



# **EFFECTIVE RADIATION DOSE FROM INDOOR RN-220 CONCENTRATION**

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

# Table of Contents

<b>Table of Contents</b>	<b>v</b>
<b>List of Tables</b>	<b>vii</b>
<b>List of Figures</b>	<b>viii</b>
<b>Acknowledgements</b>	<b>ix</b>
<b>Acronyms and Abbreviations Used</b>	<b>x</b>
<b>Abstract</b>	<b>xi</b>
<b>1 Introduction</b>	<b>1</b>
1.1 Isotopes of Radon . . . . .	1
1.1.1 Discovery of Thoron . . . . .	2
1.1.2 Physical Properties of Thoron . . . . .	2
1.2 Thoron( <sup>220</sup> Rn) in the Environment . . . . .	4
1.2.1 Thoron Entry into the Atmosphere . . . . .	5
1.2.2 Thoron in Mines . . . . .	7
1.2.3 Thoron in Water . . . . .	7
1.2.4 Thoron in Construction Materials ( <sup>220</sup> Rn). . . . .	8
1.2.5 Health Effects of Thoron Progeny . . . . .	8
1.2.6 Thoron and its Importance . . . . .	9
1.3 Rationale of the Study of <sup>220</sup> Rn . . . . .	9
1.4 General Objectives of the Study . . . . .	10
<b>2 Literature Review</b>	<b>11</b>
2.1 Thoron Measurement Methods . . . . .	11
2.1.1 Active Measuring Methods . . . . .	12
2.1.2 Passive Measuring methods . . . . .	14
2.2 Typical Thoron Measurements Across the Globe . . . . .	17
<b>3 Materials and Methods</b>	<b>18</b>

3.1	Sampling Site . . . . .	18
3.1.1	Sampling the Air . . . . .	19
3.2	Experimental Method . . . . .	20
3.2.1	Experimental Set-up . . . . .	21
3.2.2	Data Collection Method . . . . .	23
3.2.3	Counting the Activity on the Filtered Samples . . . . .	24
3.2.4	Method of Analysis . . . . .	24
3.3	Determination of Annual Effective Dose . . . . .	28
3.3.1	Equilibrium Equivalent Concentration . . . . .	28
3.3.2	Effective Dose . . . . .	29
<b>4</b>	<b>Results and Discussion</b>	<b>30</b>
4.1	Results . . . . .	30
4.2	Discussion . . . . .	38
4.3	Comparison with other areas of the World . . . . .	38
<b>5</b>	<b>Conclusion and Recommendation</b>	<b>41</b>
5.1	Conclusion . . . . .	41
5.2	Recommendations . . . . .	41
	<b>Bibliography</b>	<b>42</b>

## List of Tables

1.1	Isotopes of radon available in nature . . . . .	1
1.2	Physical properties of $^{220}\text{Rn}$ . . . . .	2
1.3	Decay scheme of the thorium series and their properties . . . . .	3
2.1	Most common modes of operation of $^{220}\text{Rn}$ detectors (Ahn & Lee, 2005)	16
2.2	$^{220}\text{Rn}$ levels in dwellings in literature ( $\text{Bq}\cdot\text{m}^{-3}$ ) . . . . .	17
3.1	Efficiency table . . . . .	29
4.1	Sample of Data collected from GM Tube . . . . .	30
4.2	Computed Values of Rn and Thoron progeny, and EEC . . . . .	34
4.3	Calculated annual effective dose due to $^{220}\text{Rn}$ . . . . .	36
4.4	The Thoron concentrations in out door and in door air [UNSCEAR, 2000]	38
4.5	Average worldwide exposure to natural radiations [UNSCEAR, 2000] . .	40

## List of Figures

1.1	Radioactive decay chain Thorium-232 (Porstendörfer, 1994) . . . . .	4
1.2	World Resource of thorium (IAEA, 2016). . . . .	4
1.3	Typical thoron sources and entry routes (EPA, 2005). . . . .	7
1.4	Radon-220 health risk (UNSCEAR, 2000). . . . .	9
3.1	Study area . . . . .	18
3.2	The suction pump and sampling head . . . . .	19
3.3	Design of the sampling head (all lengths are in mm) . . . . .	20
3.4	The sampling head and GM counting system . . . . .	21
3.5	Sample holding shelf and lead-castle to house the detector . . . . .	22
3.6	(A) Assembling the apparatus (B) Assembled sampling head . . . . .	23
4.1	Picture showing one of the plots of the analysis . . . . .	33
4.2	Equilibrium Equivalent Concentration of $^{220}\text{Rn}$ . . . . .	35
4.3	Annual effective dose due to $^{220}\text{Rn}$ . . . . .	37

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Addis Ababa University

Zewdineh Asefa Yilma

## Acronyms and Abbreviations Used

IAEA	≡ International Atomic Energy Agency
NCRP	≡ National Council on Radiation Protection
NORM	≡ Naturally Occurring Radioactive Material
WNA	≡ World Nuclear Association
UNSCEAR	≡ United Nations Scientific Committee on the Effects of Atomic Radiation
SSNTD	≡ Solid State Nuclear Detector
US EPA	≡ United States Environmental Protection Agency
WHO	≡ World Health Organization
CAS	≡ Chemical Abstracts Services;
DOE	≡ Department of Energy
ICRP	≡ International Commission For Radiological Protection
EPA	≡ Environmental Protection Agency

## Abstract

Equilibrium equivalent concentration of thoron (EECTh) were measured in the Nuclear Physics laboratory of the Addis Ababa University over a period of 21 days in the months of April and May 2017. The laboratory is located in the first floor of the Department's building. The method, used in this work, is based on gross beta counting of filtered aerosol samples counted over successive time intervals using an end-window Geiger-Müller detection system. i.e., grab sampling of air followed by absolute beta counting was used to determine thoron concentration.

The gross beta-count was then fitted to a mathematical model using least-square fitting method. The concentrations of the radon and thoron daughter products were determined from the best fit. Equilibrium Equivalent Concentrations of Radon and Thoron were calculated from the concentrations of the progeny. This EEC was used to determine the effective indoor inhalation dose due to thoron.

It was found that the effective annual effective doses for thoron inhalation by the inhabitants were found to vary in the range (0.06 - 0.20 mSv/y) with a mean of  $0.1 \frac{\text{mSv}}{\text{y}}$ . These results are close to the maximum permissible dose (0.1 mSv/y) to the public due to thoron progeny recommended by (ICRP, 1990).

## Introduction

### 1.1 ISOTOPES OF RADON

The presence of radon in the atmosphere has been known since its original discovery in 1900. Even then, its distribution in space and time, its physical state and its role in the dynamics of the atmosphere are still not entirely understood. In many cases, however, the isotopes of radon provide a unique set of tracers for the study of transport and mixing processes happening in the atmosphere. Minute amount of Nuclides belonging to the three naturally occurring radioactive series are found throughout the earth's crust. Table 1.1 lists, the radon isotopes with their principal characteristics (Wilkening, 1990).

Series	Long-lived Parent	Crustal Abundance (ppm)	Radon Isotope	Common Name	Half-life	Particle and Energy (MeV)
Uranium	$^{238}\text{U}$	2.7	$^{222}\text{Rn}$	radon	3.824 day	$\alpha$ (5.49)
Thorium	$^{232}\text{Th}$	8.5	$^{220}\text{Rn}$	thoron	55.6 sec	$\alpha$ (6.29)
Actinium	$^{235}\text{U}$	0.02	$^{219}\text{Rn}$	actinon	3.96 sec	$\alpha$ (6.82)

**Table 1.1:** Isotopes of radon available in nature

The isotopes of radon exist as free atoms in the air. The daughter products may appear briefly as ions, and then become attached to aerosols. Their behavior in each case has been the subject of intensive study, yielding information both about the atmospheric part of the natural radiation environment and about the behavior of the atmosphere through a variety of tracer-type studies.

$^{222}\text{Rn}$  mostly referred to simply as radon and its short-lived decay products in the atmosphere are the major contributors to human exposure from natural sources, producing an average effective dose to the population of 1.15 mSv/y (UNSCEAR, 2008). The average annual effective dose due to  $^{220}\text{Rn}$  usually referred to as thoron, the radon isotope belonging to the decay chain of  $^{232}\text{Th}$  and its progeny is estimated to be over 10 times smaller than that due to radon: 0.1 mSv/y (UNSCEAR, 2008). For this reason, exposure to thoron and its decay products has often been neglected in

the past. However, several studies have shown that in some cases doses from thoron and its progeny can be comparable to those from radon and its short-lived decay products, or even larger (Steinhäusler et al., 1994).

### 1.1.1 Discovery of Thoron

Thoron ( $^{220}\text{Rn}$ ) was discovered in 1899 by R.B Owens at Mc Gill University in collaboration with Ernest Rutherford (Kumar et al., 1991). Most of the early work focused on the fundamental physical properties of natural properties of natural radio activity, but some of it is still relevant to modern environmental consideration. Important step in ( $^{220}\text{Rn}$ ) research occurred in the atmospheric sciences when it was realized that  $^{220}\text{Rn}$  and its progeny are a major source of atmospheric ions near the earth's surfaces.  $^{220}\text{Rn}$  and its progeny have been used as tracer in studies of atmospheric transport processes, such as eddy diffusion. Much at these early atmospheric research was by Israel and other (Bemenet, 2006) and the field has continued to be more in isolation from  $^{222}\text{Rn}$ . Most of these are connected with industrial application of thorium.

### 1.1.2 Physical Properties of Thoron

Thorium ( $^{232}\text{Th}$ ) is the ultimate progenitor of  $^{220}\text{Rn}$  its distribution in the earth crust is important for controlling the productions at  $^{220}\text{Rn}$ . Trace amount of  $^{232}\text{Th}$  permeate almost all soils and rocks, in part due to the influence of ground water from which  $^{232}\text{Th}$  can precipitate over geological time scales.  $^{232}\text{Th}$  usually exist in plus four valence state. It is not highly soluble itself, but forms completions which are more soluble (Langmmuir & Herman, 1980). The physical properties of thorn are summarized in table 1.2

Boiling point	-61.8 <sup>0</sup> C
Melting point	-71.8 <sup>0</sup> C
Solubility in water:	
At 0 <sup>0</sup> C	0.51
20 <sup>0</sup> C	0.25
50 <sup>0</sup> C	0.14
Solubility in Acetone	8 at 0 <sup>0</sup> C
Diffusion coefficient in air	0.1cm <sup>2</sup> /secatSTP
Diffusion coefficient in water	1.1x10 <sup>-5</sup> cm <sup>2</sup> /secat18 <sup>0</sup> C

**Table 1.2:** Physical properties of  $^{220}\text{Rn}$  (Durrani, 1997).

### Radioactivity of Radon

Radon has a relatively long half-life of about four days. It can accumulate and build up to high concentrations in relatively less ventilated areas such as basements. Thoron has a relatively short half-life (about 1 minute) and decays substantially

and therefore cannot build up to high concentrations over time in basements. The concentrations of these gases are expressed in units of either pCi/L or Bq/m<sup>3</sup>. It is well known that the main hazard from radon or thoron is not due to the gases themselves but to the radioactive decay products of these gases.

The decay products of radon have a relatively shorter half-life (about 30 minutes). Because of the short half-life of decay products compared to the radon gas, the decay products build up rapidly and it is hard to find radon gas without the associated decay products. In normal homes it is common to find an equilibrium ratio of about 50 percent. It is not difficult to make an assessment of the decay product concentration from the radon gas concentration or vice versa. The decay products of thoron have a relatively long half-life (about 10 hours) compared to the parent thoron gas. Because of this property, the equilibrium is virtually not possible in typical homes. It is difficult to predict a thoron decay product concentration from the measured thoron gas or vice versa. Very close to the source of thoron, the gas concentration can be high with very little decay product concentration. Similarly, at some farther distance, there can be no thoron gas but the decay products carried by ventilation can still be present. The decay types and half life of thoron progeny are summarized in table 1.2 and figure 1.1.

Nuclide	Half life	Types of Decay	Particle energy in (MeV)
<sup>232</sup> Th	1.4x10 <sup>10</sup> y	α	4.01
<sup>228</sup> Ra	6.7 y	β	0.05
<sup>228</sup> Ac	6.13 h	β	1.11
<sup>228</sup> Th	1.9y	α	5.43
<sup>224</sup> Ra	3.64d	α	5.68
<sup>220</sup> Rn	55.5s	α	6.29
<sup>216</sup> Po	0.1585s	α	6.78
<sup>212</sup> Pb	10.6h	β	0.35
<sup>212</sup> Bi	60.6min	β	2.25
<sup>212</sup> Po	3x10 <sup>-7</sup> s	α	1.57
<sup>208</sup> Tl	3.05min	β	8.78
<sup>208</sup> Pb	stable	-	-

**Table 1.3:** Decay scheme of the thorium series and their properties (UNSCEAR, 1988).

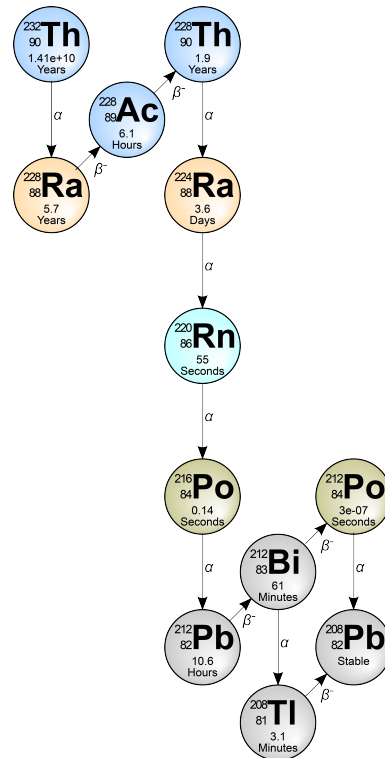


Figure 1.1: Radioactive decay chain Thorium-232 (Porstendörfer, 1994)

## 1.2 THORON ( $^{220}\text{Rn}$ ) IN THE ENVIRONMENT

Thoron nuclides ( $^{220}\text{Rn}$ ) are gaseous radioactive products of the decay of the radium isotopes  $^{224}\text{Ra}$  which are present in all terrestrial materials such as rocks, thorium ores and soils.

