RADON CHARACTERISATION IN SOIL OF OIL EXPLORATION AREAS IN MIZORAM

A THESIS SUBMITTED IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF DOCTOR OF PHILOSOPHY

REMLALSIAMA
MZU REGN. NO: 1702102
Ph.D REGN NO: MZU/Ph.D/1101 OF 24.04.2018

DEPARTMENT OF PHYSICS
SCHOOL OF PHYSICAL SCIENCE
FEBRUARY, 2023

RADON CHARACTERISATION IN SOIL OF OIL EXPLORATION AREAS IN MIZORAM

By

Remlalsiama

Department of Physics

Professor Zaithanzauva Pachuau

Supervisor

Professor B. Zoliana

Joint Supervisor

Submitted in partial fulfillment of the requirement of the Degree of Doctor of Philosophy in Physics of Mizoram University, Aizawl.

Prof. Zaithanzauva Pachuau
Phone: 9862770341(M)

Mizoram University
Department of Physics
(A DST-FIST Supported Department)
School of Physical Sciences
Aizawl 796 004 Mizoram
E-mail : zaiapach14@gmail.com, mzut032@mzu.edu.in

Date: 28th February 2023

Certificate

This is to certify that the thesis entitled '*Radon characterisation in soil of oil exploration areas in Mizoram'* submitted by Shri Remlalsiama, for the degree of Doctor of Philosophy of the Mizoram University, Aizawl, embodies the record of original investigations carried out by him under my supervision. He has gone through his training at BARC, Mumbai for one week during 7th -14th January 2018. The thesis presented is worthy of being considered for the award of the Ph. D. degree. This work has not been submitted for any degree to any other University.

(Prof. ZAITHANZAUVA PACHUAU)

Supervisor

(Prof. B. ZOLIANA)

Jt. Supervisor

Declaration
Mizoram University
February, 2023

*I, **Remlalsiama**, hereby declare that the subject matter of this thesis is the record of work done by me, that the contents of this thesis did not form basis of the award of any previous degree to me or to the best of my knowledge to anybody else, and that the thesis has not been submitted by me for any research degree in any other University/Institute.*

This is being submitted to the Mizoram University for the degree of Doctor of Philosophy in Physics.

(REMLALSIAMA)
Candidate

(Prof. ZAITHANZAUVA PACHUAU)
Head

(Prof. ZAITHANZAUVA PACHUAU)
Supervisor

(Prof. B. ZOLIANA)
Jt. Supervisor

Acknowledgment

I would like to express my deepest appreciation to my supervisor Prof. Zaithanzauva Pachuau, Department of Physics, Mizoram University, Aizawl, for his valuable guidance and oversight throughout my research work. His support in publication works will be remembered.

I would also like to extend my heartiest gratitude to my Joint Supervisor, Prof. B. Zoliana, Principal, Govt. Zirtiri Residential Science College, who had constantly supported and guided me to perform field works; and in the preparation of the final manuscript. His advice throughout my research work is worth remembering. I am also grateful to him for lending me the RnDuo and related instruments and Radon laboratory, without which my research work could never have been materialized.

I also would like to thank my senior colleague Dr Rosangliana, Associate Professor of Govt. Zirtiri Residential Science college for lending me his RnDuo instruments to perform my research work. I am very much grateful to him.

I acknowledged all the encouragement and the suggestions from Prof. Diwakar Tiwari, Dean, School of Physical Sciences and Prof. Zaithanzauva Pachuau Head, Department of Physics. I also thank the Teaching Faculties of the Department of Physics, Mizoram University, for their guidance and motivations throughout the course work and during my research work. I would also like to thank all the non-teaching staff members of the Department of Physics, Mizoram University, for their endless support and co-operation.

I sincerely thank Dr. B.K. Sahoo and Radiological Physics and Advisory Division, Bhabha Atomic Research Centre, Mumbai, for the hands on training given to me to handle various Radon related instruments.

I would like to thank the Head, Department of Geology, Mizoram University, Aizawl for lending Sieve Shaker instruments to perform soil analysis.

I would like to extend my sincere gratitude to the radon research group, especially to Dr Hmingchungnunga, Dr Vanramlawma, Dr Lawrence Zonunmawia, Dr H. Lalremruata who had helped me to conduct field work, further supported me in performing necessary calculations, and giving me suggestions to

have an accurate and reliable research work, last but not the least who have helped me in framing the final manuscript.

It may not be appropriate for me if I fail to mention all the supports and co-operations I received from my family. They have dedicated and sacrificed much of their valuable time and energy that this research work may be shaped.

Above all, I would like to thank God for his overall approval to materialize this tiny piece of research work.

Dated: 8th December 2023

Department of Physics,
Mizoram University, Aizawl. (REMLALSIAMA)

CONTENTS

Contents		**Page No.**
Title of the Thesis		*i*
Certificate		*ii*
Declaration		*iii*
Acknowledgment		*iv*
Contents		*vi*
List of Figures		*ix*
List of Tables		*xi*
Chapter 1	**Introduction**	1
1.1	Introduction	1
1.2	Radon, its discovery, decay, nature, sources and effects	7
1.3	Uranium	14
1.4	Radon in Rock and Soil	18
1.5	Radon and uranium in water	20
1.6	Transport of Radon	22
1.7	Literature review and observations on radionuclides	24
1.8	Scenario of Natural radioactivity studies in Mizoram	32
Chapter 2	**Theory, Instruments And Experimental Methodology**	35
2.1	Description of study area	35
2.2	Measurement of background Gamma radiation	38
2.2.1	Technical specifications	39
2.3	Surveillance of location using Global Positioning System	40
2.3.1	Technical specifications	41
2.4	Soil Type and Grain Size determination using Sieve Shaker	42
2.5	Measurement of soil radioactivity with NaI(Tl) Detector	44
2.5.1	Calibration of NaI(Tl) detector	47
2.5.2	Efficiency calibration of NaI(Tl) detector	49
2.5.3	Determination of soil radioactivity	50
2.5.4	Determination of Radium Equivalent Activity	50
2.6	The Smart RnDuo	51

2.7	Measurement of radon mass exhalation from soil by smart RnDuo	54
2.7.1	Protocol for measurement of radon mass exhalation rate	55
2.8	Smart RnDuo for radon content in water	57
2.8.1	Protocol for measurement of radon concentration in water	57
2.9	Measurement of Uranium in water using LED Fluorimeter	60
2.9.1	Protocol for determination of uranium concentration in water	60
2.9.2	Technical specifications	61
2.10	*In-situ* measurement of radon concentration in soil with Smart RnDuo fitted with Soil Probe	63
2.10.1	Protocol for measurement of radon concentration in soil	64
Chapter 3	**Determination Of Radon Mass Exhalation Rate, Soil Radioactivity And Soil Grain Size**	66
3.1.	Measurement of radon mass exhalation	66
3.1.1	Result of radon mass exhalation rate	66
3.1.2	Slope of radon concentration in soil with mass exhalation	70
3.2	Measurement of soil radioactivity using NaI(Tl) detector	72
3.2.1	Result of soil radioactivity	73
3.3	Measurement of Background Gamma Radiation and Global Positioning System	75
3.3.1	Observations of background gamma radiation and GPS location	75
3.4	Measurement of soil type and soil grain size	77
3.4.1	Observation and discussions	77
3.5	Measurement of radon content in water using Smart RnDuo	80
3.5.1	Result and observations	80
3.6	Measurement of Uranium in water	81
3.6.1	Preparation of Standard solution, Buffer solution and Blank solution	82
3.6.2	Result and observations	83
3.7	Correlation between radon in water and uranium in water	84

Chapter 4 ***In-situ*** **Measurement of Radon Concentration in Soil with soil Probe** 91

4.1 *In-situ* measurement of radon concentration in soil with soil probe 91

4.1.1 Measurement protocol 92

4.1.2 Result and Discussion 93

4.2 Oil field wise graphical representation of radon concentration 96

4.3 Oil field wise correlation between gamma radiation and radon concentration at 10cm, 30cm, 50cm and 70cm 100

4.3.1 Observations drawn from the correlation graph between gamma radiation and radon concentration at different baptism depth 115

4.3.2 Depth wise variation of correlation coefficient between gamma radiation and radon concentration 116

4.3.3 Comparison with studies from other areas 118

Chapter 5 **Conclusion** 121

References : 129

Brief bio-data of the author : 146

List of Publications : 148

Particulars of Candidate : 152

List of Figures

Figure No.	Title of the Figure	Page
1.1	Radon in nature	8
1.2	Radon, the single most contributor of radiation	9
1.3	Uranium in nature	14
1.4	Decay diagram of 238U series with the half-life of radionuclide	16
1.5	Transport of radon	23
2.1(a)	Map of all the oil exploration areas in Mizoram	36
2.1(b)	Location of oil exploration areas in Kolasib district	36
2.2(a)	Map of all the oil exploration areas in Mizoram	37
2.2(b)	Location of oil exploration areas in Aizawl district	37
2.3(a)	Map of all the oil exploration areas in Mizoram	38
2.3(b)	Location of oil exploration areas in Serchhip district	38
2.4	Gamma Survey Meter PM 1405	39
2.5	GPS tracking devices Garmin GRB 21	41
2.6	Dressing of soil samples for soil type and grain size	43
2.7	Sodium Iodide, NaI(Tl) detector	46
2.8	GSPEC-SA	47
2.9	IAEA Standard Source for Energy and Efficiency Calibration	48
2.10(a)	Schematic of radon measurement process in RnDuo	52
2.10(b)	SMART RnDuo	52
2.11	Mass exhalation chamber	54
2.12	Measurement of radon mass exhalation from soil	55
2.13	Schematics of water sample collection	58

