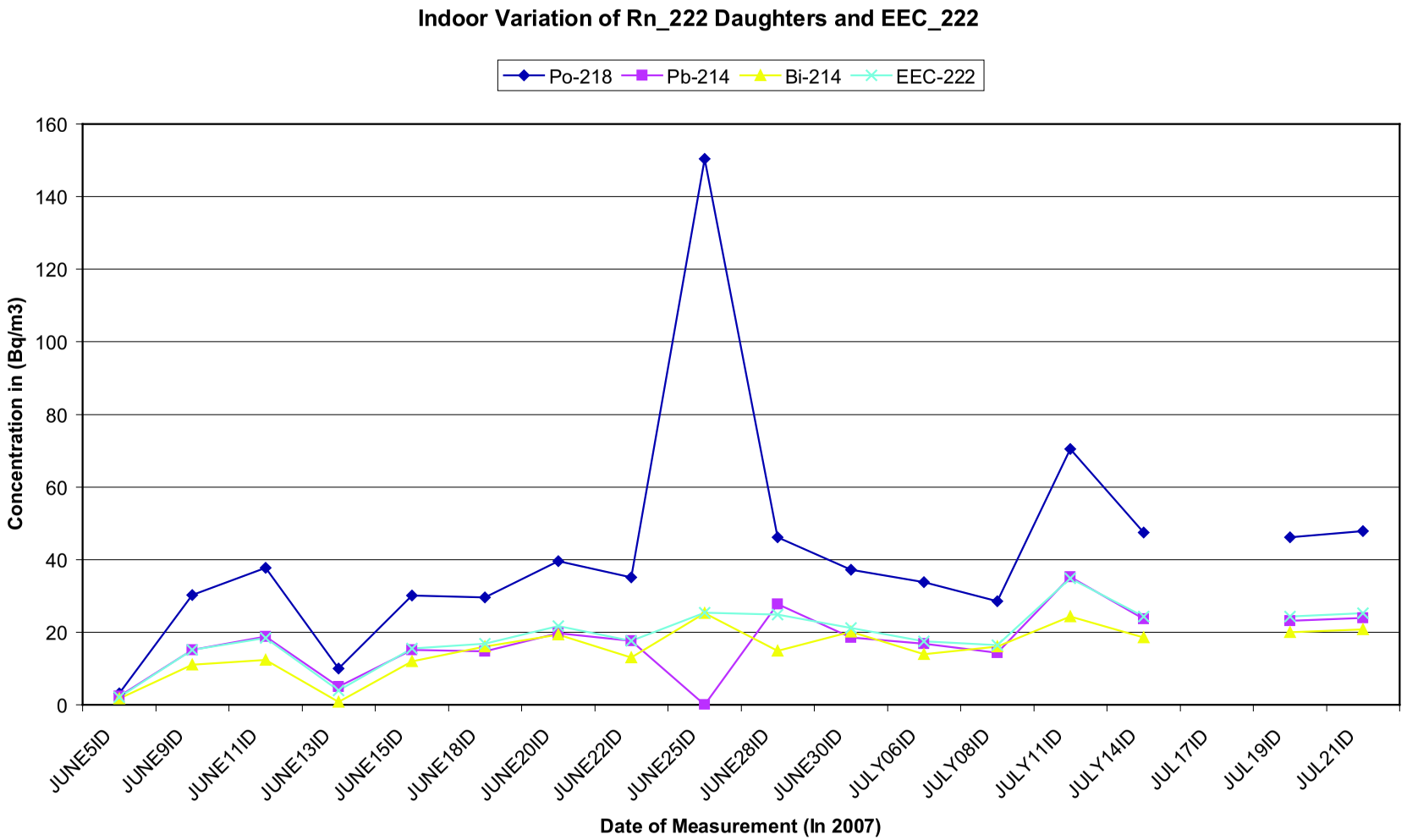

Figure 4.2: Radon and Progeny concentration Indoor

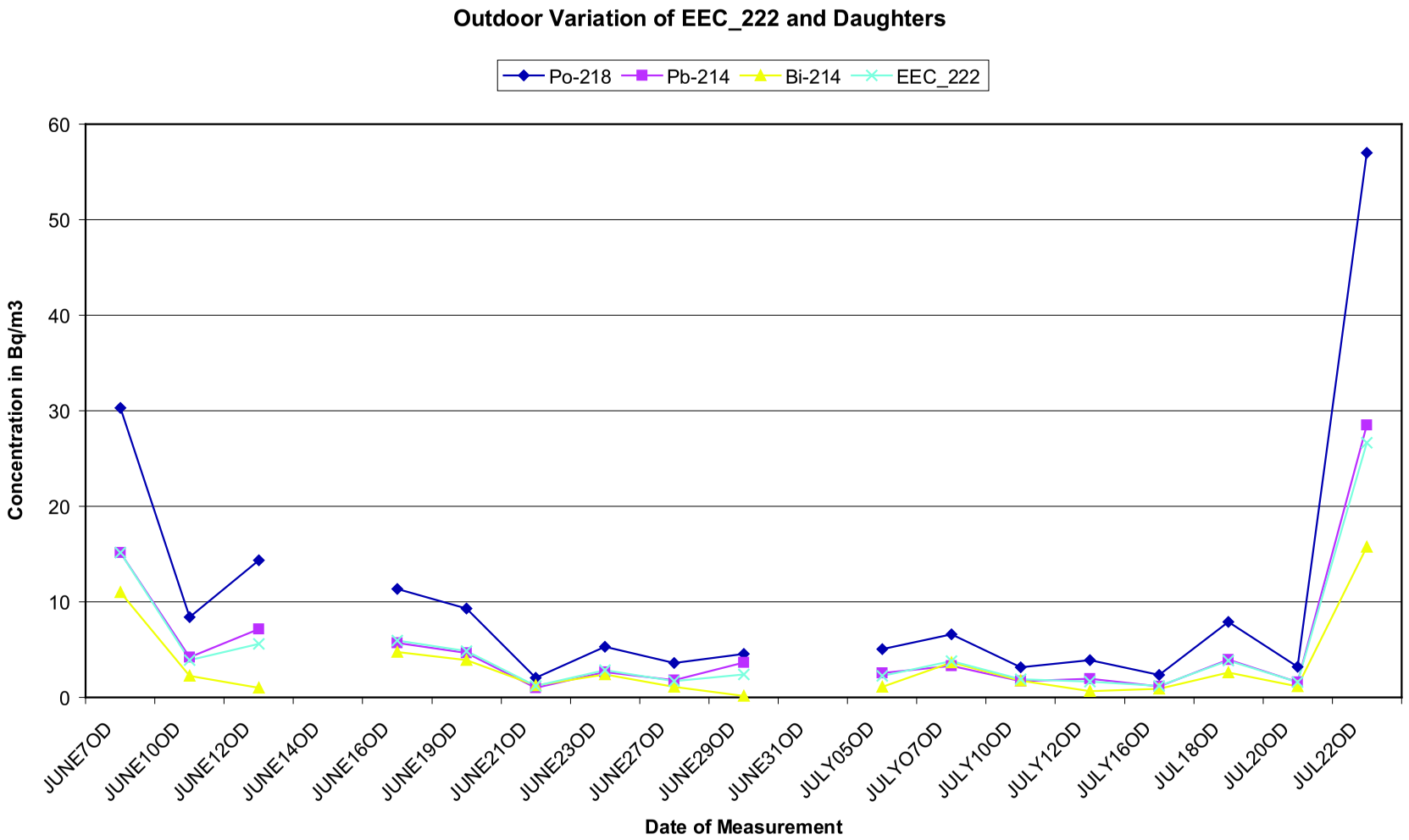

Figure 4.3: Radon and Progeny concentration Outdoor

These results were compared with other results (Tesfaye et al., 1998) and (Liguo, 2004). It showed a good agreement in that the EEC concentration for ^{222}Rn is four to six times the outdoor concentration. This result is also in good agreement with the theory explained in the beginning of this section.

Chapter 5

Conclusion

In this work, the method of defined solid angle absolute beta counting, using an end-window Geiger-Müller counter, was tried and tested in the nuclear science laboratory of the physics department. In view of the portability and low cost aspect of the method it is promising for future wide area survey of radon.

Using above method, equilibrium equivalent concentration of radon progeny and EEC of ^{222}Rn was determined. The indoor outdoor variation of the EEC of ^{222}Rn was studied and the results obtained are in agreement with earlier works in other parts of the world.

In the future, this method may be used to study various aspects of radon concentrations in air. Some potential areas of research include:

- Radon monitoring from radiation perspective (emphasis on mining areas of the country);
- Study of Radon isotopes as atmospheric tracer.
- Seasonal variation of radon and radon progeny concentration at locations of interest;
- Radon and progeny measurement in all parts of Ethiopia so as to establish "Radon map of Ethiopia";
- Study of correlation between incidence of Earth quake and radon level in earthquake prone areas of the country.

Improvements Proposed on the Method

It was an excellent news on hearing the re opening of nuclear physics laboratory after many years of closure. On the other hand, the inadequacy of experimental equipments is affecting the acceleration and efficiency of the works unlike the work done in this thesis which is not this much affected with these drawbacks. Rather the manual type data taking should be replaced in a computerized data acquisition system such that it saves excess time and energy lost in data taking. The second improvement needed is shielding of the detection system to decrease the back ground measurement variation. The other thing is simultaneous measurement of the back ground, indoor and outdoor leads to near accurate results.

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DECLARATION

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

Name: _____

Signature: _____

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

Name: _____

Signature: _____