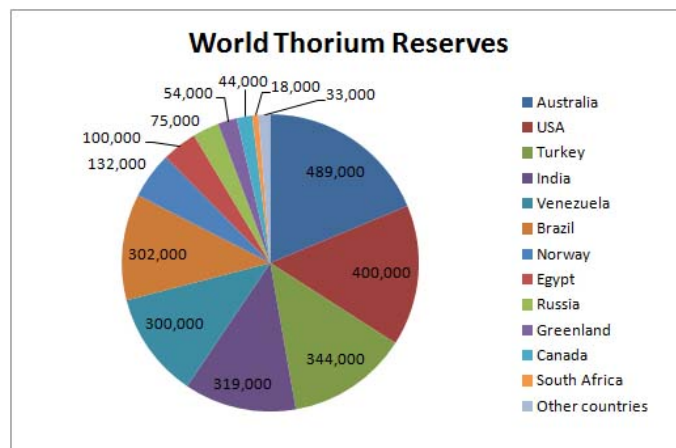


Figure 1.2: World Resource of thorium (IAEA, 2016).

### 1.2.1 Thoron Entry into the Atmosphere

Some of the atoms of these Thoron nuclides ( $^{220}\text{Rn}$ ) are released from the solid matrix of the material by recoil when the radium decay. Thoron atom entering the pore space are then transported by diffusion through this space until they in turn decay or are released into the atmosphere exhalation. Thoron 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. Microscopic fractures and fissures, called nonporous, and pits or openings caused by previous radioactive decays provide additional pathways for radon release. Particularly in sand-sized and larger grains, nonporous can increase the specific surface area of the grain, enhancing emanation by one or two orders of magnitude (EPA, 2005).

Soil moisture, directly affects radon emanation by capturing the radon that recoils from the solid matrix. These captures increase the likelihood that radon atom will remain in the pore space instead of crossing the pores and imbedding themselves in adjacent soil grains (Liesel, 2005).

The main mechanism for the entry of radon into the atmosphere is molecular diffusion. Although diffusive entry of radon into the outdoor atmosphere usually dominates, there is also some advection caused by wind and changes in barometric pressure. Measurements of exhalation rates of Rn from soil show a variability of concentrations in near surface pore spaces. Concentrations of  $^{220}\text{Rn}$  in soil gas vary over many orders of magnitude from place to place and show significant time variations at any given site. Data have shown that there were prominent increases in radon concentrations in outdoor air and in ground water just before the larger earthquake at Kobs, Japan in 1995 (UNSCEAR, 2000).

Under normal circumstances, thoron concentrations in soil gas would be roughly comparable to or perhaps somewhat less than the concentrations because of the generally similar production rates in rocks and soils and their behavior in the ground. On the other hand, high thoron entry rates from the ground are rarely encountered. Whereas fractures in the ground and/or bedrock allow to be pulled to the surface from substantial depths and volumes the time frame may be such that most of the thoron present at these depths decays before reaching the surface (UNSCEAR, 2000).

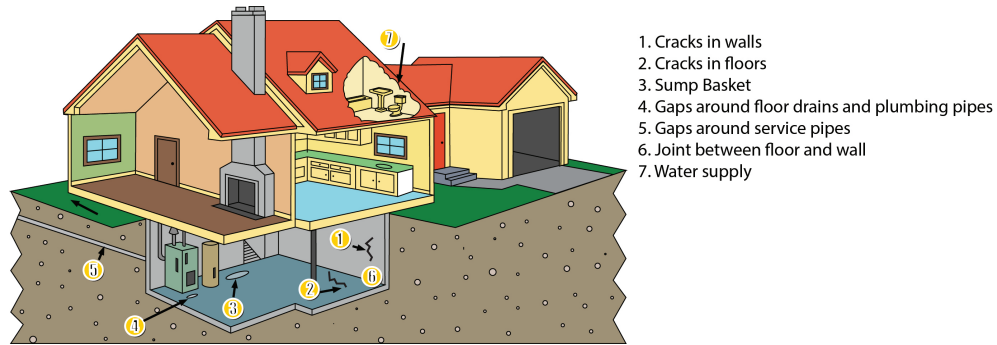
### *Thoron in outdoor air*

Outdoor air usually acts as a diluting factor, due to its normally low radon content concentration, but in some cases, as in high rise apartments built with materials having very low radium, thoron gas concentration in the atmosphere at ground level was usually assumed to be of the order of few Bq/m<sup>3</sup>: e.g., in the range of 4 to 15 Bq/m<sup>3</sup> in USA (Knoll, 2000). Concentrations of Thoron in the outdoor environment are affected not only by the magnitude of exhalation rates in the general area but also by atmospheric mixing phenomena. Solar heating during the day time to induce some turbulence, so that radon is more readily transported upwards and away from conditions are found, which tend to trap the radon closer to the ground (UNSCEAR, 2000).

There are also seasonal variations related to the effects of precipitation or to changes in the prevailing winds. These effects must be taken when interpreting the available measurements (UNSCEAR, 2000). Although data are scarce for thoron, considerable variability from place to place would be expected because of thorn's short half- life. Even more important is the fact that thorns's short half- life results in a very steep vertical gradient in its atmospheric concentration at any location.

### *Thoron in Indoor Air ( <sup>220</sup>Rn )*

The main source of indoor thoron is its immediate parent radium (<sup>224</sup>Rn) in the ground of the site and in the building materials (James, 1988). The outdoor air also contributes to the radon concentration indoors, via the ventilation air. Tap-water and the domestic gas supply are usually radon sources of minor importance, with a few exceptions. levels originate from radon in the underlying rocks and soils in most situations it appears that elevated indoor radon (Tassos & Horalabos, 2003). This thoron may enter living spaces in dwellings by diffusion or pressure driven flow if suitable path ways between the soil and living spaces are present(see Figure 1.3) typical thoron sources and entry routes. It should be that in a minority of cases elevated indoor radon levels may arise due to the use of building materials containing high levels of radium-226. The United Nation Scientific Committee on the Effects of Atomic Radiations (UNSCEAR) has made a very simple model to try to estimate the relative contribution of these sources: for a "typical" house, with a thoron concentration of 50 Bq/m<sup>3</sup> at ground floor, the contributions of soil, building materials and outdoor air respectively, 60 percent, 20 percent while for the upper floors in high rise buildings, where the radon concentration is estimated to be "typically" 2 Bq/m<sup>3</sup>, these values become 0 percent, 50 percent (UNSCEAR, 2000).



**Figure 1.3:** Typical thoron sources and entry routes (EPA, 2005).

### 1.2.2 Thoron in Mines

Radium available as part of the Earth's crust is the major source of thoron in mines. Production and release into the mine atmosphere depends on the grades, its emanation power, porosity and permeability of host rock to thoron and moisture content of the ore. Water coursing through the ore body remains under high pressure which dissolves significant amounts up to 23 % of thoron available in the ore spaces through which it passes; this acts as an efficient medium of transport for thoron carrying it from far-off places and discharging it into the mine cavity.

The moment thoron-laden water enters the mine openings and flows through the mine galleries, dissolved radon is released due to depressurization and constant agitation (UNSCEAR, 2000). Thoron ( $^{220}\text{Rn}$ ) 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. Thoron gas, on entering the mine air by there till it is carried along in the ventilation current and discharged above ground. Because of its comparatively short half life 55.6 sec half life 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).

### 1.2.3 Thoron in Water

Thoron is also found in the water, in homes, in particular homes that have their own well rather than municipal water when the water is agitated, as when showering or washing dishes, scopes into the air. However, radon from domestic water generally contributes only a small proportion (less than one percent) of the total radon in indoor air. Municipal water systems hold and treat water, which helps to release radon, so that levels are very low by the time the water reaches homes. But people,

who have private wells, particularly in areas of high radium soil content, may be exposed to high levels of radon (EPA, 2005).

#### 1.2.4 Thoron in Construction Materials ( $^{220}\text{Rn}$ ).

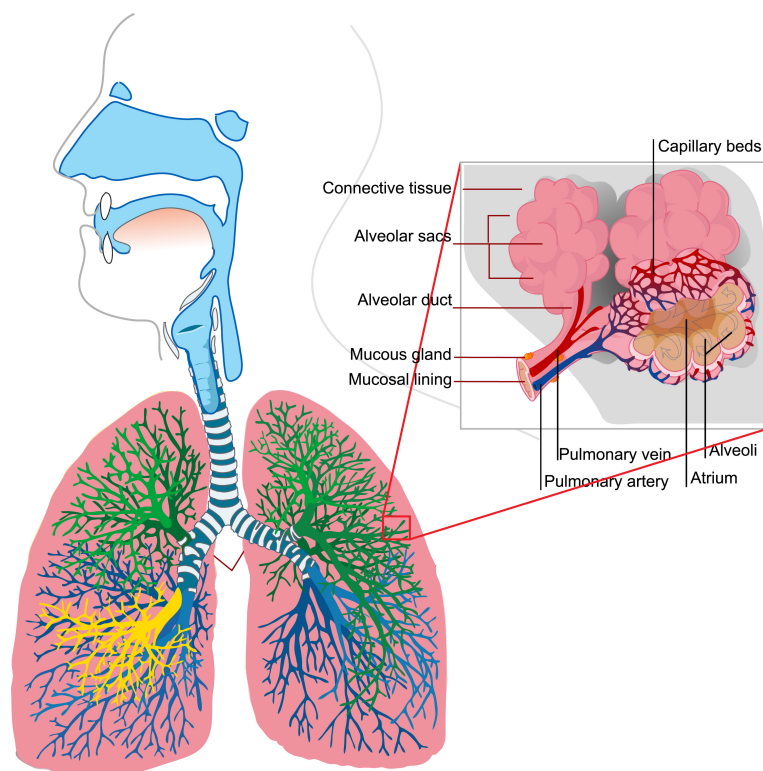
Building materials from soil and rock (such as cement, block, ceramic, etc.) contain radioactive material of natural origin such as uranium, radium and thorium. Permeability of these materials is sufficient to seal off the thoron generated by radioactive decay. Building materials are the main sources of thoron in indoor air.

Thoron exhalation from building materials depends not only on the radium concentration, but also on factors such as the fraction of thoron produced which is released from the material, the porosity and the surface preparation and finish of the walls. Building materials containing by product gypsum and concrete containing alum shale may have much higher radium concentration (UNSCEAR, 1982). Due to its short half-life (55.6 sec), thoron originating in soil, in effect, is usually prevented from entering buildings and therefore makes negligible contribution to indoor thoron levels. For this reason, thoron or progeny concentration measurements are very much fewer than those for radon (UNSCEAR, 1982).

#### 1.2.5 Health Effects of Thoron Progeny

Since Radon and Thoron are gases, they easily mix with the atmosphere and they can enter into human lung during inhalation and exhalation. Most of the thoron gas inhaled is also exhaled. However, thoron decay products that are attached to dusts and aerosol in the air are readily deposited in the lungs. Some of these are removed by the lungs natural defence system and swallowed or coughed out (EPA, 2005). The human respiratory system is indicated in figure 1.4.

Radon progeny attached to particles with a diameter of 100–500 nm can deposit in the alveoli and give some dose to the lung periphery. deposited Radon and its progeny can cause small cell lung carcinomas (SCLCs), which arise in the larger airways, as well as non-SCLCs derived from pluripotential basal cells in the bronchial mucosa. The free fraction or unattached fraction of radon progeny gives a significant dose to larger airways. Most thoron progeny are attached to aerosol particles in the air since thoron progeny have relatively long half-lives when compared with radon progeny. Therefore, it is unlikely for thoron progeny to give a significant dose to bronchial mucosa. However,  $^{216}\text{Po}$ , a thoron progeny with half-life of 0.15 s emitting alpha radiation, may be present in the unattached form in the air. Whether  $^{216}\text{Po}$  can give a significant dose in the bronchial mucosa is yet unclear (Akiba1 et al., 2010).



**Figure 1.4:** Radon-220 health risk (UNSCEAR, 2000).

### 1.2.6 Thoron and its Importance

There are several situations where measurement of thoron and thoron progeny is important. In thorium refineries and in areas rich in thorium, such as those found in Brazil and India, it is important to make measurements of thoron and thoron progeny. These contribute significantly to the dose received by lungs. If you suck air from under the soil at a fast rate, then the air can have relatively high levels of thoron. Usually flow-through instruments are calibrated for giving results of thoron concentrations. If such instruments are used for making soil gas measurements, the result will not be a true value of radon but some value higher than the true value. One way to overcome this problem is to build in a delay loop long enough to decay the thoron. If passive devices are used for making such soil gas measurements, only those which discriminate thoron should be used if the correct thoron concentration is needed.

## 1.3 RATIONALE OF THE STUDY OF $^{220}\text{Rn}$

It is an established fact that inhalation of Rn and its daughter products is a health hazard. So one must be aware of his/her environs radon and thoron concentrations take the necessary steps for the reductions.

It is also necessary to measure radon and thoron levels of a given locale as part of accumulations of environmental radiation data. Future generations may use the data for possible nuclear activities in the country. In this regard, our county seem lagging behind even by African standards.

Currently in Ethiopia, there is no radon concentration standard in air for indoor houses. There are few measurements here and there as part of training activities in various universities like ours.

#### **1.4 GENERAL OBJECTIVES OF THE STUDY**

The present study aims to investigate thoron equilibrium equivalent concentration and corresponding effective annual dose due to thoron in the nuclear physics laboratory of the physics department, AAU.