2.14	Measurement of Radon content in water using Smart RnDuo	58
2.15	LED Fluorimeter LF-2a.	61
2.16	Set up for *in-situ* measurement of radon in soil	63
2.17	Typical Soil probe top and bottom and a wooden hammer	64
3.1	Slope of radon concentration with time of Meidum oil field	67
3.2	Slope of radon concentration with time of Zanlawn oil field	67
3.3	Slope of radon concentration with time of Phulmawi oil field	68
3.4	Slope of radon concentration with time of Maubuang oil field	68
3.5	Slope of radon concentration with time of Keifang oil field	69
3.6	Slope of radon concentration with time of Thenzawl oil field	69
3.7	Radon mass exhalation rate of the study area	71
3.7a	Slope of radon concentration with Mass exhalation rate	71
3.8a	Activity concentration of ^{238}U radionuclide	75
3.8b	Activity concentration of ^{232}Th radionuclide	75
3.8c	Activity concentration of ^{40}K radionuclide	76
3.8d	Comparison of the average value of 238U, 232Th, 40K radionuclides	76
3.9a	Background gamma radiation at ground surface and at 1m above	79
3.9b	Average gamma radiation at ground surface and at 1m above	79
3.10	USDA Triangular Plot for determination of soil type	82
3.11a	Radon concentration at oil exploration areas	84
3.11b	Minimum, Maximum and Average Radon concentration	84
3.12a	Uranium Concentration in Water of all the oil field area	88
3.12b	Minimum, Maximum and Average Radon concentration of the study area	89
3.13	Correlation between radon content in water and uranium in water	90

4.1	Radon concentration in soil at different baptism depth of Meidum oil field	96
4.2	Radon concentration in soil at different baptism depth of Zanlawn oil field	97
4.3	Radon concentration in soil at different baptism depth of Phulmawi oil field	97
4.4	Radon concentration in soil at different baptism depth of Maubuang oil field	98
4.5	Radon concentration in soil at different baptism depth of Keifang oil field	98
4.6	Radon concentration in soil at different baptism depth of Thenzawl oil field	99
4.7	Correlation between gamma radiation and radon concentration at 10cm, 30cm, 50cm and 70cm deep of Meidum oil field	103-104
4.8	Correlation between gamma radiation and radon concentration at 10cm, 30cm, 50cm and 70cm deep of Zanlawn oil field	104-105
4.9	Correlation between gamma radiation and radon concentration at 10cm, 30cm, 50cm and 70cm deep of Phulmawi oil field	106-107
4.10	Correlation between gamma radiation and radon concentration at 10cm, 30cm, 50cm and 70cm deep of Maubuang oil field	108-109
4.11	Correlation between gamma radiation and radon concentration at 10cm, 30cm, 50cm and 70cm deep of Keifang oil field	110-111
4.12	Correlation between gamma radiation and radon concentration at 10cm, 30cm, 50cm and 70cm deep of Thenzawl oil field	112-113
4.13	Decrement of R^2 of radon concentration at different depth	116
4.14	Comparison Bar of minimum and maximum radon concentration in soil of some areas in India and Pakistan.	119
4.15	Comparison of minimum and maximum radon concentration in dwellings of some areas in India and Pakistan	120

List of Tables

Table No.	Title of the Tables	Page
2.1	Initial settings of GSPEC-SA instrument	48
3.1	Slope of Radon concentration and radon mass exhalation rate from soil of all the oil exploration areas	70
3.2	Efficiency Calibration of ^{232}Th, ^{238}U & ^{40}K standard source	73
3.3	Activity Concentrations of ^{238}U, ^{232}Th & ^{40}K radio-nuclides in soil samples collected from all the oil exploration areas	74
3.4	Gamma radiation at ground surface and 1 meter above the ground and a GPS coordinates	77-78
3.5	Determination of soil grain size in oil exploration areas	80-81
3.6	Radon content in water sample of Oil exploration Areas in Mizoram	83-84
3.7	Uranium content in water samples of Oil exploration Areas in Mizoram	86
4.1	Radon Concentration in soil gas at various baptism depth of all the oil exploration areas in Mizoram	93-96
4.2	Ground level Gamma Radiation and Radon Concentration in soil at various depth of oil exploration areas in Mizoram	100-102
4.3	Depth wise correlation coefficient of different oil field	115
4.4	Radon gas Concentration in soil at various places in India and Pakistan	118-119

1

Introduction

1.1. Introduction

One of the main contributors of natural radioactivity in the earth's crust is radon (^{222}Rn). Being a noble gas and having a relatively long life-time, it has a great mobility to reach considerable distances in different environments. Radon is present everywhere, in rocks and soil, in subsurface and deep water, in atmosphere and indoor air, in different concentrations. Radon originated from the natural breakdown of uranium and thorium series. It is present in soil, rock and water. Radon has the capability to enter any kind of buildings such as homes, offices, schools, shoping malls and all kinds of auditorium, and is present everywhere in the entire world. In general, human being exposed to radon is greatest in peoples' homes (Scott 1994). The damage to health resulting from the exposure to radiation from radon has been a matter of concern to the public and most radiation scientists.

Radon is also found in coal, oil and natural gas which are brought into buildings to provide an energy source for domestic use like heating and cooking. Radon also takes the oportunity to enter into buildings directly from the underlying soil and rock provided there are permeable floors or cracks and crevices through which it can pass freely. (Bottrel 1991; Faulkner & Gillmore 1995; Gillmore *et al*. 2002).

Radon enters into the atmosphere by passing through the soil and cracks in the rock (O'Riordan *et al.* 1983; Swedjemark & Mjones 1984; Malanca *et al.* 1995; Anastasiou *et al*. 2003; El-Hussein 2005). When radon reaches the atmosphere, it get spreaded thus diluted. But under certain circumstances it become concentrated and severely increase background radiation levels also. The radon concentration in the open air is often lower than closed houses. On an average the radon gas concentration

inside homes is estimated to be 2-10 times more than in the outside atmosphere (Bale 1980; Bodansky *et al*. 1987; Bovornkitti 2002).

There has been an increased awareness about the dangers to health posed by indoor radon even if there is only short-term exposure (Papworth 1997). Concern about this health issue is due to the risk of lung cancer when the lungs are exposed to radon and its daughter progenies. Studies in uranium mines show that there is a direct relationship between the number of lung cancers contracted in the workers and concentration of radon gas (Darby *et al.* 2005). According to the report by Nero (NRC 1999) in the United States, radon is the cause of approximately 10% of the recorded cases of lung cancer. The Public Health Service in the United States announced that lung cancer occurred at a rate that was five times higher than normal amongst the uranium mining population. In spite of a general agreement in the scientific literature that increases of lung cancer amongst uranium miners are due to high concentrations of radon, and its daughter products, some argue that there is a lack of proof of the risk of lung cancer increasing with increasing in exposure time period in the general population (Lubin *et al.* 1998).

Many research organisations are involved in the radon problems debate, such as the International Agency for Research on Cancer (IARC); the International Commission on Radiological Protection (ICRP); the United Nations Scientific Committee on the Effects of Ionising Radiation (UNSCEAR); the World Health Organisation (WHO); the Environmental Protection Agency (EPA) in the USA and the Health Protection Agency (HPA) in the United Kingdom. These organisations have attempted to drive forward an international agenda, which seeks to create a general agreement on regulatory standards. There are a number of countries in the developed world, such as Sweden, the UK and the USA, that have been undertaking radon research for many years.

Background Radiation

Radiation originating from the primordial radionuclides from beneath the earth‘s crust certainly contributes to the exposure of human beings, who are affected

by natural and artificial radiation. Due to their ionizing nature, it can alter the checmical composition as well as the biological state of living beings. It can cause serious effect on the health of an individual. This fact is reported by the United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR 2000). The quantity of naturally occurring radiation increases in areas with uranium and thorium ore deposits in which the granite so formed have a large amount of natural uranium content (Man & Yeung 1998). Other than natural uranium, globally, other sources of radon are water, especially spring water, uranium tailings, phosphate residues, coal and building materials. A high concentration of radon is found in spring water due to the deposits of isotopes in volcanic areas where co-precipitation with silica occurs (NCRP 1975; Franke *et al*. 1997; Erickson 2004; Zdrojewicz & Strzelczyk 2006). It has been estimated that 87% of radiation dose received by human beings originated from naturally occurng radionuclides and the remaining 13% from anthropogenic or man made sources (UNSCEAR, 1993)

It has been observed that a shellfish can accumulate radioactive material present in water. This in turn can cause radiation exposure to people who consume mussels or winkles (Pentreath *et al*. 1989; FSA 2002). Exposure to natural radiation differ in many ways. As for an example, an airline pilots are exposed to high levels of radiation from cosmic rays (Pukkala *et al*. 1995; Oksanen 1998).

Radiation Sources

The natural radioactivity is called the phenomenon of spontaneous emission of extremely penetrating radiations from heavy elements with an atomic weight greater than around 206 occurring in nature. The elements that show this property are called radioactive elements. The radioactive element atoms emit radiations that are made of three distinct types of rays. In the process, the elements break up leading to irreversible self-disintegration and it is a spontaneous activity. Radioactivity is not affected by any external factor, such as strong electrical and magnetic fields,high pressure and temperature. The advanced technique of artificial transmutation of elements has also been capable of achieving radioactivity in several other elements. An even lighter than what they are in natural order. Radioactivity initiated by

bombarding an element with alpha particles, neutrons, protons and some other particles or radiation is called artificial radioactivity. Accordingly, there is a difference between natural radioactivity which is naturally occurring elements and intentionally generated radioactivity. But whatever its origin, the activity is always spontaneous. Artificial radioactive elements usually, but not always, have short lifespans.During their decay, they emit electrons, positrons and other particles, as well as gamma rays.

An ionizing radiation that originates when primary photons and α particles from beyond the solar system converse with atmospheric components of the earth are known as cosmic radiations . A further cause of cosmic radiation is the emission from the sun, which become harmful during solar flare cycles. Cosmic radiation that extends from the sun to the earth and interplanetary space differs, its energy is adequately absorbed and affected by the magnetic field of the earth. The impact on the body varies depending on the latitude, elevations and duration of exposure to which an individual is exposed.

Ionizing radiation

The types of radiation, that, on interaction with an atom or molecule, can knock off electrons from the outer shell of an atom and creates positive ions are termed as Ionizing radiation. Ionizing radiations such as alpha, beta and gamma radiation directly ionize atoms and are therefore known as directly ionizing radiations, while interactions of neutrons with atoms of other elements to produce ionizing radiations are classified as indirectly ionizing radiations.

a) Alpha radiation: Alpha radiations are helium nuclei which consist of positively charged particles. Since they have a low penetrating power, the radiation caused by alpha decay cannot penetrate the skin of human beings or even a thin sheet of paper. It is, therefore, considered harmless externally. However, if alpha emitting radionuclide are ingested or inhaled, they can cause damage to the internal organs of the body, especially to the lungs, stomach and kidneys.

b) Beta radiation: Beta radiation, depending upon their mode of decay are different. The beta decay due to heavy nuclei involves electron emission, positron emission or electron capture. In electron emission, a nucleus contains an excess neutron and then emits an electron and anti-neutrino. In positron emission, a nucleus contains an excess proton, and then emits a positron and a neutrino. In heavy nuclei, where electron orbits are closely packed and are much closer to the nucleus, the excess positive charge of the nucleus may sometimes be neutralised by the capture of an orbital electron, this process is known as electron capture. The penetrating power of beta radiation lies between those of alpha and gamma radiations and can be stopped by an aluminium sheet of a few millimeters thickness.

c) Gamma radiation: Gamma radiations are the photons emitted when an alpha or a beta particles from a radioactive substance leave the daughter nucleus in one or more excited states and those nucleus in the excited state passes to the ground state or to a lower excited state from a higher excited state. The emission of alpha or beta particles from naturally occurring radionuclide is invariably followed by the emission of gamma radiation. Gamma radiations have high penetrating power and can easily penetrates the body and cause damage to the body cells, but can be stopped by a lead or concrete block.

d) Neutrons: Neutron is electrically neutral and do not directly produce ionization. But they can interact with atoms of other element which could in turn produce ionizing radiations in the form of alpha, beta, gamma radiations as well as X-rays. Neutrons have a high penetrating power because they are electrically neutral and are not deflected by electric and magnetic fields.

Man-Made Radiation

Based on atomic number divisions, all nuclides with an atomic number greater than 82 are known as radionuclides (Meinrath *et al*. 2003). There are four series of radioactive elements found in the earth and named as terrestrial sources. There are also twenty-two non series primordial radionuclides in nature.

Plenty of sources of man-made radiation exist. In medical investigationsman made radiation is associated with x-rays and diagnostic or therapeutic materials, whilst in industry, and consumer products radiation is associated with smoke detectors and television sets. In addition the earth‘s atmosphere has been contaminated with the fallout from atmospheric testing of nuclear weapons.

The primary sources of internal and external doses to humans are the presence of radionuclides in our environment. Internal dose is produced as a result of the intake of radionuclides into the body. Ingestion and inhalation are two main routes of intake of radionuclides for members of the public. Inhalation is due to intake of radionuclides through breathing in dust particles containing radioactive materialst whilst ingestion involves the intake of the radionuclides from drinking materials such as milk and water, and consumption of food products.

Extra-Terrestrial Radionuclide

Radionuclide having extra-terrestrial origin mostly comes from cosmic radiations. Cosmic radiations can be classified into primary and secondary cosmic radiations. Primary cosmic radiations are those which are initially incident on the earth’s outer boundary of the atmosphere. They are mainly composed of protons (92%), alpha particles (7%) and about 1% of heavier nuclei of almost all atoms from Li to Ni.

Primary cosmic radiations, on interaction with earth’s atmospheric gases like nitrogen and oxygen, produces secondary cosmic radiations, which in turn produces large number of radionuclide. Up to a height of 20km above the earth’s surface, all cosmic radiations are secondary. At sea level, secondary cosmic radiations mainly composed of meson (about 70%), electron-positron pairs (29%) and heavy particles (1%). Radiations from cosmic rays are found to have contributed to the radiation dose rate received by human beings, and studies conducted by Nambi *et al* (1986) have shown that the dose rate of radiation contributed by cosmic radiation is 31.96 nGy/h at sea level.

Terrestrial radionuclide

Natural radioactivity produced by terrestrial radionuclide originates from radioactive elements present on the surface of the earth.Terrestrial radionuclide like ^{238}U, ^{232}Th and ^{40}K are prominent in nature and have a long half life which are comparable to the age of the earth, and are therefore referred to as primordial radionuclide. Primordial radionuclide is found all around us and is detected in certain amounts in air, water,rock, soil and vegetation, from which it enters the body mainly through inhalation and ingestion.Human beings inhale or ingest many radionuclidethat are present all around us, and the main exposure comes from outdoor natural terrestrial radiation that originates predominantly from upper 30 cm layer of soil present on earth (Chikasawa *et al,* 2001). Moreover, gamma radiations emitted from terrestrial radionuclide represents the main external source of irradiation of the human body (Alaamer, 2008; UNSCEAR, 1993).

Their distribution on the terrestrial surface mainly depends on the distribution of rocks from which they originate and on the processes through which they are concentrated (Mahur *et al,* 2008; Kabir *et al,* 2009). They continuously disintegrate into their radioactive daughter elements giving out α, β, and γ radiations directly or through their daughter elements. Hence, measurement of natural radionuclide is needed to identify the origin and abundance of their daughter elements like radon, thoron and their progenies.

1.2 Radon, its discovery, decay, nature, sources and effect

Radon, formerly identified as "Radium Emanation" was discovered in 1898 by a German Physicist Friedrich Ernst Dorn. Radon is known to have 35 different isotopes. Amongst the different isotopes of radon, Actinon (^{219}Rn), Thoron (^{220}Rn) and Radon (^{222}Rn) are of natural origin and are produced as the daughter elements of the Actinium Series, the Thorium Series and the Uranium Series respectively. The most stable isotope of radon, ^{222}Rn, has a half-life of 3.82 days and along with ^{220}Rn (having a half-life of 55.6 seconds), they are the only isotopes of radon which are of significance to the environment.

Natural radioactivity arising from ^{238}U decay series is the main source of natural radiations on the earth's environment. Amongst the daughter elements of ^{238}U, ^{222}Rn is the single most contributors of natural radiations (Figure 1.2) because they are continuously being formed in the soil and released into the earth's atmosphere (UNSCEAR, 2000).