## Literature Review

The studies on uranium miners have established the presence of a positive risk coefficient for the occurrence of lung cancer in miners exposed to elevated levels of  $^{220}\text{Rn}$  and its progeny. Simultaneously, there was a great upsurge of interest in the measurement of  $^{220}\text{Rn}$  in the environment. It was also hoped that in conjunction with epidemiological studies, a large-scale  $^{220}\text{Rn}$  surveys might lead to a quantitative understanding of the low dose effects of  $^{220}\text{Rn}$  exposures. Considerable data has been generated on the levels of  $^{222}\text{Rn}$  in the environment (UNSCEAR, 2000). In contrast, data on  $^{220}\text{Rn}$  is scarce due to the general perception that its level is negligible due to its shorter half-life (55.6 sec) and its contribution to inhalation dose is ignored, in the presence of other more significant natural radiation. This may not be true from the recent studies which observed high  $^{220}\text{Rn}$  in the living environments in various countries and it is increasingly felt that it may be necessary to have information on  $^{220}\text{Rn}$  levels in the environment for obtaining a complete picture of inhalation dose (Porstendörfer, 1994; Steinhäusler et al., 1994).

Various literatures and previous works were reviewed for this work. Reports by different international organizations on the different aspects of the issue, academic thesis, published and unpublished journals about thoron measurement and the methodologies were consulted with focus on the most recent ones.

Many techniques and instruments are available for the measurement of thoron and its decay products, with their own advantages and disadvantages. This chapter provide highlights monumental and previous works on thoron measurement.

### **2.1 THORON MEASUREMENT METHODS**

Many techniques have been developed over the years for measuring thoron and thoron progeny in the atmosphere, including indoor and outdoor air. Thoron and thoron progeny emit alpha and beta particles and gamma rays. Therefore techniques of thoron measurement methods have been based on detecting alpha particles, beta particles or gamma rays, independently or in some combination.

Thoron measurements techniques are generally classified as *passive* and *active methods*. In the passive methods of measuring thoron the measurements is usually made over a long period of time and the result is reported as the average over the measured time interval. In active measurement methods the thoron concentration is measured at given measuring point in time. Active method for thoron measurements and that for decay products were adopted for continuous measurements to investigate variation of concentration with time. These methods are standard methods which are described in details in "indoor thoron and thoron decay product measurements device protocols Published by U. S environmental protection agency (EPA, 1993).

### 2.1.1 Active Measuring Methods

Grab radon Sampling GM muller scintillation cells, ionization chamber, continuous sampling decay product method are active measuring methods.

#### *Grab sampling*

Here the activity of thoron or thoron daughter in a discrete sample of air taken at a single location in a short period of time (from about 1 sec to about 20 min) is measured. This approach is at best useful for initial screening purposes or for spot-checking of the efficacy of remedial actions. It is of very limited use for determinations of average indoor air radon concentrations which are more appropriately determined on the basis of long-term measurements. Grab sampling which is based on direct beta counting of filtered aerosol sample over successive time intervals by end window Geiger- Muller counter. This method can be used for simultaneous measurement of radon and thoron decay products (Singru, 1974).

#### *Continuous sampling*

Here air is drawn either continuously (or semi-continuously) for long periods of time through a Rn or Rn daughter detecting instrument. This type of approach gives information on the time dependence of the airborne activities in a building. Information which may be obtained using continuous sampling include the ratio between day-time and night-time concentrations in a building, diurnal variations etc. Such information is quite useful in deciding on strategies used to reduce occupational exposures where occupancy factors are much less than in dwellings. The recommendations of the Commission of the European Communities of February 1990 (ICRP-60, 1990).

### *Scintillation cells*

This is one of the oldest and most reliable type of device for measuring the concentration of radon gas. It exists in a number of forms and can be used for grab-sampling or for continuous long term measurements. A radon scintillation cell typically is a small metal cylinder equipped with one or two vacuum-tight inlet/outlet valves mounted on one end. The opposing end of the cylinder is a clear glass or plastic window. The internal volume of such a cell is typically about 100 cm<sup>3</sup>. The inner surfaces of the cylinder, excepting the window, is uniformly coated with ZnS (Ag) powder which is a very efficient scintillator for alpha particles. The most common form of such a scintillation cell is called a Lucas cell (A.S. & Aleissa, 1957). The scintillation cell filled with an air sample is placed in optical contact with a photomultiplier tube (PMT). The scintillations or flashes of light caused by the alpha particles from radon, Po-218 and Po-214 which strike the ZnS(Ag) are recorded by the PMT and its associated electronics. Using appropriate calibration and decay scheme factors the radon gas concentration may be determined from the rate at which the pulses are recorded (A.S. & Aleissa, 1957).

In grab sampling mode an air sample is taken into the cell which is then sealed and after a decay of 3 hours, to allow for approximate radioactive equilibrium between radon and its short-lived decay products to be reached, a count rate is taken. Active versions using flow through scintillation cells are commercially available and can be used for continuous monitoring of radon concentrations in a building. They are usually equipped with data storage and printout facilities and a range of cycle times (Singru, 1974).

### *Ionization chambers*

In an ionization chamber an electrical field is established between two or more electrodes. Filtered air is either allowed to diffuse into the chamber, or it is pumped in, and the current caused by ionization of the gas inside the chamber is detected. The ionization measured is that caused by the decay of thoron and its thoron decay products. Either the total ionization in the chamber is measured, or the pulses caused by individual alpha particles are counted separately. The latter technique has the advantage that it is possible to distinguish between the pulses caused by different decay products and by radon. If the associated electronics are set to reject counts from polonium-214 (the last of the short-lived decay products, with the highest energy alpha particle at 7.7 MeV), a fast response time can be obtained. The response time of the instrument also depends on the rate of replacement of air in the ionization

chamber. In recent years commercial ionization chambers have been widely adopted as secondary standards in thoron calibration laboratories humidity of the air, so a desiccant is normally used to remove water vapor (EPA, 1992).

### 2.1.2 Passive Measuring methods

Passive measuring methods are charcoal detectors, electret ion chambers and solid state nuclear track detector.

#### *Charcoal detectors*

Activated charcoal has an affinity for many gases including thoron. Thoron adsorbed on charcoal will decay, and the decay products formed will be retained, allowing the adsorbed thoron to be measured by beta counting of the emissions from lead-212 and bismuth-212 (George, 1984). An alternative to beta counting is liquid scintillation counting. For this, charcoal which has been exposed to thoron is mixed with a liquid scintillation cocktail, in which the thoron dissolves readily. The liquid is counted in standard liquid scintillation counting equipment. The detectors usually comprise a bed of granulated activated charcoal held in position by a metal mesh in a metal canister with a removable lid. Before use the open canister is heated to remove any adsorbed gas and water vapor. The lid is then taped in place and the canister moved to the measurement location where the lid is removed, exposing the charcoal. At the end of the exposure period the lid is replaced and secured and the canister returned to the laboratory for analysis. Charcoal detectors are not true integrators, as the absorbed at the start of an exposure will decay and partially desorb from the charcoal during the exposure. The desorption can be reduced if a diffusion barrier is placed between the surface of the charcoal bed and the atmosphere. Measurements are carried as the 55.6 sec. Half-life of thoron and its desorption from charcoal makes longer measurements meaningless. Charcoal detectors can make accurate measurements of thoron concentrations. The principal drawback to their use in measuring radon concentrations in buildings is that the concentrations vary over longer time periods than a few days, so the result is not truly representative of the long-term average (George, 1984).

#### *Electret ion chambers*

Electrets are the electrostatic equivalent of permanent magnets, having a permanent surface charge resulting in a surface potential that may be several kV. In a commercial development of this technique (Kotrappa et al., 1992) a teflon electret is placed at the bottom of a conducting plastic chamber, known as an electret ion chamber (EIC).

Thoron diffuses into the chamber volume and the electret loses charge because of the general air ionization produced by thoron and its decay products in the chamber volume. This detector acts as a true time-integrator of thoron exposure, but has a limited dynamic range. Two electret elements of different thickness, and hence sensitivity, are available, and three different chamber sizes may be used. The devices are sensitive to gamma rays and a compensation for this has to be applied. Where the most precise measurements are called for, correction for elevation should be made to compensate for the effect of atmospheric pressure variation. In using these devices, it is essential that the instructions preparing and reading out the electrets are followed closely. Dust on the charged surface of the electret and dropping the on a hard surface can both partially discharge the electret, leading to an overestimate of radon exposure (Kotrappa et al., 1992).

### *Solid State Nuclear Track Detectors*

Solid State Nuclear Track Detector consists of a small piece of plastic or film enclosed in a container. Thoron diffuses in container and particles emitted by the Thoron and its 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 thoron 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 thoron 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. Thoron enters the holder with a half-life for entry about 1 minute which is long compared with the thoron half-life of 55.6 second this means that the thoron concentration inside the detector chamber quickly approaches that of outside. It can be shown that the long-term average thoron concentration inside the detector chamber is the same as that outside, despite any variations in the outside concentration. But the thoron concentration may be overestimated because the short half-time for entry will allow some thoron to enter the detector (Ahn & Lee, 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 thoron concentration (Ahn & Lee, 2005).

### *Time integrating sampling*

Techniques using time integration consist of using a device which will yield a single determination of airborne activity averaged over some chosen period from a few days to a year or longer. As time integrating sampling is usually but not exclusively carried out with inexpensive passive detectors it is the preferred approach in survey work. In reaching a decision on the necessity of remedial action it is generally considered in European Community countries that integrating measurements of minimum duration 3 months should be made.

Grab sampling or short-term integrating sampling of a few days are considered inadequate for making accurate estimates of long term exposure of occupants of a building to thoron. In countries such as the USA, where real-estate transactions may require urgent evidence of the indoor thoron concentration in a building short-term integrating techniques of a few days duration may be recommended provided they are carried out according to a recognized measurement protocol (White & Alexander, 1991).

Detector	Grab	Integrating	Continuous	Active	Passive
Scintillation cell	Yes	-	Yes	Yes	Yes
Alpha Track	-	Yes	-	-	Yes
Charcoal Detector	-	Yes	-	-	Yes
Electret	-	Yes	-	-	Yes
Electronic	Yes	-	-	Yes	-

**Table 2.1:** Most common modes of operation of  $^{220}\text{Rn}$  detectors (Ahn & Lee, 2005)

## 2.2 TYPICAL THORON MEASUREMENTS ACROSS THE GLOBE

Measured  $^{220}\text{Rn}$  concentration varied from widely from place to place depending on the geologic formation. World wide study shows this variation. For example in India Thoron concentration varies from 5.7 to 42.4  $\text{Bq.m}^{-3}$  with a mean of 12.2  $\text{Bq.m}^{-3}$ . Such variations are summarized in table 2.2 (Ramachandran & Sathish, 2014).

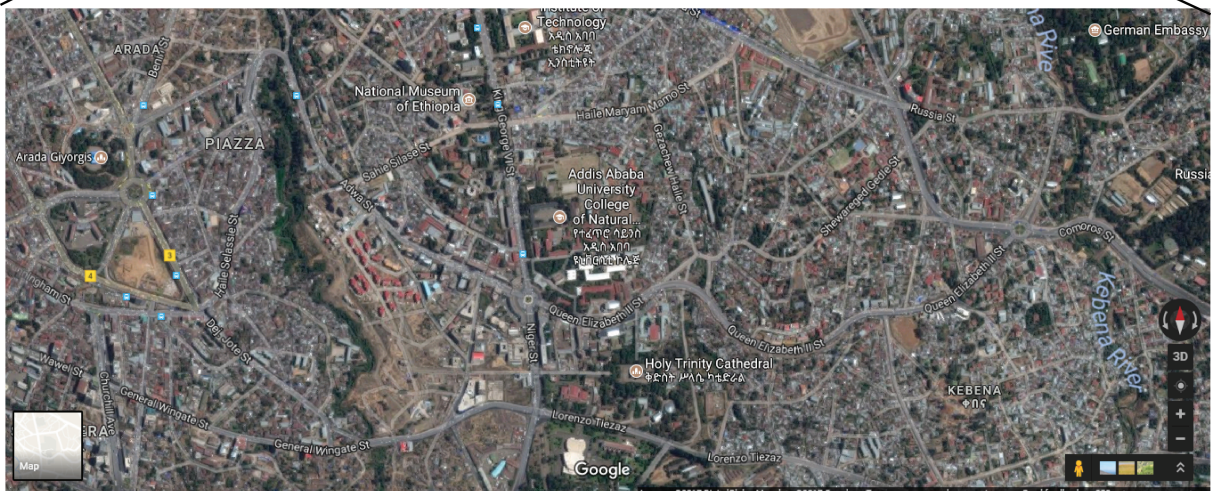
**Table 2.2:**  $^{220}\text{Rn}$  levels in dwellings in literature ( $\text{Bq.m}^{-3}$ )

Country	Location	No. of data	Mean	Max	Min
Austria	Dwelling	9	19.0	74.0	< 3.3
Brazil	Dwellings	1	19.0		
Germany	Cellars	4	8.9	39.1	2.2
	Lecture room	1	0.7		
	Garagee	1	7.6	8.3	4.1
Italy	Dwellings	21	8.5	54.7	
Sweden	Apartment			10.0	5.0
	Wooden house			2.0	1.0
	Basement			200.0	5.0
	Dwellings	45	31.0	430.0	1.0
Japan	Dwellings	21	8.5	54.7	
China (HBRA)	Dwellings		168.0		
USA	Dwellings	7	10.0	34.0	2.0
	Basement	6	13.0	40.0	MDL
	Garage	1	10.0	18.0	6.0
	Ground floor	1	12.0	16.0	9.0
India	Dwellings	2000	12.2	42.2	5.7

## Materials and Methods

### 3.1 SAMPLING SITE

The sampling site of this work is the Nuclear and Radiation Physics Laboratory of the Physics Department, Addis Ababa University. Addis Ababa, the capital city of Ethiopia, is located at  $38^{\circ}42'$  E longitude and  $9^{\circ}, 02'$  N latitude.



**Figure 3.1:** Study area

The laboratory is located on the first floor of the physics building. Windows were open during day time and are closed over night throughout the period of this study.