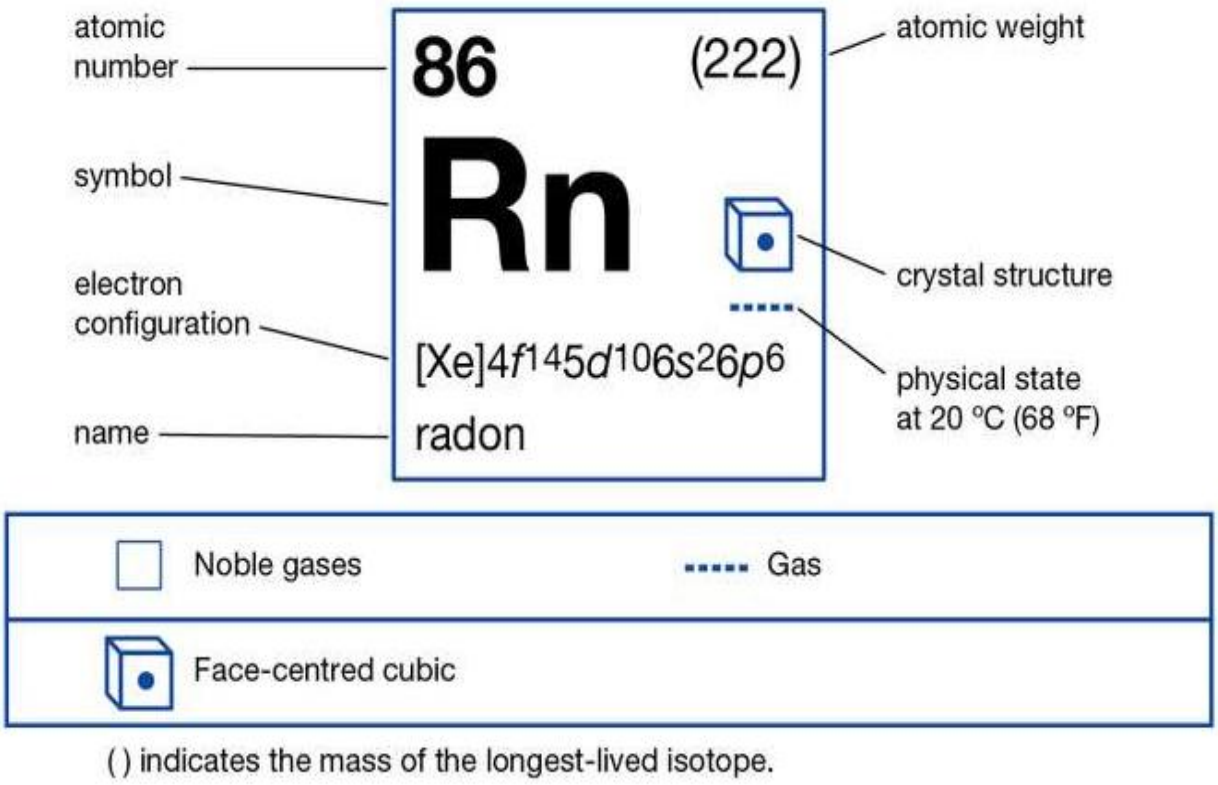


Fig.1.1.: Radon in nature (Source: Encyclopedia Britannica)

The radioactive elements, uranium and thorium are present in the earth‘s crust in significant but varying quantities in most places. These two radioactive elements are the parent elements of two well-known radioactive decay series, i.e., uranium and thorium. There are two elements in these two series which occur as a gas namely, 222Rn, and 220Th. These two gases can be released from the soil to the atmosphere. 222Rn is an unstable element and breaks down into two parts. This type of break down is called decay. These two parts consist of a large decay product, and the small part called "alpha" radiation. The decomposition of 222radon to its decay products happens very fast. In fact, it takes less than 4 days for one-half of 222radon to disintegrate. There are different quantities of radon gas and radon daughters everywhere in the soil, water, and atmosphere. High radon concentrations occur in areas where the soil or rock is rich in uranium and radium.

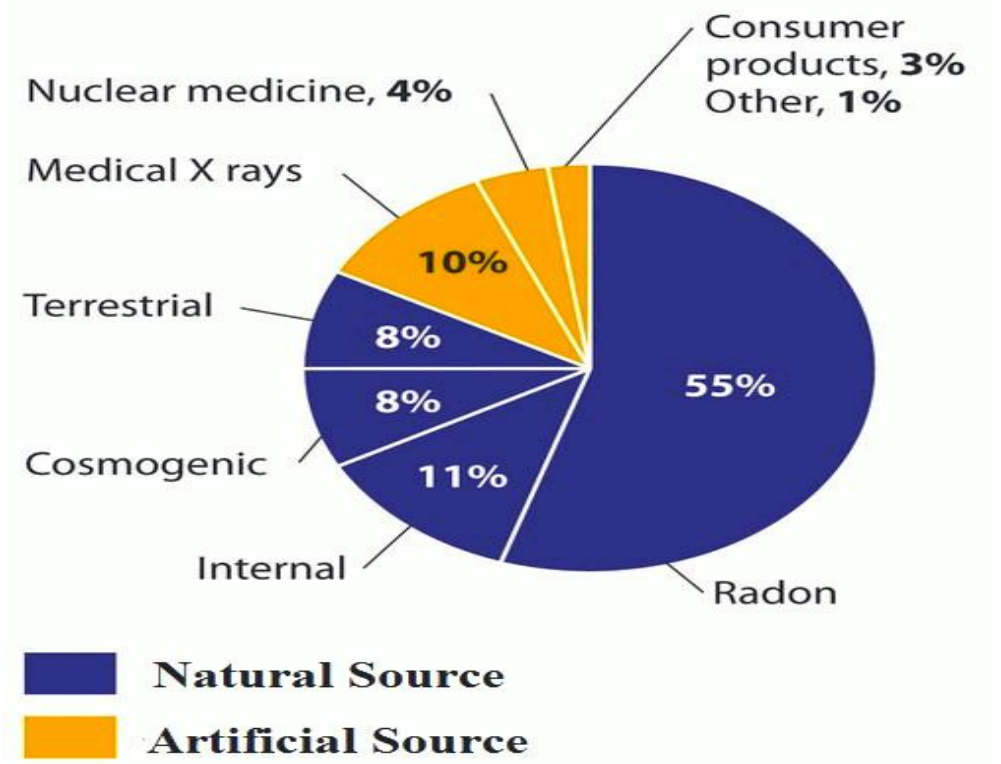


Fig. 1.2. Radon, the single most contributor of radiation

Radon is the result of disintegration of radium in the ground, groundwater and building materials. It can accumulate in indoor air, in poorly ventilated areas. In confined air spaces, such as basements and crawl spaces, radon and radon daughters can accumulate to harmful levels. The existence of radon and its daughters in the atmosphere means that it can be inhaled and deposited in lungs. The alpha particles emitted by radon and radon daughters are absorbed by the lung, resulting in an increased radiation dose and an increased risk of contracting lung cancer.

The radioactive gases radon and thoron and their progeny are found in higher concentrations in the confined atmospheres of buildings and underground workplaces. The main radon source of high radon concentrations in workplaces which are constructed above ground is the soil, but there are also significant contributions from building materials, groundwater, and the storage of large quantities of materials with elevated concentrations of radium such as old watch and instrument parts (O`Riordan 1996; Crockett & Gillmore 2009). Radon can accumulate preferentially leading to high radon levels in underground workplaces, natural caves and abandoned mines (Robert 2006b). Exposures to radon and thoron and their progeny are extremely variable, but in some conditions, members of the public may be exposed to enhanced cocentrations of radon and thoron and their decay products in their workplaces.

Physical Properties of Radon

Radon is a radioactive, colorless, odorless, tasteless, noble gas, having an atomic radius of 1.34 Å, occurring naturally as a decay product of Radium (^{226}Ra) along the Uranium (^{238}U) Decay Series. It is the heaviest member of the rare gas group (approximately 100 times heavier than hydrogen and about 7.5 times heavier than air) and remains a gas under normal conditions. Due to its noble nature, radon is chemically inert to reaction with other gases; hence it is able to travel freely through pores and fractures in rocks and soils, thereby releasing itself into the atmospheric air. It has been estimated that from the total radiation dose received by human beings, radon and its decay products contributes 51% through inhalation and 0.21% through ingestion (Kumar*et al*, 2017;Gusain *et al*, 2009). Table 1.1. shows the physical properties of radon.

Table 1.1.: Physical Properties of radon (UNSCEAR 1982)

Sl. No.	Properties	Values
1	Atomic Radius	1.34 Å
2	Atomic Volume	50.5 cm^3/mol
3	Boiling Point	-61.85 ^{0}C
4	Critical Point	377 K at 6.28 MPa
5	Critical Pressure	62 atm.
6	Critical Temperature	104 ^{0}C
7	Density	0.00973 g/cm^3 at 293 K
8	Electrical Conductivity	0.1 mOhm-cm
9	Enthalpy of Fusion	2.7 kJ/mol
10	Enthalpy of Vaporization	18.1 kJ/mol
11	Heat of Fusion	2.89 – 3.247 kJ/mol
12	Heat of Vaporization	16.4 – 18.1 kJ/mol
13	Ionization Energy	10.745 eV
14	Mean Excitation Energy	794.0 eV
15	Melting Point	-71 ^{0}C
16	Molar Volume	50.5 cm^3/mol
17	Polarizability	5.3 A^3
18	Specific Heat Capacity	94 J/kg.K
19	Thermal Conductivity	3.61 mW/m.K at 300 K
20	Thermal Entropy	176.1 kJ/mol.K (at 298.15)

Effect of Radon on the body

Radon and the radon decay series contribute to a major part of the radiation exposure to the general public and its progeny might lead to the development of lung cancer if inhaled in high concentrations for long periods (Lubin *et al*. 1995; Miles 1998). Due to short half- lives radon and radon daughter decay products, when they are inhaled, can easily deposit on the lining of the lung (Brill *et al*. 1994; Gillmore *et al*. 2000). These radionuclides by emitting alpha particles produce heavy ionisation in the sensitive cells of the lining of the lung. They damage these cells and lead to lung cancer. In the atmosphere of uranium mines these daughter products emit alpha particles and bombard the cells of the respiratory system, and potentially cause lung cancer according to report by Villier and Windish (Villier & Windish 1964).