### 3.1.1 Sampling the Air

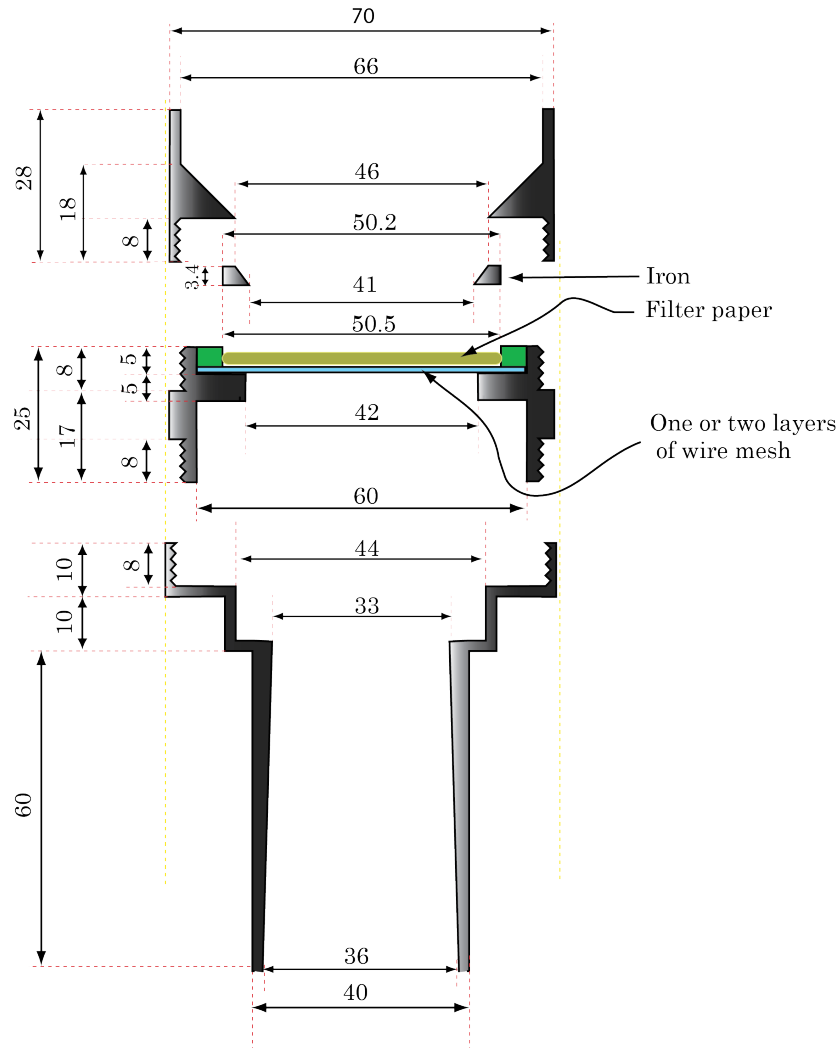
Each morning, air was sampled, using a suction pump fitted with a sampling head designed for this purpose, for 15 minutes in the morning hours (between 6:00 am and 7:00 pm) of the 21 sampling days.

A suction pump with air flow rate of  $0.18 \text{ m}^3/\text{minute}$  was used to suck air on a Whatman®-glass fiber filter paper that has more than 99% retention of aerosols. The filter paper deposit the aerosols while allowing air to pass through. To this effect the filter was fitted between two “O”-rings in the sampling head and its base was supported by a wire mesh to stand the pressure of air pumping during sampling. The effective filter surface, available for the passage of air was 3 cm in diameter.



**Figure 3.2:** The suction pump and sampling head

The sampling head was kept in each case at the center of the room and at a height of approximately 1 m to 1.5 m above the floor and the height of nuclear physics laboratory first floor room approximately about 5 m from the ground. Air sucked through by a built in pump was passed through the air suction pump to the beta counting detector for the measurement of radon concentration.



**Figure 3.3:** Design of the sampling head (all lengths are in mm)

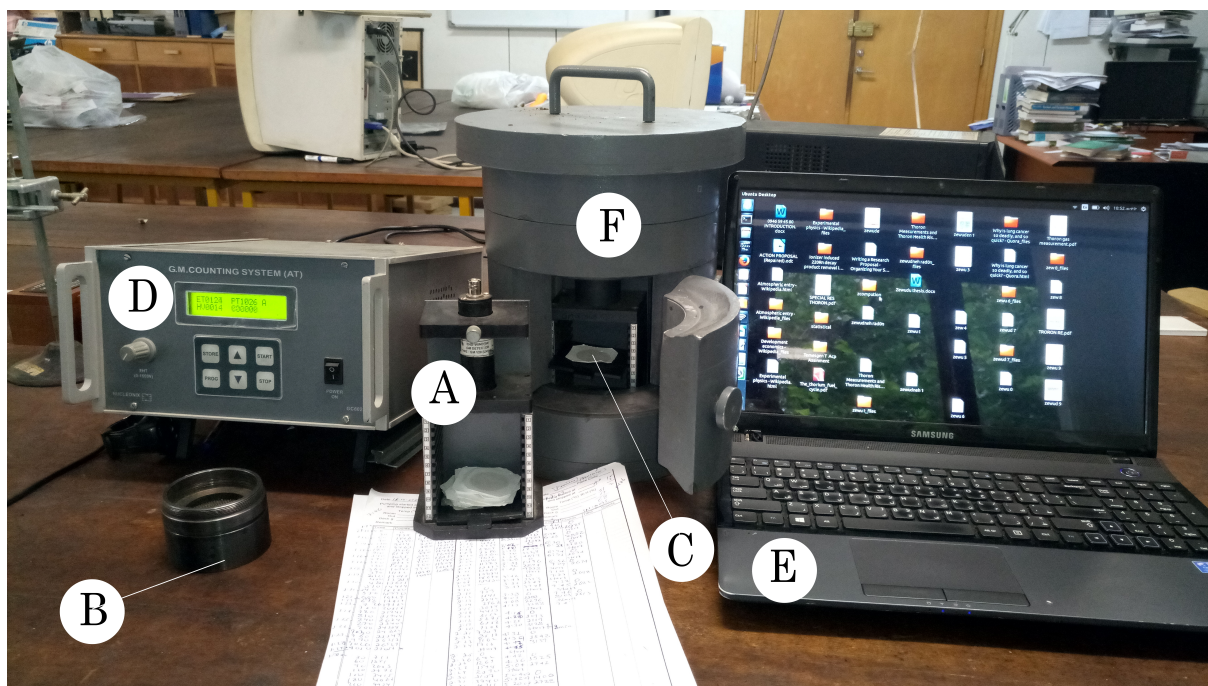
## 3.2 EXPERIMENTAL METHOD

A grab sampling method was employed for the determination of radon progeny concentrations in air. Air was sampled by using a suction pump at a rate of  $0.18 \text{ m}^3/\text{min}$  through a filter paper, that was fitted airtight on a home made sampling head, of high retention efficiency ( $> 99\%$ ).

After 15 minutes of air sampling, the filter paper was carefully removed from the sampling head and placed under a Geiger Muller tube and a counting system.

The gross beta count was registered for successive intervals of time. The gross count was fitted with a mathematical model representing radon daughter products decay rate using least-square fitting techniques to obtain the activity concentrations of radon progeny on the filter paper and hence in the volume of the air that has passed through the filter paper.

### 3.2.1 Experimental Set-up

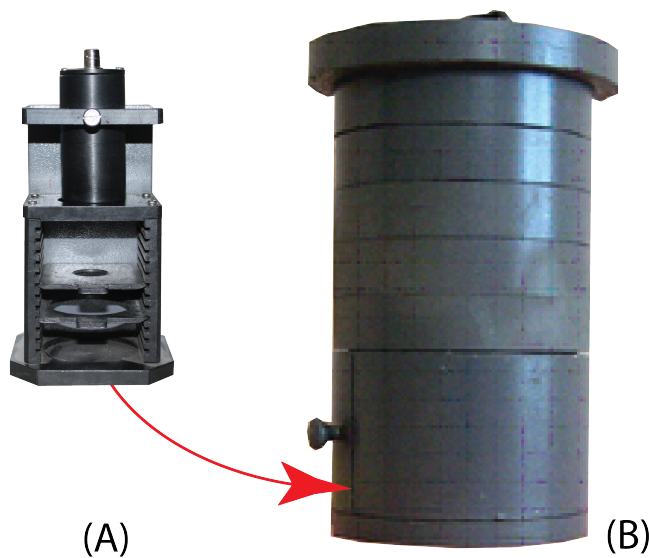


**Figure 3.4:** The sampling head and GM counting system of the nuclear and radiation physics lab, AAU is used in this work. (A) GM-Tube; (B) Sampling head; (C) Glass fiber filter; (D) Counting GM tube system beta counter containing high voltage supply (500 V); (E) Computer; (F) lead shield

Materials used in the experimental method of this work are shown in figure 3.4. Detailed description of the apparatus used in our experimental setup is given below.

- (A) **Geiger-Müller Tube:-** The GM tube is filled with argon to be ionized by the incoming radiation while the counter collects electrons and reports through its window screen. The GM tube type: GM 125 (LND72314) wide window GM detector was used.
- (B) **Sampling Head:-** The sampling head, has longitudinal cross section view shown in figure 3.3, which was also used in Papp (1997). Sampling head was locally crafted by Abaya mechanical Engineering firm in Addis Ababa.
- (C) **Glass Fiber Filter:-** Whatman glass fiber filter is used to and deposit aerosols and radon progeny in air. It is placed on the sampling head during sampling.
- (D) **Geiger-Müller Counting System:-** has two functions. Its first function is to supply the operating voltage to the tube and its second function is to receive and record the number of counts, i.e., pulses created in the active volume of the detector.

- (E) **Computer:-** Computer is used to analyse the gross count data and fit it with mathematical model.
- (F) **Lead castle with door for G.M detector:-** This consists of 40 mm lead shielding cylindrical rings assembly with total of seven lead assembly parts. There is a hinged door in the bottom ring through which sample can be loaded in to the G.M stand sample tray. A 1 mm aluminum lining is provided on the inside surface of the lead shielding. When it is dispatched from here usually it is packed in about four wooden boxes.



**Figure 3.5:** (A) the Shelf to hold filter paper and be housed in the lead-castle during counting and (B) the lead-castle

### *Counting Geometry*

The shelf was used to hold the tube, facing downward, inside a thick, cylindrical lead shield. The filter was fixed on the shelf sample holder plate with a circular opening at its center. This opening in the plate was in order to avoid any back scattering of beta particles emitted from the filter, which otherwise may create difficulties while evaluating their exact contribution to the count-rate. The clean side of the filter faced downward. The distance between the filter and the window was 0.9 cm.

A plastic sheet was used to cover the detector window to absorb alpha particles. The number of counts was corrected for coincidence loss and the background events.

The detector was housed in a thick lead shield that is internally lined with aluminium sheet (figure 3.5).



(A)



(B)

**Figure 3.6:** (A) Assembling the apparatus (B) Assembled sampling head

### 3.2.2 Data Collection Method

Grab sampling technique followed by gross beta counting of the sample was employed in this study. Grab sampling is a sampling technique in which a single sample air is taken over a short period of time. Grab samples provide an immediate and representative sample, and are thus preferred for laboratory tests of this kind. A grab sampling technique is also known as a catch sampling or individual sampling technique.

Our experimental method is based on gross beta counting of a filtered aerosol sample over successive time intervals by an end-window Geiger-Müller (GM) counter. The evaluation of the activity concentrations was based on the following procedure:

1. Sampling known volume of air on a sampling head using filter paper.
2. Placing, the filtered air sample under an end-window GM counting system, with in a minute or two after the end of sampling.
3. Record the gross count in successive intervals of time for sufficiently large number of intervals (more than 100) over a period of 9 to 10 hrs.
4. Analysis of the count rate versus time and fitting of experimental points with the mathematical model.
5. Determination of EECs from the best-fit of experimental points and the mathematical model.

### 3.2.3 Counting the Activity on the Filtered Samples

Within one or two minutes after sampling is ended, the filter was placed below GM tube on the shelf. Counting of the activity, on the filtered air samples, was done using a GM tube (window thickness of  $2 \times 10^{-3} \text{ g/cm}^2$  and a diameter of 3 cm). The operating voltage the GM tube was determined to be 500 V.

Gross beta counts were recorded over a number of successive time intervals each of them are 0.5 min, 1 min, 5 min, 8 min, 17 minutes duration. This was repeated for each of 21 sampling days for 8-10 hours.

The back ground counting rate was also measured by using clean filter before and after measurements.

For all the measurements taken, in this work, the distance between the tube and the filter was 9 mm.

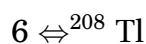
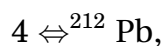
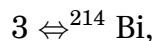
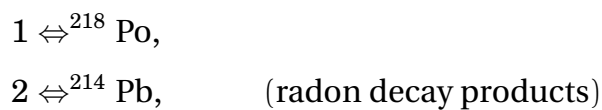
### 3.2.4 Method of Analysis

#### *Analysis of the Gross Count*

Defined Solid Angle Absolute Beta Counting (DSAABC) method has been used to measure the activities of the filtered air samples. Some of the features are outlined below (Papp, 1997).

#### *Mathematical Modeling of the Counts*

##### **Nomenclature:**



**Constants:**

$T$  = air sampling time.

$k$  = air sampling flow rate.

$t_b$  = time at the beginning of a counting interval.

$t_e$  = time at the end of a counting interval.

$C$  = total  $\beta$  counts over the interval  $(t_b, t_e)$

$M$  = number of counting intervals.

$\varepsilon_i$  =  $\beta$  counting efficiency of the detector for the  $i^{\text{th}}$   $\beta$  – emitting radionuclide  
( $i = 2, 3 \dots 7$ ).

$\lambda_i$  = decay constant of the  $i^{\text{th}}$  radionuclide, ( $i = 1, 2, \dots 7$ ).

$\lambda_{ij} = \lambda_i - \lambda_j$ , ( $i, j = 1, 2, \dots 7$ .)

$e_{Tij} = \exp(-\lambda_i T) - \exp(-\lambda_j T)$ , ( $i, j = 1, 2, \dots 7$ ).

$\hat{e}_i = \exp(-\lambda_i t_b) - \exp(-\lambda_i t_e)$ , ( $i = 1, 2, \dots 7$ ).

$e_{T0j} = 1 - \exp(-\lambda_j T)$ , ( $j = 1, 2, \dots 7$ ).

**Variables**

$n_i$  = number of atoms per unit volume of sampled air, ( $i = 1, 2, \dots 7$ .)

$\alpha_i$  = activity of the  $i^{\text{th}}$  radionuclide per unit volume  
of the sampled air, ( $i = 1, 2, \dots 7$ .)

$N_{Ti}$  = number of atoms of the  $i^{\text{th}}$  radionuclide in the filter at the end of sampling  
( $i = 1, 2, \dots 7$ )

$t$  = time elapsed since the end of sampling.  $t = 0$  at the end of sampling.

CR = total  $\beta$  count rate

$e_i = \exp(-\lambda_i t)$ , ( $i = 1, 2, \dots 7$ ).

$e_{ij} = \exp(-\lambda_i t) - \exp(-\lambda_j t)$ , ( $i, j = 1, 2, \dots 7$ .)

$e_{0j} = 1 - \exp(-\lambda_j t)$ , ( $j = 1, 2, \dots 7$ .)

**Buildup during Sampling.**

Assuming the sampling flow rate,  $k$  and the number density ( $n_i$ ) of the radionuclides in the sampled air are constant during the sampling period, the solutions of the

equations for the number of radionuclides at the end of sampling will be:

$$n_1 = \frac{N_{T1}\lambda_1}{ke_{T01}} \quad (3.1a)$$

$$n_2 = \frac{\lambda_2 N_{T2}}{ke_{T02}} - n_1 \left[ 1 - \frac{\lambda_2 e_{T21}}{e_{T02}\lambda_{12}} \right] \quad (3.1b)$$

$$n_3 = \frac{\lambda_3 N_{T3}}{ke_{T03}} - n_1 \left[ 1 - \frac{\lambda_3 e_{T23}}{\lambda_{32} e_{T03}} - \frac{\lambda_3 \lambda_2 e_{T23}}{\lambda_{32} \lambda_{12} e_{T03}} + \frac{\lambda_3 \lambda_2 e_{T31}}{\lambda_{13} \lambda_{12} e_{T03}} \right] - n_2 \left[ 1 - \frac{\lambda_3 e_{T23}}{\lambda_{32} e_{T03}} \right] \quad (3.1c)$$

$$n_4 = \frac{N_{T4}\lambda_4}{ke_{T04}} \quad (3.1d)$$

$$n_5 = \frac{\lambda_5 N_{T5}}{ke_{T05}} - n_4 \left[ 1 - \frac{\lambda_5 e_{T54}}{e_{T03}\lambda_{45}} \right] \quad (3.1e)$$

$$n_6 = \frac{\lambda_6 N_{T6}}{ke_{T06}} - 0.36n_4 \left[ 1 - \frac{\lambda_6 e_{T56}}{\lambda_{65} e_{T06}} - \frac{\lambda_6 \lambda_5 e_{T56}}{\lambda_{65} \lambda_{45} e_{T06}} + \frac{\lambda_6 \lambda_5 e_{T64}}{\lambda_{46} \lambda_{45} e_{T06}} \right] - 0.36n_5 \left[ 1 - \frac{\lambda_6 e_{T56}}{\lambda_{65} e_{T06}} \right] \quad (3.1f)$$

$$n_7 = \frac{N_{T7}\lambda_7}{ke_{T07}} \quad (3.1g)$$

### Decay After Sampling

After the end of sampling the differential equations, describing the decay and build up of each radionuclide, are solved with known boundary conditions:  $N_i(t) = N_{Ti}$ , at  $t = 0$  and the decay parameters of the deposited radionuclides to obtain the number of radionuclides  $N_i(t)$  on the filter at any latter time  $t$ . In the case of  $N_6(t)$ , due to the fact that only 36% of  $^{212}\text{Bi}$  ( $i = 5$ ) and therefore  $^{212}\text{Pb}$  ( $i = 4$ ) decay via  $^{208}\text{Tl}$ , we introduce a factor of 0.36 in the expressions derived. Thus:

$$N_1(t) = N_{T1}e_1 \quad (3.2a)$$

$$N_2(t) = N_{T2}e_2 + N_{T1} \left[ \frac{\lambda_1 e_{12}}{\lambda_{21}} \right] \quad (3.2b)$$

$$N_3(t) = N_{T3}e_3 + N_{T2} \left[ \frac{\lambda_2 e_{23}}{\lambda_{32}} \right] + N_{T1} \left[ \frac{\lambda_2 \lambda_1 e_{32}}{\lambda_{32} \lambda_{21}} + \frac{\lambda_2 \lambda_1 e_{13}}{\lambda_{31} \lambda_{21}} \right] \quad (3.2c)$$

$$N_4(t) = N_{T4}e_4 \quad (3.2d)$$

$$N_5(t) = N_{T5}e_5 + N_{T4} \left[ \frac{\lambda_4 e_{45}}{\lambda_{54}} \right] \quad (3.2e)$$

$$N_6(t) = N_{T6}e_6 + 0.36N_{T5} \left[ \frac{\lambda_5 e_{56}}{\lambda_{65}} \right] + 0.36N_{T4} \left[ \frac{\lambda_4 \lambda_5 e_{46}}{\lambda_{54} \lambda_{64}} + \frac{\lambda_4 \lambda_5 e_{65}}{\lambda_{54} \lambda_{65}} \right] \quad (3.2f)$$

$$N_7(t) = N_{T7}e_7 \quad (3.2g)$$

### The $\beta$ -count Rate (CR)

The  $\alpha$ -particles emitted by the members of the two decay series are absorbed by the absorber, of thickness  $0.012 \text{ gcm}^{-2}$  (deliberately introduced to this effect), and by the window of the GM tube. Therefore the gross  $\beta$ -count, at a given time interval is the sum of the contribution by each beta emitter in the series and by an unknown beta emitter(if any) deposited on the filter paper. Therefore the count rate at a given time  $t$  is given by:

$$\text{CR} = \sum_{i=2}^7 \varepsilon_i \lambda_i N_i(t) \quad (3.3)$$

where  $\varepsilon_i$  is the absolute detection efficiency of the detection system for the  $\beta$ -particle emitted by radionuclide  $i$ .

Substituting equations (3.2a) to (3.2g) in equation (3.3) and integrating with respect to time  $t$  between the beginning  $t_b$  and end  $t_e$  of a counting interval, we obtain

$$C = \sum_{i=1}^7 N_{Ti} X_i \quad (3.4)$$

where

$$\begin{aligned} X_1 &= \frac{\varepsilon_1 \lambda_2 \hat{e}_1}{\lambda_{21}} - \frac{\varepsilon_2 \lambda_1 \hat{e}_2}{\lambda_{21}} + \frac{\varepsilon_3 \lambda_2 \lambda_3 \hat{e}_1}{\lambda_{21} \lambda_{31}} - \frac{\varepsilon_3 \lambda_1 \lambda_3 \hat{e}_2}{\lambda_{21} \lambda_{32}} + \frac{\varepsilon_3 \lambda_1 \lambda_2 \hat{e}_3}{\lambda_{32} \lambda_{31}}, \\ X_2 &= \varepsilon_2 \hat{e}_2 + \frac{\varepsilon_3 \lambda_3 \hat{e}_2}{\lambda_{32}} - \frac{\varepsilon_3 \lambda_2 \hat{e}_3}{\lambda_{32}}, \\ X_3 &= \varepsilon_3 \hat{e}_3, \\ X_4 &= \varepsilon_4 \hat{e}_4 + \frac{\varepsilon_5 \lambda_5 \hat{e}_4}{\lambda_{54}} - \frac{\varepsilon_5 \lambda_4 \hat{e}_5}{\lambda_{54}} + \frac{0.36 \varepsilon_6 \lambda_5 \lambda_6 \hat{e}_4}{\lambda_{54} \lambda_{64}} - \frac{0.36 \varepsilon_6 \lambda_4 \lambda_6 \hat{e}_5}{\lambda_{54} \lambda_{65}} + \frac{0.36 \varepsilon_6 \lambda_4 \lambda_5 \hat{e}_6}{\lambda_{65} \lambda_{64}}, \\ X_5 &= \varepsilon_5 \hat{e}_5 + \frac{0.36 \varepsilon_6 \lambda_6 \hat{e}_5}{\lambda_{65}} - \frac{0.36 \varepsilon_6 \lambda_5 \hat{e}_6}{\lambda_{65}}, \\ X_6 &= \varepsilon_6 \hat{e}_6, \\ X_7 &= \varepsilon_7 \hat{e}_7 \end{aligned}$$

Assuming that total  $\beta$ -counts were measured over  $M$  ( $M > 7$ ) successive time intervals, these series of measurements can be described by a series of linear equations of the type equation (3.4):

$$C_m = \sum_{i=1}^7 N_{Ti} X_{mi} \quad (m = 1, 2, \dots, M), \quad (3.5)$$

where  $C_m$  are the measured total  $\beta$ -counts, corrected for background and coincidence losses, and  $X_{mi}$  are the values of  $X_i$  for the different time intervals, respectively.

A system of  $M$  equations, of seven unknowns, generated from each interval of measurement were used to determine the air concentration of the daughter products. Counting was made for a large number of intervals (ranging from 100 to 180 in this case), to make full use of the statistical nature of the decay process in the determination of air concentration of daughters.

A weighted least square regression analysis was performed to determine air concentration of daughter products that best fit the decrease of the count rate with time. Parameters that provide less than 10% systematic error were taken. One example of a curve fitted with this procedure is shown in fig 4.1.

### *Determination of Activity Concentration (EECs)*

If  $M > 7$  and the columns of the matrix, generated by each counting interval by the use of equation (3.5),  $X_{mi}$  ( $m = 1, 2, \dots, 7$ ) were linearly independent then unknowns  $N_{Ti}$  could be estimated using the weighted least squares fitting method. If  $N_{Ti}$  were known  $n_i$  could be computed according to equations (3.1a) to (3.1g) (Papp, 1997).

The six  $\beta$  emitting daughters of  $^{222}\text{Rn}$  and  $^{220}\text{Rn}$  denoted by subscripts  $i$  &  $j$ : ( $i, j = 1, 2, \dots, 7$ ). i.e. 1  $\rightarrow$   $^{218}\text{Po}$ ; 2  $\rightarrow$   $^{214}\text{Pb}$ ; 3  $\rightarrow$   $^{214}\text{Bi}$ ; 4  $\rightarrow$   $^{212}\text{Pb}$ ; 5  $\rightarrow$   $^{212}\text{Bi}$ ; and 6  $\rightarrow$   $^{208}\text{Tl}$  and 7  $\rightarrow$  U. The last one is to take care of the existence of "unknown" long-lived  $\beta$  emitting radionuclide in air.

Aerosols are collected on a filter paper. Air sampling flow rate ( $k$ ) and concentration of radionuclides ( $n_i$ ) are assumed to be constant during sampling time.

### *Counting efficiency determination*

Papp and others determined, both experimentally and analytically, the efficiencies of detection of radon and thoron products for a specific geometry and window thickness (Papp, 1997). We used the efficiencies determined in this work by adjusting our window thickness, geometry and dead time of the GM tube used in this experiment. The efficiency of our beta counter in counting thoron and radon gas is determined to be as shown in table 3.1:

## **3.3 DETERMINATION OF ANNUAL EFFECTIVE DOSE**

### **3.3.1 Equilibrium Equivalent Concentration**

Equilibrium factor between thoron and short lived progenies is very important for dose assessment from inhalation of thoron and it must be determined in each thoron monitoring. According to the ICRP recommendations, for a factor of equilibrium can be assumed value of 0.4, however, since this factor depends largely on environmental

Name of nuclide	recorded efficiency
$^{218}\text{Po}$	0.2501
$^{214}\text{Pb}$	0.2799
$^{214}\text{Bi}$	0.119
$^{212}\text{Pb}$	0.1866
$^{212}\text{Bi}$	0.119
$^{208}\text{Tl}$	0.2994

**Table 3.1:** Efficiency table

conditions (hours and mode of ventilation, humidity etc.) it is necessary to develop a method of measuring the progeny concentrations in order to calculate equilibrium equivalent concentration.

$$\text{EEC}_{\text{Th}} = 0.913C_1 + 0.087C_2 \quad (3.6)$$

$C_1$  is concentration of  $^{212}\text{Pb}$  and  $C_2$  is concentration of  $^{212}\text{Bi}$  (ICRP, 1990).

### 3.3.2 Effective Dose

Effective dose is the sum of the products obtained by multiplying the equivalent doses to various organs and tissues by the appropriate risk weighting factor for each. This quantity is considered to be proportional to the total probability of stochastic effects. Its SI unit is the Sievert (Sv), as for equivalent dose.

$$1 \text{ Sv} = 100 \text{ rem (old unit)}.$$

The annual effective dose due to exposure of radon progeny has been calculated by the relation given by UNSCEAR:

$$\text{Effective Dose} \left( \frac{\text{mSv}}{\text{y}} \right) = \left( \frac{\text{Bq}}{\text{m}^3} \right) \times 24 \text{ h} \times 365.25 \times 0.8/\text{y} \times 10^{-5} \left( \frac{\text{mSv/Bqh}}{\text{m}^3} \right) \quad (3.7)$$

$$= \text{EEC}_{\text{Th}} \times 7 \times 10^{-5} \text{ Sv/y} \quad (3.8)$$

where  $\text{EEC}_{\text{Th}}$  is Thoron equilibrium equivalent concentration

## Results and Discussion

### 4.1 RESULTS

Measurements were taken in the nuclear physics laboratory located on the first floor of physics building. Air was sampled at morning pumping start 6:46:00 pumping stop, 7:01:00 and sampling time 00:15:00., A total of 21 measurements were made and each was recorded for about (8-10) hrs in successively increasing intervals of time.