Problems Associated with Establishing Safe Levels of Radon

There has been a considerable controversy over legislation and regulations to establish standards. In order to determine areas with high radon concentration and demonstrate areas of enhanced risk, a number of studies have been presented. Based on epidemiological and theoretical understanding of radon risk, the National Radiological Protection Board (NRPB) proposed an Action Level of 200 Bqm^{-3} in 1990 for domestic properties and a level of 400 Bqm^{-3} in workplaces. The NRPB was absorbed into the Health Protection Agency (HPA) in 2000. The current Action Level is 15 under review by the HPA (who intend to introduce a new limit of 100 Bqm^{-3} in which case more homes will be classified as radon affected). In the United States the Action Level suggested for domestic properties is 148 Bqm^{-3} (4 pCi l^{-1}).

The level of indoor radon in a house depends on the emanation of radon gas from solid and fractured walls, roof and floor, and even more on the emanations enter the property from underlying porous broken rock surfaces. Radon becomes a health hazard when alpha particles enter the body via an open wound, by ingestion or by inhalation (ICRP 1987). If there is an elevated level of radon concentration in an enclosed area for a long time the likelihood of lung cancer for any occupant increases significantly (Nazaroff & Teichman 1990). The risk of contracting lung cancer from

radon depends on three factors: the duration of exposure, the radon concentrations and individuals smoking habits (ICRP 1989).

Exposure to radon at the levels found in our homes, schools, and office buildings, has received increasing attention in the past decade from scientists, governments, and regulatory bodies. Since children are more sensitive to radiation and also spend more time at home, high radon levels in the home are a particular cause for concern, as this may pose a much greater threat to their health, although this is by no means certain (BEIR 1999). Epidemiologic studies of miners suggests that with increasing time exposure to raised radon levels there is increased risk of lung cancer (Qureshi *et al*. 2000). The major source of radon is natural radioactivity and continuous exposure to radon (which comprises approximately 50% of dose to an individual in a year), which may cause respiratory tissue damage and lung cancer (Sevc *et al*. 1979; Samet & Hornung 1990; Vaupotic 2002). Therefore measuring radon concentrations in regions of high radioactivity and in houses and public areas is important in order to evaluate the radiological hazards to residents.

There are several types of methods for monitoring and detecting radon. In order to measure accurately radon concentrations and dose received it is necessary to take readings relating to individuals over long term periods, because radon levels vary with the time of day and season. In general, radon levels in buildings are highest during the winter season, especially when buildings are not sufficiently ventilated (UNSCEAR 1988). The present work focuses on 222Rn, produced from the natural decay of 238U via 226Ra. This isotope (222Rn) is more significant in health terms than the other isotopes, that is 220Rn and 219Rn which have much shorter half lives.

Sources of Radon

Radon originated from Uranium present in the earth. The decay diagram (Shown in fig 1.4) shows that radon is one of the decay outcome of Uranium-238 series. It is in the form of a gas but its presence can be detected.

1.3 Uranium

Uranium with an atomic number of (P=92) is the heaviest element, which exists naturally in weighable amounts. In 1789, uranium was discovered by Martin Klaproth in an ore, obtained from near Freiberg, Germany (Cliff & Gillmore 2001; Robert 2006a). Significant mining activities around Freiberg occurred in a granite formation that contained unusually high concentrations of uranium.

The amount of uranium in soil is variable and the average is about 2 parts of uranium per million parts of soil (2ppm) (Lieser 1980; Meinrath *et al*. 2003). There is a small quantity of uranium in most rocks, soil, water, plants, and animals. One of the sources of natural radiation which increases exposure to man from natural radionuclides is typically uranium in phosphate rock. High levels of uranium are found in phosphate rock, which is often used to make phosphate fertilizer which is applied to land to enhance soil fertility. The average uranium concentrations in the earth's crust are about 3 mg kg^{-1} (Bertine *et al*. 1970; Turekian & Chan 1971; Sackett *et al*. 1973). The typical uranium concentration in river water by comparison is in the region of (0.2 - 0.6) $\times 10^{-3}$ mg kg^{-1} (Dang *et al*. 1995).

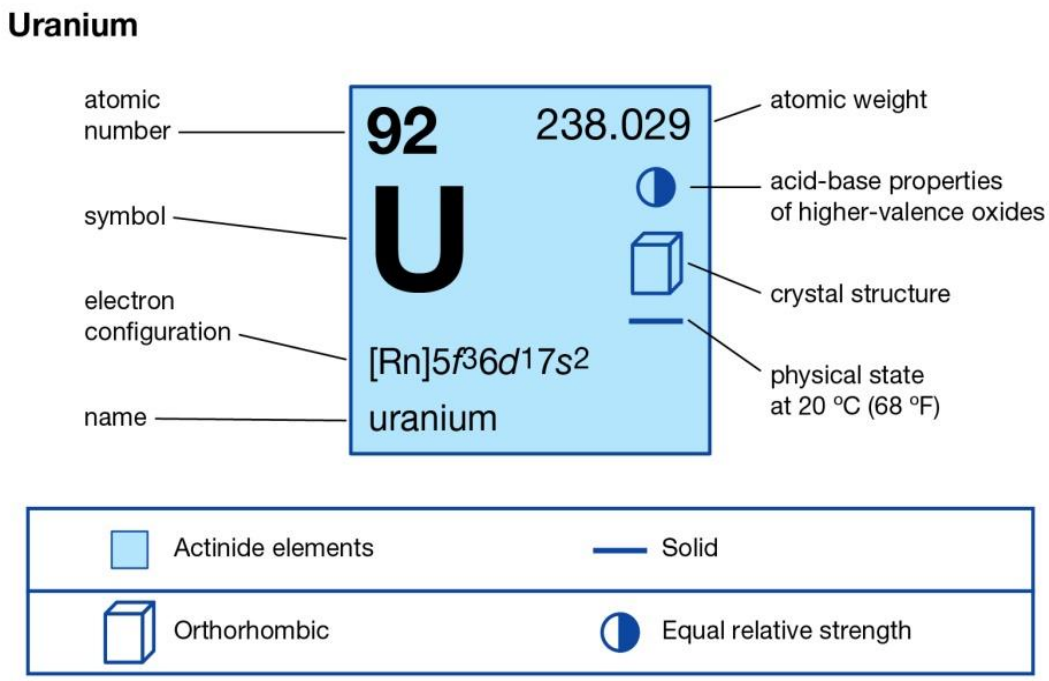


Fig. 1.3. Uranium in nature (Source: Encyclopedia Britannica)

Small amounts, around 0.1mg, of uranium can be found in the human body from the ingestion of food and drinking water; with a daily intake for the average individual of about 1.5×10^{-3} mg (Priest 2001). If the amounts of uranium absorbed in the body via ingestion increase by up to 2%, nearly 90% of this uranium is excreted within 24 hours from body (Morken 1980; Dang *et al*. 1995; Gilliland *et al*. 2000). In spite of the existence of this amount of uranium in the body and especially in the kidneys, no serious problem from lifetime dialysis has been reported in humans.

In order to prevent permanent renal damage in humans it is necessary to limit of consumption of uranium. It has been suggested that the uptake of about 8 mg of soluble uranium is the limit for non permanent renal injury (Dang *et al*. 1995; Knoch-Weber 1998).

In spite of uranium being a toxic heavy metal similar to lead, no drinking water regulation exists for uranium in many countries. Uranium chemical toxicity as a heavy metal may be of less concern than it radiotoxicity for consideration of health. The World Health Organization (WHO) has suggested a tolerable daily intake for uranium of 0.6µg kg^{-1} body weight, and for drinking water, 2µgl^{-1} (uranium per litre) (WHO 1993).

Natural uranium has three different isotopes which are all radioactive in nature, namely,^{238}U, ^{235}U, and ^{234}U. Amongst the three natural isotopes of uranium, ^{238}U is the most abundant and constitute more than 99% of the total uranium present in nature. The high abundance of ^{238}U in nature makes it an isotope of interest, and its concentration and distribution in soils and rocks, as well as water could have an adverse effect on human health condition. Moreover, ^{238}U isthe parent element of the most hazardous and most studied isotope of radon, ^{222}Rn (Figure 1.1).

Although ^{238}U is mostly found in rocks and soil, through the process of leaching, it can enter the water bodies as well. When water flows through soil and rocks containing ^{238}U, it gets dissolved in the flowing water and gets transported (Chandrashekara, 2017). Also that drinking water contributes about 85% of ingested uranium while food contributes about 15% (Cothern *et al*, 1983). Though uranium is considered to be a weak radioactive element, ingestion of water containing high concentration of uranium may lead to certain health hazards.

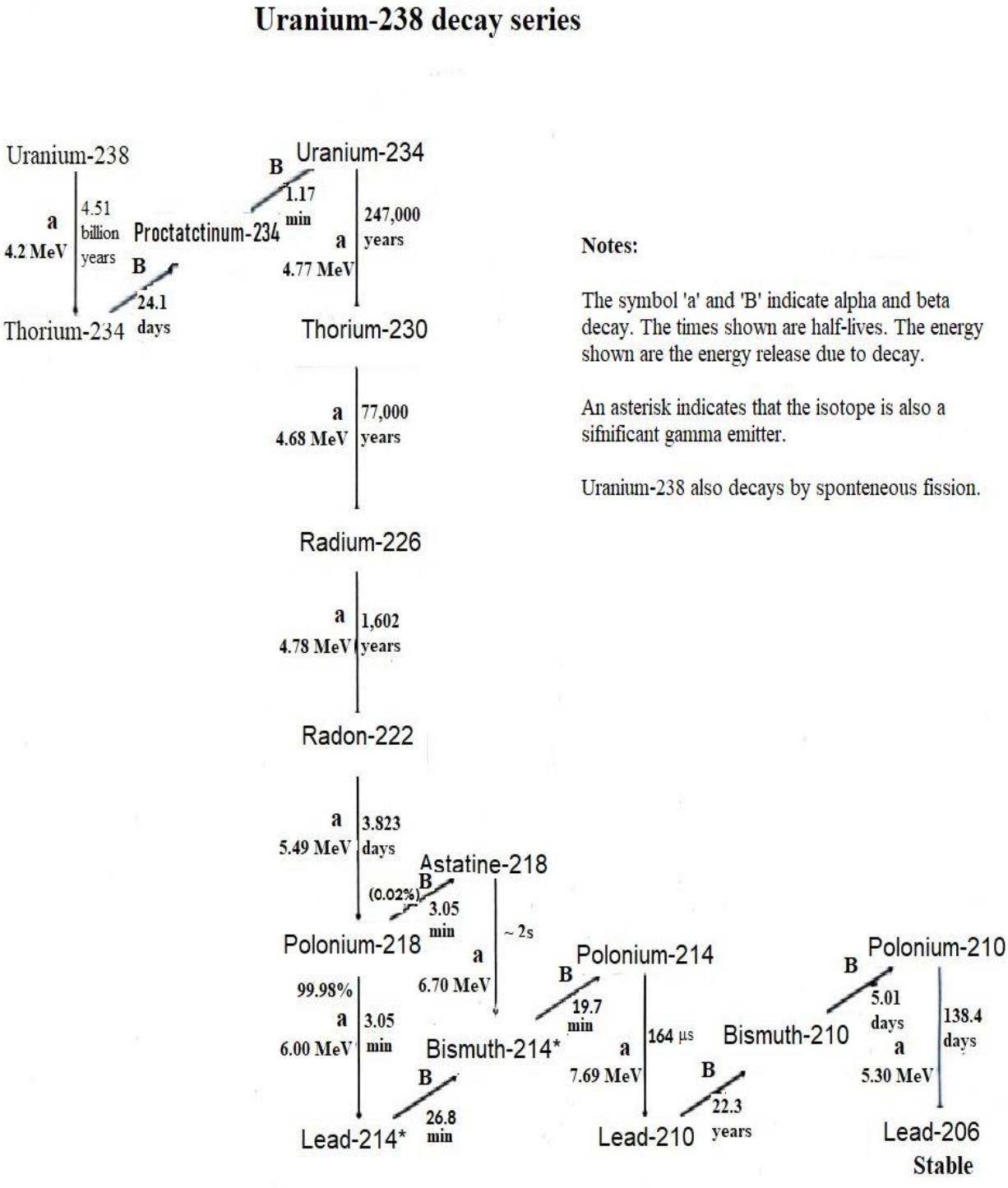


Fig. 1.4. Decay diagram of 238U series with the half-life of each radionuclide.

(Source: Handbook on Radon Transport Models

and Measurement Method, Cover Page)

Radon relation with Coal field Miners

German scientists since the 1920s have been suggesting that radon was the cause of the great excess of lung cancers in some mining areas (Snih 1992; Webb 1992). This proposal was based on examining accurate data collected during autopsies. In the hundred year period from the 1820s to the 1920s, more than 400 miners from one particular region alone were found to have died of lung cancer. In the early 1950s, based in part on part work by the American scientist W.F. Bale, the majority of researchers accepted that radon was the major cause of radiation damage to lung tissue in miners (Bale 1980). It is recognized that not all mines are the same in terms of the amount of radon; for example tin, iron and uranium miners were exposed to higher levels of radon than coal miners (HSE 1997).

In the 1950s, some houses were constructed in the Western regions of the USA with materials salvaged from old uranium mines, and these have been shown to be prone to very high radon levels. The origin of the source of such high concentration in these buildings was gas diffusing out of the uranium mill tailings that were used as backfill around the basements. During that time, scientists considered that the original source of radon entering into buildings was building materials, rather than from the underlying soil. They suggested that in order to obtain further information about radon flux more fundamental research was needed to be carried out on measuring radon concentration in dwellings. Since the mid-1960s in the UK, many surveys of radon in mines were undertaken, as a consequence of these surveys it was suggested that approximately 40% of miners in non-coal mines were exposed to levels considered dangerous to health (Dixon *et al*. 1996b). High levels of radon were noted in domestic dwellings in Cornwall (HSE 1985; HSC 1988). One particular survey in schools and offices was carried out in the southwest of England, which confirmed that there were many instances of elevated radon levels in the region.

In 1985, for the first time, based on the above surveys, the Ionising Radiation Regulations introduced statutory control of radon in workplaces, which was and is implemented by the Health and Safety Executive (Dixon *et al*. 1996a). Workplaces in which the radiation was above the Action Level of 400 Bqm^{-3} either had to reduce levels to below 400 Bqm^{-3} or restrict staff doses in accordance with the Ionising

Radiation Regulations. If radiation levels were above 1,000 Bqm^{-3} it is suggested that companies should consider these under a new designation of a Controlled Area (Dixon *et al*. 1996). Measurement of workplace radon in 1996 highlighted 6,000 workplaces in the UK with high radon (Denman 1994). Cornwall was noted as the worst affected area with 21% of workplaces above the Action Level; Northamptonshire had 14% and Somerset was the lowest affected area with 5%. Around 300 registered businesses in Derbyshire and approximately 700 in Northamptonshire were chosen for a survey. The general aim of the HSE is to educate employers about the need to include radon in their risk assessments (Denman 1994). At that time (1994) it was suggested that radon in the workplace should be considered a priority area for the future action, as there is legislation that can be used to control its levels in the UK. However, in India and in Mizoram, due to a lack of information on radon levels in the country, measuring radon in homes should be considered as a priority both for now and in the future as until this has been achieved it is not possible to produce an average radon level for the whole country or assess the impact of radon on the health of the Indian population. One of the big challenges limiting the production of a suitable database has been (and continues to be) the cost of such radon programmes to employers. In 1992, Denman suggested that a programme of evaluation in the UK‘s National Health Service premises in Northamptonshire had found high levels of radon (Denman & Parkinson 1996). With further investigation it was found that there were certain workers who were receiving very high doses of radiation (Denman & Parkinson 1996; Denman *et al*. 1997a). In order to clarify matters, a large radon measurement programme was performed and some 1,038 locations were tested which revealed that the highest levels of radiation reached 3,750 Bqm^{-3} (NCRP 1984; NRPB 1992).

1.4 Radon in Rock and Soil

Due to the extended half-lives of uranium and radium and their abundance in the earth's surface, radon is continually being formed in rock and soil and released to air. The normal emanation of radon from ^{238}U via ^{226}Ra in soils is the largest single source of the radon that is found in the air (Hand & Banikowski 1988). Uranium is

often redistributed by ground water and becomes concentrated into limestones (calcium carbonate) and dolomites (Segovia *et al*., 1999).

Radon migrates from its site of production within rocks through two processes; emanation and exhalation. Emanation is the transport of radon from the site of production into rock pore spaces, while exhalation is the transfer from pore spaces to the environment outside the rock (King 1993; Gillmore *et al*. 2002). Temporal variations of radon emanation from soil and water suggest a sensitivity to its release as a consequence of tectonic disturbances in the Earth's crust (Etiope & Martinelli 2002; Garcia -Vindas & Monnin 2005). Radon near the soil surface may be released to ambient air and may also be released into groundwater. When the groundwater reaches the surface, most of the radon gas will quickly be released to ambient air, but small amounts may remain in the water. In groundwater, radon moves by diffusion and, primarily, by the mechanical flow of the water. Radon solubility in water is relatively low and, with its short radioactive half-life of 3.8 days, much of it will decay before it can be released from groundwater. Radon is able to move over large distances within the soil or the subsoil before decaying away completely. The short half-life of ^{222}Rn (T1/2 = 3.82 d) also limits its diffusion in soil, so that radon measured at the ground surface cannot be released from a deep origin, unless there exists a driving mechanism other than simple diffusion.

When radon migrates over large distances; it is transported by underground water or by carrier gases. The amount of radon released to groundwater is a function of the chemical concentration of ^{238}U via ^{226} Ra in the surrounding soil or rock and in the water (Hess *et al*. 1985; Ioannides *et al*. 2003). Radon can dissolve in groundwater following radioactive decay of the uranium via radium. High radon concentrations are associated with groundwater running over granitic rock or through alluvial deposits originating from granite (Hess *et al*. 1985), as is the case in Hamadan. The physical characteristics of the rock matrix are also important since it is believed that much of the radon released diffuses along microcrystalline imperfections in the rock matrix (Horton 1983; WHO 1993; NAS 1999).