A typical data accumulated for the purpose of this work is indicated in Table 4.1. The first and the second columns were recorded from the Geiger counter apparatus. The third column 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 time as measured from the end of sampling as origin. i.e. the time in the six column thus indicate the filtered air sample as measured from the end of sampling. The seventh column shows the length of measurement of each time interval whereas the eighth column is the gross count in the interval.

**Table 4.1:** Sample of Data collected from GM Tube

observe t	disply cnt	Interval	start t	stop t	time(min)	$\Delta t$	count
7:02:00	0	1	7:02:00	7:02:30	1	0.5	693
7:02:30	693	2	7:02:30	7:03:00	1.5	0.5	699
7:03:00	1392	3	7:03:00	7:03:30	2	0.5	689
7:03:30	2081	4	7:03:30	7:04:00	2.5	0.5	654
7:04:00	2735	5	7:04:00	7:04:30	3	0.5	667
7:04:30	3402	6	7:04:30	7:05:00	3.5	0.5	641
7:05:00	4043	7	7:05:00	7:05:30	4	0.5	637
7:05:30	4680	8	7:05:30	7:06:00	4.5	0.5	646
7:06:00	5326	9	7:06:00	7:06:30	5	0.5	667
7:06:30	5993	10	7:06:30	7:07:00	5.5	0.5	587
7:07:00	6580	11	7:07:00	7:07:30	6	0.5	637
7:07:30	7217	12	7:07:30	7:08:00	6.5	0.5	629
7:08:00	7846	13	7:08:00	7:08:30	7	0.5	617
7:08:30	8463	14	7:08:30	7:09:00	7.5	0.5	719
7:09:00	9182	15	7:09:00	7:09:30	8	0.5	519
7:09:30	9701	16	7:09:30	7:10:00	8.5	0.5	652
7:10:00	10353	17	7:10:00	7:10:30	9	0.5	641
7:10:30	10994	18	7:10:30	7:11:00	9.5	0.5	530

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Table 4.1 – continued from previous page

observe t	disply cnt	Interval	start t	stop t	time(min)	delta t	count
7:11:00	11524	19	7:11:00	7:11:30	10	0.5	577
7:11:30	12101	20	7:11:30	7:12:00	10.5	0.5	577
7:12:00	12678	21	7:12:00	7:12:30	11	0.5	602
7:12:30	13280	22	7:12:30	7:13:00	11.5	0.5	619
7:13:00	13899	23	7:13:00	7:13:30	12	0.5	592
7:13:30	14491	24	7:13:30	7:14:00	12.5	0.5	637
7:14:00	15128	25	7:14:00	7:14:30	13	0.5	571
7:14:30	15699	26	7:14:30	7:15:00	13.5	0.5	574
7:15:00	16273	27	7:15:00	7:15:30	14	0.5	552
7:15:30	16825	28	7:15:30	7:16:00	14.5	0.5	562
7:16:00	17387	29	7:16:00	7:16:30	15	0.5	531
7:16:30	17918	30	7:16:30	7:17:00	15.5	0.5	604
7:17:00	18522	31	7:17:00	7:17:30	16	0.5	591
7:17:30	19113	32	7:17:30	7:18:00	16.5	0.5	529
7:18:00	19642	33	7:18:00	7:18:30	17	0.5	541
7:18:30	20183	34	7:18:30	7:19:00	17.5	0.5	514
7:19:00	20697	35	7:19:30	7:20:00	18.5	0.5	567
7:19:30	0	36	7:20:00	7:20:30	19	0.5	546
7:20:00	567	37	7:20:30	7:21:00	19.5	0.5	534
7:20:30	1113	38	7:21:00	7:21:30	20	0.5	503
7:21:00	1647	39	7:21:30	7:22:00	20.5	0.5	560
7:21:30	2150	40	7:22:00	7:22:30	21	0.5	514
7:22:00	2710	41	7:22:30	7:23:00	21.5	0.5	573
7:22:30	3224	42	7:23:00	7:23:30	22	0.5	520
7:23:00	3797	43	7:23:30	7:24:00	22.5	0.5	493
7:23:30	4317	44	7:24:00	7:24:30	23	0.5	529
7:24:00	4810	45	7:24:30	7:25:00	23.5	0.5	490
7:24:30	5339	46	7:25:00	7:25:30	24	0.5	463
7:25:00	5829	47	7:25:30	7:26:00	24.5	0.5	521
7:25:30	6292	48	7:26:00	7:26:30	25	0.5	485
7:26:00	6813	49	7:26:30	7:27:00	25.5	0.5	525
7:26:30	7298	50	7:27:00	7:27:30	26	0.5	502
7:27:00	7823	51	7:27:30	7:28:00	26.5	0.5	518
7:27:30	8325	52	7:28:00	7:28:30	27	0.5	477
7:28:00	8843	53	7:28:30	7:29:00	27.5	0.5	486
7:28:30	9320	54	7:29:00	7:29:30	28	0.5	503
7:29:00	9806	55	7:29:30	7:30:00	28.5	0.5	480
7:29:30	10309	56	7:30:00	7:30:30	29	0.5	487
7:30:00	10789	57	7:30:30	7:31:00	29.5	0.5	503
7:30:30	11276	58	7:31:00	7:31:30	30	0.5	497
7:31:00	11779	59	7:31:30	7:32:00	30.5	0.5	456
7:31:30	12276	60	7:32:00	7:32:30	31	0.5	449
7:32:00	12732	61	7:32:30	7:33:00	31.5	0.5	450
7:32:30	13181	62	7:33:00	7:34:00	32	1	867
7:33:00	13631	63	7:34:00	7:35:00	33	1	877
7:33:00	0	64	7:35:00	7:36:00	34	1	910
7:34:00	867	65	7:36:00	7:37:00	35	1	826
7:35:00	1744	66	7:37:00	7:38:00	36	1	840
7:36:00	2654	67	7:38:00	7:39:00	37	1	823
7:37:00	3480	68	7:39:00	7:40:00	38	1	839
7:38:00	4320	69	7:40:00	7:41:00	39	1	786
7:39:00	5143	70	7:41:00	7:42:00	40	1	798
7:40:00	5982	71	7:42:00	7:43:00	41	1	644
7:41:00	6768	72	7:44:00	7:45:00	43	1	798
7:42:00	7566	73	7:45:00	7:46:00	44	1	748
7:43:00	8210	74	7:46:00	7:47:00	45	1	724
7:44:00	0	75	7:47:00	7:48:00	46	1	719
7:45:00	798	76	7:48:00	7:49:00	47	1	751
7:46:00	1546	77	7:49:00	7:50:00	48	1	700
7:47:00	2270	78	7:50:00	7:51:00	49	1	704
7:48:00	2989	79	7:51:00	7:52:00	50	1	673

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Table 4.1 – continued from previous page

observe t	disply cnt	Interval	start t	stop t	time(min)	delta t	count
7:49:00	3740	80	7:52:00	7:53:00	51	1	694
7:50:00	4440	81	7:53:00	7:54:00	52	1	684
7:51:00	5144	82	7:54:00	7:55:00	53	1	688
7:52:00	5817	83	7:55:00	7:56:00	54	1	685
7:53:00	6511	84	7:56:00	7:57:00	55	1	634
7:54:00	7195	85	7:57:00	7:58:00	56	1	651
7:55:00	7883	86	7:58:00	7:59:00	57	1	620
7:56:00	8568	87	7:59:00	8:00:00	58	1	635
7:57:00	9202	88	8:00:00	8:01:00	59	1	632
7:58:00	9853	89	8:02:00	8:03:00	61	1	590
7:59:00	10473	90	8:03:00	8:04:00	62	1	539
8:00:00	11108	91	8:04:00	8:05:00	63	1	590
8:01:00	11740	92	8:05:00	8:06:00	64	1	559
8:02:00	0	93	8:06:00	8:11:00	65	5	2737
8:03:00	590	94	8:11:00	8:16:00	70	5	2495
8:04:00	1129	95	8:16:00	8:21:00	75	5	2339
8:05:00	1719	96	8:22:00	8:27:00	81	5	2193
8:06:00	2278	97	8:27:00	8:32:00	86	5	2027
8:06:00	0	98	8:32:00	8:37:00	91	5	1810
8:11:00	2737	99	8:38:00	8:43:00	97	5	1776
8:16:00	5232	100	8:43:00	8:48:00	102	5	1575
8:21:00	7571	101	8:48:00	8:53:00	107	5	1551
8:22:00	0	102	8:54:00	8:59:00	113	5	1410
8:27:00	2193	103	8:59:00	9:04:00	118	5	1419
8:32:00	4220	104	9:04:00	9:09:00	123	5	1338
8:37:00	6030	105	9:10:00	9:15:00	129	5	1221
8:38:00	0	106	9:15:00	9:20:00	134	5	1150
8:43:00	1776	107	9:20:00	9:25:00	139	5	1101
8:48:00	3351	108	9:26:00	9:31:00	145	5	1037
8:53:00	4902	109	9:31:00	9:36:00	150	5	1057
8:54:00	0	110	9:36:00	9:41:00	155	5	1065
8:59:00	1410	111	9:42:00	9:47:00	161	5	926
9:04:00	2829	112	9:47:00	9:52:00	166	5	949
9:09:00	4167	113	9:52:00	9:57:00	171	5	850
9:10:00	0	114	9:58:00	10:03:00	177	5	900
9:15:00	1221	115	10:03:00	10:08:00	182	5	880
9:20:00	2371	116	10:08:00	10:13:00	187	5	836
9:25:00	3472	117	10:14:00	10:22:00	193	8	1344
9:26:00	0	118	10:27:00	10:35:00	206	8	1257
9:31:00	1037	119	10:35:00	10:43:00	214	8	1255
9:36:00	2094	120	10:44:00	10:52:00	223	8	1188
9:41:00	3159	121	10:52:00	11:00:00	231	8	1191
9:42:00	0	122	11:01:00	11:09:00	240	8	1170
9:47:00	926	123	11:09:00	11:17:00	248	8	1129
9:52:00	1875	124	11:28:00	11:36:00	267	8	1165
9:57:00	2725	125	11:36:00	11:44:00	275	8	1096
9:58:00	0	126	11:45:00	11:53:00	284	8	1088
10:03:00	900	127	11:53:00	12:01:00	292	8	1088
10:08:00	1780	128	12:02:00	12:10:00	301	8	1113
10:13:00	2616	129	12:10:00	12:18:00	309	8	1076
10:14:00	0	130	12:19:00	12:36:00	318	17	2278
10:22:00	1344	131	12:37:00	12:54:00	336	17	2232
10:27:00	0	132	12:55:00	13:12:00	354	17	2226
10:35:00	1257	133	13:29:00	13:46:00	388	17	2129
10:43:00	2512	134	13:47:00	14:04:00	406	17	2120
10:44:00	0	135	14:06:00	14:23:00	425	17	2118
10:52:00	1188	136	14:24:00	14:41:00	443	17	2032
11:00:00	2379	137	14:42:00	14:57:00	461	15	1760
11:01:00	0	138	14:58:00	15:15:00	477	17	2051

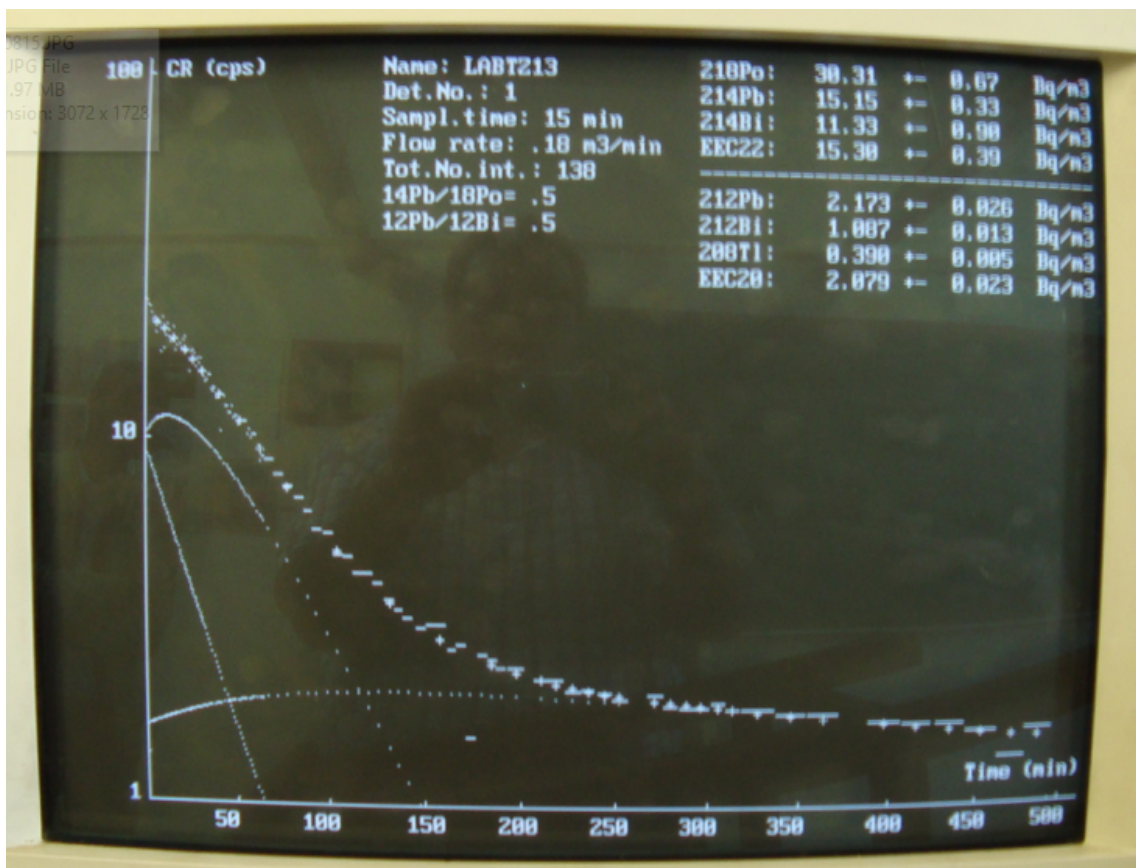
In the computation the program assumes the following points.