The rate of emanation is typically slower in very dry soils since alpha recoil may also result in moving the recoiled atoms into an adjacent wall of another soil particle rather than an open pore space. The actual release of radon from the pore space or soil-gas to ambient air is called exhalation, while its release from water is called evaporation. The rates of these processes are functions of many variables including the concentration of radon in the soil-gas or water, soil porosity and moisture, meteorologicalfactors (such as temperature and precipitation), and variations in atmospheric pressure (Horton 1983). Soil moisture has an important but varying effect on radon release to the air. While lower levels of soil moisture greatly increase emanation by preventing recoiling atoms from embedding into adjacent soil particles, saturated soil conditions in which the pores are filled with water tend to slow the rate of diffusion to the surface since the diffusion coefficient of radon is about 3 orders of magnitude lower in water as compared to air (Stranden *et al*. 1984). The influence of moisture and temperature on the radon exhalation rate in concrete, alum shale, and alum shale (fissile rock) bearing soil was studied in laboratory experiments (NAS 1999). Soil and water radon concentrations are not strongly related to each other, but it is possible to estimate the contribution of waterborne radon to air in a house (Segovia & Bulbulian 1992).

Mechanisms for the transport of radon in groundwater are complex; the transport of radon in groundwater is accomplished by diffusion and, primarily, by the mechanical flow patterns of groundwater (NRC 1988). The diffusion coefficient of radon in water is sufficiently low so that diffusion is only important for movement in very small and poorly ventilated spaces (such as pore spaces).

As can be deduced from the information given above, the key factors that affect radon soil gas levels include radium content and distribution, soil porosity, moisture, and the bulk density of the soil (Stranden *et al*. 1984).

1.5. Radon and uranium in Water:

Ingestion of water containing natural radionuclide is known to contribute to the radiation dose received by human beings, and due to the radiation-induced public

health hazards they caused, measurement of uranium and dissolved radon levels in water remains a topic of interest.

In Lebanon, a preliminary national average radon level was determined to be about 11.4Bq/l. Since these determined concentrations were well below the 100 and 146 Bq/l revised reference levels proposed in the European Union and the United States respectively, it was concluded that there is no reason to believe these water sources pose any radon-related hazard (Abdallaha *et al,* 2007).

Preliminary studies on groundwater samples from selected wells in three communities in the Greater Accra region of Ghana was carried out to determine the concentration of ^{222}Rn using gamma spectrometry and the average activity concentration obtained was 8.1 Bq/l with an average annual effective dose of 59.2 μSv. This result was found to be within the range published by other countries and the recommended limit for radon in drinking water set by the World Health Organization (Darko *et al,* 2009).

In Amritsar city of Punjab in India, radon concentration was estimated in drinking water samples using RAD7 and the values of radon concentration in these samples were found below the recommended limit proposed by the United States Environmental Protection Agency(USEPA, 1991) and European Commission (2001) (Kumar *et al,* 2016). Radon exhalation rate from the soil shows a positive correlation with radon concentration in water in summer season in Budhakedar, Garhwal Himalaya (Prasad *et al*, 2009).

Uranium in Water:

In a study conducted by Sahoo *et al*(2010) on packaged drinking water samples using laser fluorimetry, the total uranium content in water varies from 0.04 - 3.88 μg/l, which was well within the USEPA drinking water limit of 30 μg/l(USEPA, 2000a) and WHO limit of 15 μg/l (WHO, 2004). Measurement of uranium and radon concentration in drinking water was also conducted by Singh *et al* (2008), Kaur *et al*(2017), Singh *et al*(2014), Bajwa *et al*(2003) in different parts of India and their results were found to be within the safe limit. Poor correlation between radon

dissolved in water and uranium concentration was observed by Kumar *et al* (2017) in Jalandhar district of Punjab. Similar result was reported by Ryan *et al* (2003) in Wicklow, Ireland. The possible reason for this poor correlation may be due to the fact that radon in ground water is transported to very limited distance due to its lower half-life (3.82 days) as compared to uranium, which can travel a very long distance.

1.6. Transport of Radon:

The element Radon and Thoron are commonly formed in soil by the presence of minerals containing ^{238}U and ^{232}Th. Therefore the construction materials containing these elements can also serve as sources. The development of radon is further increased by the technological improvement of these materials in cases such as exploration and the sand and ores processing facilities. Radon in the Earth's crust and perhaps other permeable matrices is able to move freely only when the atom finds its path into pore spaces or capillaries. Radon enters the indoor atmosphere from the soil and building material matrix by two processes. The first stage is emanation from the material and the second stage is exhalation from the matrix.The two terms can be defined as follows:

Emanation: A process by which ^{222}Rn atom is released from the solid mineral grain to the air-filled pores

Exhalation: The process of transport of ^{222}Rn from air-filled pores to the atmosphere.

Even though the entire processes responsible for the radon emanation from grains is not known. The main contribution of the emanation is believed to be the rebound temperature effect on radon emanation, but moisture content has a significant impact. This is because the radon atom entering a pore that is filled or partly filled with water is more likely to stop in the pore volume without passing through the pores and to exhalation. The transportation of radon from pore space to environment occurs primarily through diffusion, as well as in several instances due to darcian flow (Advection). Many external factors can influence the diffusiveness and thus the exhalation rate. Rainfall, snowfall, freezing and rising air pressure contribute to a decrease in the rate of exhalation, while increase the wind speed and temperature may

increase the process (Handbook on Radon Transport Models and Measurement Method, 2017).

Radon may also access directly from the soil or rock that is still in the crust through utilities such as water that carries radon or from crustal materials that are incorporated into the structures of the buildings in the form of concrete, rock and brick. Graph shows the range of entry rates, as well as the probable contribution of different sources (Nazaroff, 1988).

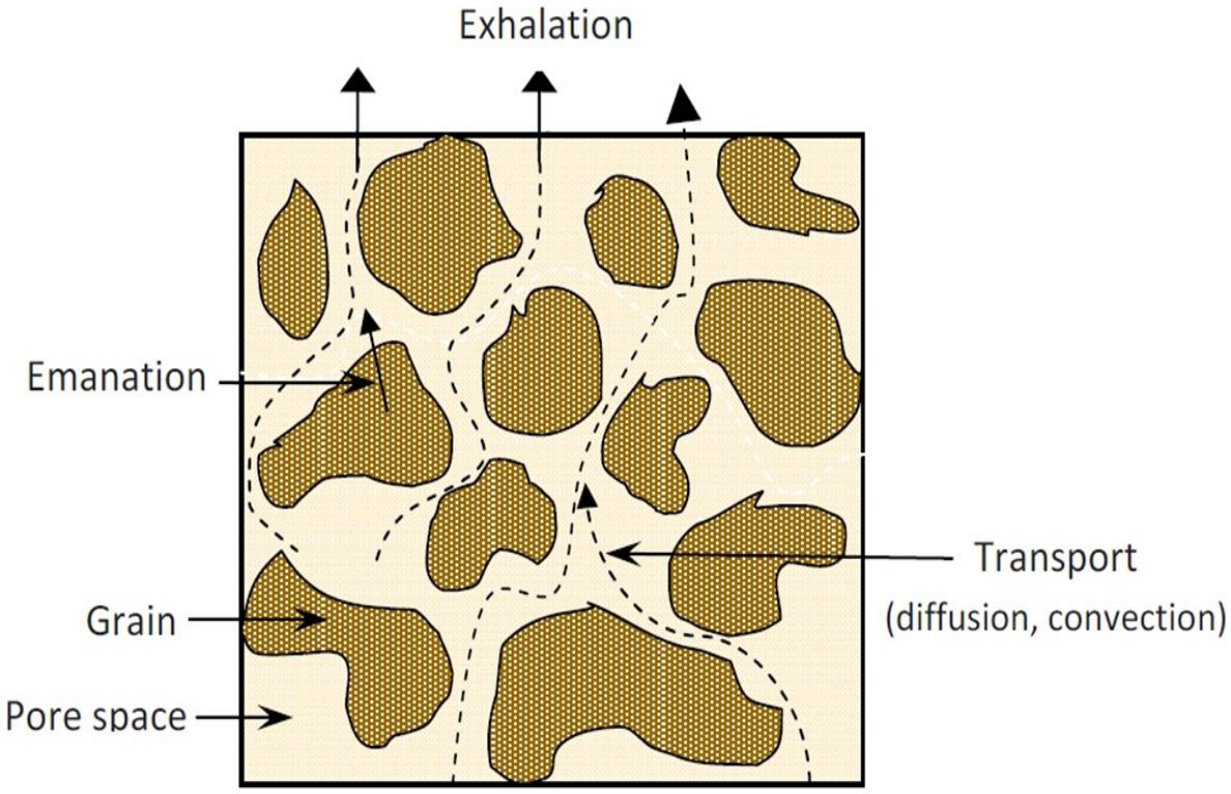


Fig. 1.5. Transport of radon (Source: Handbook on Radon Transport Models and Measurement Method, 2017)

1.7 Literature Review and observations on radionuclides

Over the last three decades or so, there has been a considerable amount of interest in the levels of natural radiation to which people are exposed. Variation in radon levels has been monitored in public buildings and houses in a number of countries including the United States of America, Sweden, Finland, Ireland, Greece, Italy, India and the United Kingdom (UNSCEAR 1988). There is a concern that exposure to persistent elevated concentrations of radon may cause an increased risk of lung cancer. High indoor levels are controlled by a number of factors such as soil porosity, uranium or radium content of the soil, building materials, style of construction of dwellings and ventilation (Miles *et al*. 1996). It has been established that radon can migrate through two processes; emanation and exhalation (Phillips 1992; Gillmore *et al*. 2002).