- The assumption of the existence of long-lived  $\beta$ -emitter in the sampled air has resulted in mathematically correct but physically meaningless concentrations that fit to the observed gross count.
- The daughter products of  $^{222}\text{Rn}$  is  $^{218}\text{Po}$  ( $t_{1/2} = 3.05$  min) and  $^{214}\text{Pb}$  ( $t_{1/2} = 26.8$  min) are linked together by the ratio

$$\frac{\text{Activity concentration of } ^{214}\text{Pb}}{\text{Activity concentration of } ^{218}\text{Po}} = 0.5 \quad (4.1)$$

- Progenies of  $^{220}\text{Rn}$  namely  $^{212}\text{Bi}$  ( $t_{1/2} = 61$  min) and  $^{208}\text{Tl}$  ( $t_{1/2} = 3$  min) are linked together when the graph is plotted.

Using these assumptions concentrations that give best fit with experimental data points were determined. See figure 4.1.



**Figure 4.1:** Picture showing one of the plots of the analysis

Each data was plotted as shown in Figure 4.1 and the EEC was determined. Table 4.2 show the results obtained for activities of the progenies in a unit volume of sampled air.

CODE	DATE	<sup>218</sup> Po		<sup>214</sup> Pb		<sup>214</sup> Bi		EEC222		<sup>212</sup> Pb		<sup>212</sup> Bi		208Tl		EEC220	
		conc	±	conc	±	conc	±	conc	±	conc	±	conc	±	conc	±	conc	±
LabTZ-01	4/24/2017	22.44	0.58	11.22	0.29	12.56	0.79	12.91	0.34	1.977	0.022	0.989	0.011	0.355	0.004	1.891	0.02
LabTZ-02	4/25/2017	38.65	0.59	19.32	0.3	16.01	0.8	20.1	0.34	2.707	0.02	1.354	0.01	0.486	0.004	2.589	0.018
LabTZ-03	4/26/2017	28.29	2.6	14.15	1.3	7.9	3.49	13.26	1.51	1.393	0.087	0.696	0.043	0.25	0.016	1.332	0.079
LabTZ-04	4/27/2017	29.78	1.11	14.89	0.56	10.86	1.49	14.93	0.64	2.034	0.038	1.017	0.019	0.365	0.007	1.946	0.035
LabTZ-05	4/28/2017	32.01	1.83	16	0.92	15.63	2.39	17.54	1.04	2.292	0.088	1.146	0.044	0.412	0.016	2.193	0.081
LabTZ-06	5/1/2017	28.75	1.98	14.38	0.99	5.26	2.59	12.43	1.12	1.942	0.077	0.971	0.038	0.349	0.014	1.857	0.07
LabTZ-07	5/2/2017	21.07	0.74	10.53	0.37	9.2	0.97	11.13	0.42	1.703	0.027	0.852	0.013	0.306	0.005	1.629	0.025
LabTZ-08	5/3/2017	35.94	2.11	17.97	1.06	16.32	2.92	19.23	1.25	3.01	0.078	1.505	0.039	0.541	0.014	2.879	0.071
LabTZ-09	5/4/2017	24.91	1.74	12.46	0.87	6.72	2.27	11.59	0.99	1.596	0.071	0.798	0.036	0.287	0.013	1.527	0.065
LabTZ-10	5/5/2017	15.25	1.73	7.62	0.86	9.42	2.3	9.11	1	1.372	0.076	0.686	0.038	0.246	0.014	1.312	0.069
LabTZ-11	5/8/2017	10.99	0.32	5.49	0.16	4.24	0.41	5.6	0.18	1.086	0.016	0.543	0.008	0.195	0.003	1.039	0.015
LabTZ-12	5/10/2017	12.1	1.59	6.05	0.8	4.8	2.17	6.21	0.93	0.974	0.066	0.487	0.033	0.175	0.012	0.931	0.06
LabTZ-13	5/11/2017	30.31	0.67	15.15	0.33	11.33	0.9	15.3	0.39	2.173	0.026	1.087	0.013	0.39	0.005	2.079	0.023
LabTZ-14	5/12/2017	14.21	0.87	7.1	0.44	3.3	1.15	6.41	0.5	0.89	0.034	0.445	0.017	0.16	0.006	0.852	0.032
LabTZ-15	5/18/2017	11.25	1.23	5.63	0.62	3.96	1.67	5.59	0.72	1.043	0.049	0.521	0.024	0.187	0.009	0.998	0.045
LabTZ-16	5/19/2017	15.84	13.04	7.92	6.52	57.47	20.17	27.53	8.46	2.12	0.537	1.06	0.268	0.381	0.096	2.028	0.491
LabTZ-17	5/22/2017	37.45	1.94	18.73	0.97	21.93	2.72	21.91	1.16	3.007	0.069	1.504	0.034	0.54	0.012	2.876	0.063
LabTZ-19	5/24/2017	31.32	1.83	15.66	0.92	12.9	2.43	16.26	1.05	2.353	0.078	1.176	0.039	0.423	0.014	2.25	0.071
LabTZ-20	5/25/2017	23.42	1.24	11.71	0.62	7.19	1.67	11.23	0.72	1.749	0.047	0.874	0.023	0.314	0.008	1.673	0.043
LabTZ-21	5/26/2017	24.37	2.55	12.18	1.28	22.21	3.51	17.26	1.51	2.51	0.1	1.255	0.05	0.451	0.018	2.401	0.091
LabTZ-22	5/27/2017	40.98	3.07	20.49	1.54	17.91	4.29	21.67	1.84	2.996	0.107	1.498	0.054	0.538	0.019	2.866	0.098

Table 4.2: Computed Values of Rn and Thoron progeny, and EEC

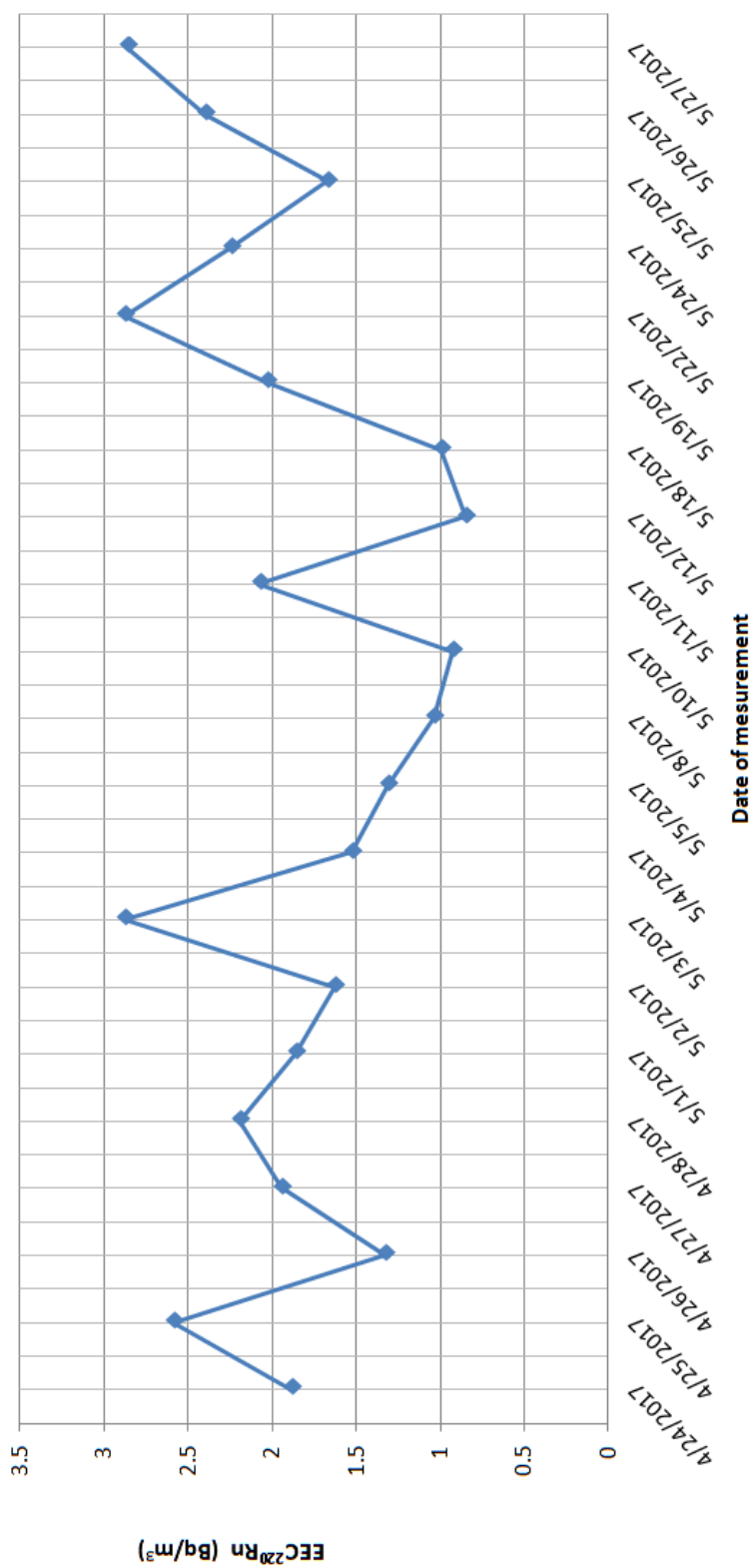
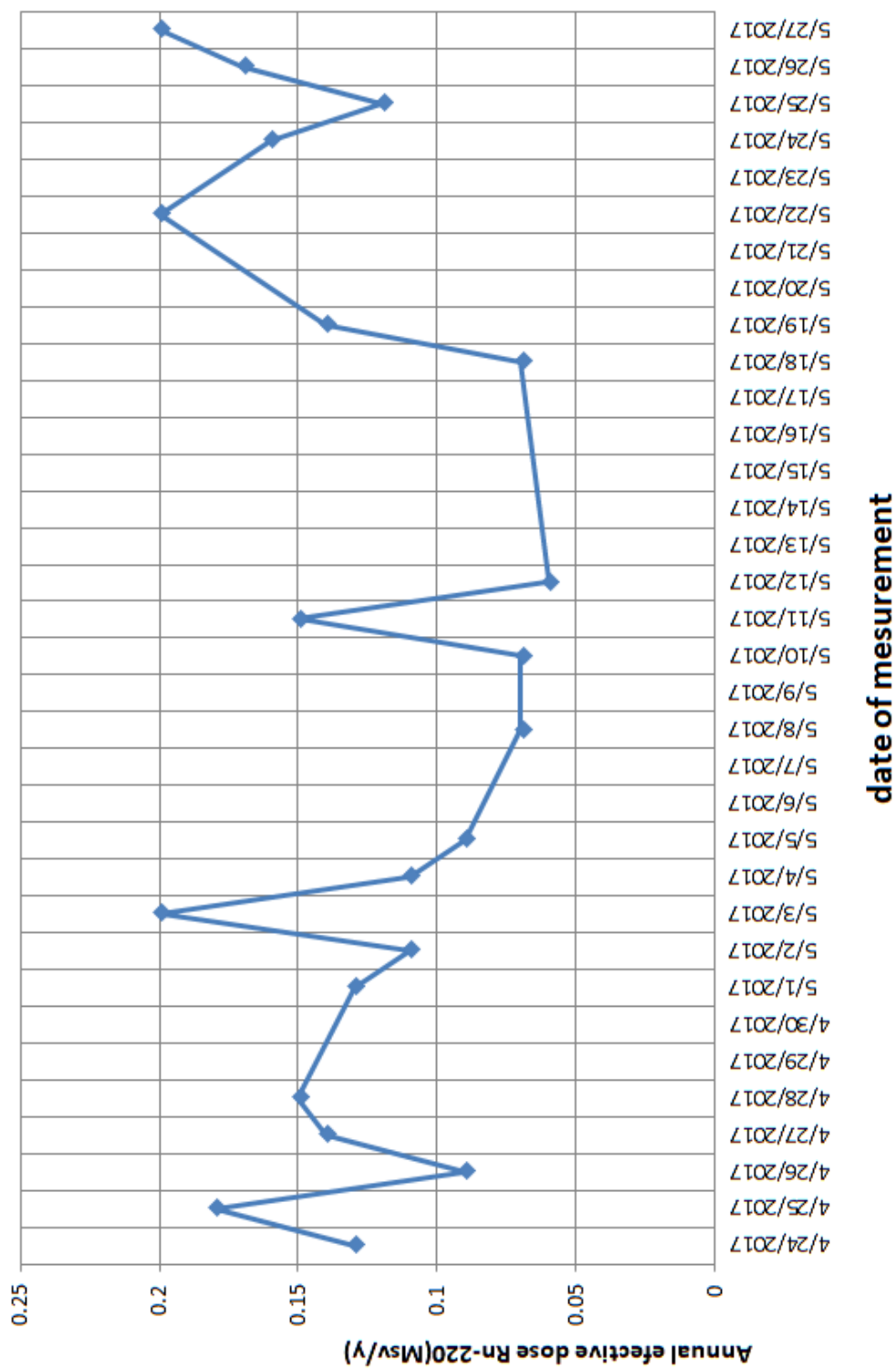


Figure 4.2: Equilibrium Equivalent Concentration of  $^{220}\text{Rn}$

The annual effective dose due to  $^{220}\text{Rn}$  and progeny is determined using the experimental values tabulated in table 4.2 and equation 3.8. Table 4.3 shows a summary of the results of the indoor thoron concentration levels and the annual effective dose in 21 different days in nuclear physics laboratory for the present study where the measurement were taken from April 24, 2017 to May, 27, 2017.

**Table 4.3:** Calculated annual effective dose due to  $^{220}\text{Rn}$

CODE	DATE	EEC( $^{220}\text{Rn}$ ) (Bq/m <sup>3</sup> )	Annual Eff. Dose (mSv/y)
LabTZ-01	4/24/2017	1.891 ± 0.02	0.13
LabTZ-02	4/25/2017	2.589 ± 0.018	0.18
LabTZ-03	4/26/2017	1.332 ± 0.079	0.09
LabTZ-04	4/27/2017	1.946 ± 0.035	0.14
LabTZ-05	4/28/2017	2.193 ± 0.081	0.15
LabTZ-06	5/1/2017	1.857 ± 0.07	0.13
LabTZ-07	5/2/2017	1.629 ± 0.025	0.11
LabTZ-08	5/3/2017	2.879 ± 0.071	0.20
LabTZ-09	5/4/2017	1.527 ± 0.065	0.11
LabTZ-10	5/5/2017	1.312 ± 0.069	0.09
LabTZ-11	5/8/2017	1.039 ± 0.015	0.07
LabTZ-12	5/10/2017	0.931 ± 0.06	0.07
LabTZ-13	5/11/2017	2.079 ± 0.023	0.15
LabTZ-14	5/12/2017	0.852 ± 0.032	0.06
LabTZ-15	5/18/2017	0.998 ± 0.045	0.07
LabTZ-16	5/19/2017	2.028 ± 0.491	0.14
LabTZ-17	5/22/2017	2.876 ± 0.063	0.20
LabTZ-19	5/24/2017	2.25 ± 0.071	0.16
LabTZ-20	5/25/2017	1.673 ± 0.043	0.12
LabTZ-21	5/26/2017	2.401 ± 0.091	0.17
LabTZ-22	5/27/2017	2.866 ± 0.098	0.20
	Min	0.852	0.060
	Max	2.879	0.202
	Mean	1.864	0.131
	Variance	0.416	0.002
	St. Deviation	0.645	0.045



**Figure 4.3:** Annual effective dose due to  $^{220}\text{Rn}$

## 4.2 DISCUSSION

Table 4.2 illustrated the concentration of thoron in this locations measured by Bq/m<sup>3</sup>. The results show that the maximum activity of thoron, during the period of measurement, was 2.87 Bq/m<sup>3</sup> in physics laboratory. With mean value 1.864 Bq/m<sup>3</sup>. Table 4.2 Indoor Radon-222 and Thoron -220 of Equilibrium Equivalent Concentration in Nuclear Physics Laboratory in Addis Ababa University.

The annual effective dose due to <sup>220</sup>and progeny is determined from the concentrations using equation 3.8. One can conclude that the dose is comparable with the global average (0.1 mSv/year) and there is no need to intervene (UNSCEAR, 2000)

## 4.3 COMPARISON WITH OTHER AREAS OF THE WORLD

The indoor Thoron concentration determined in various parts of the world is shown in table 4.4

Continental region	Country	EEC(Bq/m <sup>3</sup> )				(220Rn/222Rn) EEC ratio			
		Outdoors		Indoors		Outdoors		Indoors	
		Mean	Range	Mean	Range	Mean	Range	Mean	Range
East Africa	Ethiopia, Bemenet A.			5.2	(1.77-8.96)			0.22	
	Ethiopia, Tsega B.	3.52	(1.22-15.17)	19.12	(2.16-34.82)				
	Ethiopia, Habtamu D.			217.9	(39-1397)				
North America	United States	0.09	(0.03-0.3)	0.5	(0.03-4.7)				0.4
East Asia	China	0.4		0.8		0.05			0.07
	Hong Kong	0.3	(0.1-0.5)	0.8	(0.4-1.2)	0.04			0.06
	Japan	0.09	(0.03-0.12)	0.6	0.6(0.4-0.9)				0.1
	Malaysia	0.5	(0.3-1.8)	1.1	0.4-2.5)	0.08			0.08
Europe North	Norway			0.7	0.07-1.1)				0.04
	Sweden			0.3	(0.1-0.6)				0.01
West Europe	France			0.8	(0.6-13.3)				0.03
	United kingdom			0.3	(0.07-1.1)				0.02
Central Europe	Germany			0.5	(0.1-1.0)				
	Moldova	0.2		1	(0.1-6.4)	0.04			0.05
	Romania	0.3		1.1	(0.1-6.4)	0.05			0.04
East Europe	Russia				(1.1-7.1)				0.09 (0.02-0.24)
South Europe	Italy			12	(0.5-7.6)				0.11 (0.01-0.38)
Slovenia		0.12	(0.05-0.37)			0.013			
Range			(0.09-0.5)		(0.2-12)		(0.01-0.08)		(0.01-0.5)

**Table 4.4:** The Thoron concentrations in out door and in door air [UNSCEAR, 2000]

The above data shows contributions of <sup>220</sup>Rn and <sup>222</sup>Rn. It is clear that the detected concentration values of <sup>220</sup>Rn in the Addis Ababa University is equivalent those values reported in other worldwide locations, see Table 4.4 the median values 0.8642 Bq/m<sup>3</sup>, reported by [UNSCEAR,2000]. On the other hand, it was found that the detected concentration values of <sup>220</sup>Rn in the Addis Ababa University are in agreement with those reported in some other countries, Hong-Kong and West Europe France. The

variation in the indoor thoron concentration due to many reasons such as different nature of the building materials, source of radiation in the room, types of materials in the closed air and the weather condition of the environment. In fact, many countries set their national exposure levels based on their such as from East Asia China own studies. In addition to this the indoor thoron concentration determined in Addis Ababa university physics lab (Bemenet Alemayo, 2006) measured morning, noon and night we get average thoron concentration  $5.2 \text{ Bq/m}^3$ , I get to measure nuclear physics laboratory about 9hrs-10hrs  $1.8642 \text{ Bq/m}^3$ . The difference between the two measurements ( $3.34 \text{ Bq/m}^3$ ) is due to;

- In this work measurement was done only in the morning time in nuclear physics laboratory and I used each day only one filter paper. But Bemenet Alemayehu measured three times each day (morning, noon and night). He also used three filter paper per a day.
- The thoron in the case of Bemnet's work was higher. This can be attributed to the fact that thoron has long half life and the one accumulated during the night hours will also be available in the afternoon and evening due to relatively poor migration out of the room.

Table 4.5 show that thoron (Rn-220) average effective dose Worldwide exposure to Natural Radiation was  $0.1(\text{mSv/y})$  (UNSCEAR, 2000). Then, the average effective dose of thoron in nuclear physics laboratory first floor building  $0.1(\text{mSv})$  thoron (Rn-220) average effective dose standard Worldwide exposure to Natural Radiation (UNSCEAR, 2000).

The present experimental laboratory show that the indoor thoron concentration obtained varied from Thoron levels ranged from  $0.852 \text{ Bq/m}^3$  to  $2.879 \text{ Bq/m}^3$  an overall mean value and standard error of  $1.86 \pm 0.073 \text{ Bq/m}^3$  which is the recommended ICRP action level of  $200-600 \text{ Bq/m}^3$  (ICRP, 1993). The lowest value thoron concentration was found to be  $0.852 \text{ Bq/m}^3$ ; this is due high diffusion from indoor air to outdoor air since in the outdoor air there is heavy rain which dissolves the outdoor thoron atoms. The annual effective dose from the corresponding measured thoron concentration in the different days has which varies with a mean value which  $1.864 \text{ Bq/m}^{-3}$  is within the recommended ICRP intervention level of  $\text{mSv/y}$  (ICRP, 1993). The highest value was observed in the day of 19-05-2017 with an indoor thoron concentration of  $2.879 \text{ Bq/m}^3$  and an annual effective dose rate of  $0.81 \text{ mSv/y}$ .

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

**Table 4.5:** Average worldwide exposure to natural radiations [UNSCEAR, 2000]

## Conclusion and Recommendation

### 5.1 CONCLUSION

- Thoron levels concentration, reported in this work, range from 0.852 Bq/m<sup>3</sup> to 2.879 Bq/m<sup>3</sup> with a mean value 1.8642 Bq/m<sup>3</sup> variance 0.416 Bq/m<sup>3</sup> and standard deviation 0.645 Bq/m<sup>3</sup>, respectively.
- The annual effective dose ranged between (0.06 mSv/y-0.20 mSv/y) variance 0.002 mSv/y and standard deviation 0.045 mSv/y with a mean value 0.1 mSv/y (Thoron).
- On the basis of the current results, we may conclude that in the physics laboratory room, the levels of indoor thoron is well within acceptable values given by ICRP, 1990.

### 5.2 RECOMMENDATIONS

The research findings the following recommendations have been made: The main perspectives for future work are:

- Order to get a precise experimental result all the parameters are controlled and measured can be designed and set up, to improve the indoor thoron concentration result the measurements effective dose shall take based on seasonal variation.
- Investigation of radon concentration indoor air, by taking a very detail sampling of radon inventory i.e. spatial and temporal inventory, it will be easy to understand and quantify the level of radon and other natural radioactive materials.
- As the method employed here is cumbersome, it is recommended to automate the counting system so that time and human energy may be saved.

## Bibliography

- Ahn & Lee (2005). construction of an enviromental radon monitering system. *Nuclear enginering and technology*, 395(400), 1–21.
- Akiba1, S., 2, S. T., Bochicchio, E, McLaughlin, J., Tommasino, L., & Harley, N. (2010). Thoron: Its metrology, health effects and implications for radon epidemiology: A summary of roundtable discussions. *Radiation Protection Dosimetry*, 141(4), 477 – 481.
- A.S., L. & Aleissa, K. (1957). *Influences on Indoor Radon Concentrations in Riyadh, Saudi Arabia*. Radian measure.
- Bemenet, A. (2006). *Measuring radon concentration sampling air*. Msc thesis, Addis Ababa University, Addis Ababa.
- Durrani (1997). physical properties.
- EPA (1992). property of enviromental protection agency. Technical report, enviromental protection agency, New york.
- EPA (1993). Protocols for radon and radon decay product measurements in homes. Air and Radiation (6604J) EPA 402-R-92-003, United States Environmental Protection Agency (EPA).
- EPA (2005). EPA a citizen guide to radon. Technical report, New york united nation.
- George, A. (1984). Passive integrated measurement of indoor radon using activated carbon. *Health Physics*, 46, 767 – 862.
- IAEA (2016). Internatinal atomic energy agency. Technical report, New york united nation.
- ICRP (1990). effective anuual dose. Report to the general assembly, with annexes, Internaional commision Radiological protection, New york.

- ICRP-60 (1990). Radiation Protection Recommendations of the International Commission on Radiological Protection. Pergamon Press, Oxford.
- James, A. (1988). Lung dosimetry. In W. Nazaroff & A. Nero (Eds.), *Radon and Its Decay Products in Indoor Air* (pp. 259–309). New York: John Wiley.
- Knoll, G. (2000). *Radiation Detection and Measurement*.
- Kotrappa, P., Brubaker, T., Dempsey, J., & Steiff, L. R. (1992). Electret ion chamber system for measurement of environmental radon and environmental gamma radiation. *Radiation Protection Dosimetry*, 45, 451 – 455.
- Kumar, S., Deepak, G., P., R., & A., N. (1991). Estimation of indoor radon levels in cities of Rajasthan by ssntd. *Radiation Protection Dosimetry*, 37(2), 127–131.
- Langmuir, D. & Herman, J. S. (1980). The mobility of thorium in natural water low temperatures. *Geochimica et Cosmochimica Acta*, (44).
- Liesel (2005). Radon in soil gas-exhalation tests in and situ measurements. *The sciences of total environments*.
- Papp, Z. (1997). Defined solid angle absolute beta-counting for in the radioanalysis of environmental samples. *Radioanalytical and Nuclear Chemistry*, 1-2(157-163).
- Porstendörfer, J. (1994). Properties and behavior of radon and thoron and their decay products in the air. *J. Aerosol Sci*, 25(2), 219–263.
- Ramachandran, T. & Sathish, L. (2014). Environmental thoron ( $^{220}\text{Rn}$ ): A review. *Research Journal of Chemical and Environmental Sciences*, 2(2), 5–31.
- Singru, R. (1974). *Experimental Nuclear physics*. Wiley Eastern private limited.
- Steinhäusler, F., Hofman, W., & Lettner, H. (1994). Thoron exposure to man. a negligible issue? *Radiat. Prot Dosim.*, 56, 4–44.
- Tassos & Horalabos (2003). Indoor radon concentration measurement in Cyprus using high sensitivity portable detectors. (2), 1–21.
- UNSCEAR (1982). Ionizing radiation: Sources and biological effects. Report to the general assembly, with annexes, United Nations Scientific Committee on the Effects of Atomic Radiation, New York.
- UNSCEAR (1988). Report to the general assembly United Nations. Technical report, United Nations Scientific Committee on the Effects of Atomic Radiation, New York.

UNSCEAR (2000). Ionizing radiation: Sources and biological effects. Report to the general assembly, with annexes, United Nation Scientific Committee on the Effects of Atomic Radiation, New York.

UNSCEAR (2008). Report to the general assembly United Nation. Technical report, United Nation Scientific Committee on the Effects of Atomic Radiation, New York.

White, S.B., C. C. A. & Alexander, B. (1991). Statistical Analysis: Predicting Annual Radon-222 concentrations from two-day screening Tests. U.S. Environmental Protection Agency.

Wilkening, M. (1990). *RADON IN THE ENVIRONMENT*, volume Studies in Environmental Science of *Studies in Environmental Science*. New York, NY 10010, U.S.A.: Elsevier.

**DECLARATION**

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

MSc Thesis

Effective Radiation Dose From Indoor Rn-220 Concentration

Name of Candidate: Zewdineh Asefa Yilma

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

Signature: \_\_\_\_\_