One of the first surveys to measure radon concentrations in workplaces was carried out in Innsbruck, Austria (Steinhäusler 1975). Ten locations such as schools, offices, and warehouses were monitored and the arithmetic mean concentrations of radon ranged from 13–58 Bqm^{-3}. The geometric mean of the 10 sites was 36 Bqm^{-3}.

In the United States, a survey of nearly 930 schools chosen randomly from a population of more than 100,000 was published by the Environmental Protection Agency (Phillips 1992). Approximately 19.3% of the school buildings had a radon level above the US Action Level of 148 Bqm^{-3} (4pCil-1). This report demonstrated that approximately 0.1% of the schoolrooms exceeded 1,000 Bqm^{-3} and the highest value measured was about 2,500 Bqm^{-3}. In the north of the USA, a survey was carried out at 163 sites in 40 premises (Turk *et al*. 1986). Only one building was found which had a radon level over the US action level. In the United Kingdom, a survey by Dixon (1999) was carried out in the Cornwall and Devon and recognized areas of the hight radon concentrations within workplaces. According to Dixon (1999) approximately 8,000 workplaces have been monitored. The annual average radon concentration was estimated to be 100 Bqm^{-3} with a maximum annual average level of 7,500 Bqm^{-3} found in one building (Dixon 1999).

An investigation of radon levels in the show caves (classified as a workplace for the guides) of Creswell Crags, Derbyshire in the UK by Gillmore, *et al*. (2002), showed that the range of radon concentrations was from 27 to 7,800 Bqm^{-3} and that radon concentration increased with increasing distance into the cave. A survey was also carried out by Denman, *et al*. (2002) for staff areas in five hospitals in affected areas in England and Wales. They placed detectors in the working ground floor areas and basements in all buildings at each hospital site (Denman *et al*. 2002). The results show that the highest radon levels in one hospital was 12.9% over the action level 400 Bqm^{-3} and the lowest in another hospital, was 2.2% over the 400 Bqm^{-3} level (Coskeran *et al*. 2002).

A survey of dwellings in Luxembourg demonstrated that in this region dwellings had high indoor radon concentrations (Poffijn *et al*. 1992). A monitor of the 421 schools in Luxembourg showed an arithmetic mean of 120 Bqm^{-3} and a median of 90 Bqm^{-3}. Approximately twelve per cent of the schools showed levels over 200 Bqm^{-3} and in 2% they were over 400 Bqm^{-3}. In the radon prone areas of Luxembourg, a survey of 36 public buildings showed an arithmetic mean of 110 Bqm^{-3} and a median of 72 Bqm^{-3} (Poffijn *et al*. 1992). Ten per cent of the buildings were over 200 Bqm-3 and 3% exceeded 400 Bqm^{-3}.

Observations on some radionuclides:

Indoor radon concentration was measured in China in the year 1984 to 1990 for 10811 dwellings and covered 26 provinces and all cities all over China. The average radon concentration was found to be 22.5 Bq/m^3 and 19.6 for arithmetic and geometric mean respectively (Cheng *et al*., 2002). The atmospheric radon concentration in Beijing was continuously measured recorded hourly over a five-year period from January 2003 to December 2007. The range of average concentration of atmospheric radon each year was from 11.2 to 13.0 Bq/m^3, while the average concentration over the five years was 12.1 ± 4.9 Bq/m^3 (Zhang *et al*., 2009). Samples of granite, andesite, tuff and marble used as wall coverings were collected from mining companies in Japan and their activity concentrations of ^{222}Rn and ^{220}Rn were measured. Dose estimates were also performed for occupants living in houses built

with these materials. In all materials the activity concentration of natural radionuclides was lower than the critical values defined by the International Atomic Energy Agency (IAEA). The maximum effective doses to inhabitants was 0.68 mSv/y, which is lower than the intervention exemption level (1 mSv/y) given in the International Commission on Radiological Protection (ICRP) (Kazuki *et al*., 2012).

In India studies have been done in Budhakedar, Garhwal Himalaya, India on soil and ground water and its correlations. Radon exhalation from soil and water was measured by LR-115 type II technique. It was found that there was a weak negative correlation between the radon exhalation rate and its concentration in soil. There is also no correlation between radon exhalation rate and gamma dose rate but found that there is a positive correlation with the concentration in water (Prasad *et al*., 2009).

A study of uranium and radon levels in drinking water sources of a mineralized zone in Himachal Pradesh, India had been done and Uranium concentration in water was measured using Laser Fluorometer and radon content was measured using a scintillation based monitor. It was found out that Uranium and Radon concentration were both within safe limits as recommended by WHO and USEPA (Singh *et al*., 2015). Study was also conducted to assess the concentration of uranium and radon in drinking water from Jalandhar district of Punjab, India. Radon Concentration was measured using scintillation cell method. Laser fluorimeter was used for measurement of uranium concentration. Uranium concentration varied from a 1.53±0.06 mg/m^3 to 50.2 ± 0.08 mg/m^3 with a geometric mean value of 14.85mg m^3. The radon concentration in water varied from 0.34±0.07 kBq/m^3 to a maximum value of 3.84±0.48 kBq/m^3 with a geometric mean value of 1.46 kBq/m^3 (Kumar *et al*., 2017).

The studies about radionuclide is also conducted in Aizawl, Kolasib and Champhai Districts of Mizoram by measurement of radon and thoron concentration. Solid-state nuclear track detectors were used to obtain the time integrated concentration levels of indoor radon and thoron. Among the three districts, Champhai District had the highest radon/thoron concentrations, while Kolasib District had the maximum thoron concentration (Rohmingliana *et al*., 2010). Radon concentration in

dwellings has also been observed for about two years from May 2009 to February 2011 in Mamit Districts. Seasonal variations of radon concentration levels were observed for one year and followed by landslide in part of Mamit town. Indoor radon concentration levels were measured in landslide affected area with a time integrated method using a solid state nuclear track detector (SSNTD) type (LR-115films) kept in a twin cup dosimeter. It was found that radon concentration level during pre-landslide moment was higher than that of post-landslide.

Measurement of radon content in soil gas was conducted in Mamit town using RAD7 right after landslide. The concentration shows no high results. (Rohmingliana *et al*., 2012). Radon mass exhalation rate and radon flux from the soil was measured using Smart RnDuo detector in Saiha and Lawngtlai District of Mizoram, India. Being the state with highest lung cancer record in India, the average mass exhalation rate and radon flux from the soil were found to be lower, being 89.59 ± 1.83 mBq/kg/h and 66.66 ± 3.69 Bq/m^2/h respectively. In spite of results lower than global average, the effect of inhalation of the gas to cause lung cancer cannot be ignored (Chhangte *et al*., 2019).

The radionuclides that occur naturally in drinking water typically have more radiation than those generated artificially and are therefore of higher concern. Radon may be present in drinking water particularly from groundwater. While radon can infiltrate indoor air in buildings through taps or through showering, the most important source of radon in indoor air occurs from natural environmental accumulation. The global annual average dose per individual from all sources is approximately 3.0 mSv/yr, reported by the United Nation Atomic Radiation Effects Science Committee (UNSCEAR, 2008). For those, 80% (2,4mSv) are due to natural radiation sources, 19.6% (almost 0.6mSv) is caused by medical radiation use and the remainder 0.4% (around 0.01mSv) is caused by radiation induced by men. In the case of consumption of drinking water containing radionuclides over prolonged periods of time, evidence of an elevated cancer risk in individuals is available at doses above 100 mSv (Brenner *et al*., 2003).

This study focuses on evaluating the radon content in soil and the surrounding water source where oil and natural gases are extracted or proposed to be extracted. Regions with oil refinery is accompanied by dwellers all around. The surrounding soil, which may contain Radon and Uranium in excess may at any time bring an adverse effect on the health of all the dwellers. An *in-situ* measurement of soil radon content is done. At the same time soil radioactivity and radon percentage in water with its uranium content were studied. Soil type and grain size analysis is also conducted to determine the effects on soil radioactivity and the content of radon and uranium.

The case for miners and dweller in oil field areas may have similarities in terms of inhalation even though not much research has been conducted in refinery regions. The presence of natural oil and gas beneath the earth may on one hand show a difference in the ^{222}Rn concentration is to be studied. Baseline levels of radon and Uranium will be obtained to ensure safety of the general population.

Units of Radiation

Curie : The amount of activity radioactive elements as determined by their decay rate has traditionally been specified in curies (Ci) which is defined by the activity in one gram of naturally occurring 226Ra. 226Ra was discovered by Mme Curie and the unit of measurement named after her. The activity is determined by the number of radioactive transformations (disintegrations) of 5 a radionuclide over unit time. The curie is approximately 37 billion disintegrations (decay events) per second (3.7 x 1010 transformations per second). The System International Units (SIU) is the recognized international standard for describing measurable quantities and their units in Europe. The amount of radioactivity in a substance of interest is described by its concentration which is defined as the amount of radioactivity per unit volume or weight of that substance. Water and atmospheric samples may be expressed as activity per millilitre (mL) or per cubic metre. Radioactivity in food stuff and soil are often mentioned as activity per gram (g). Exposure, which is measured by environmental dosimetres, may be expressed in units of mill-Roentgens (mR) or more commonly in terms of dose as millirem (mrem) or micro-Sievert (µSv). (See below).

Becquerel : The amount of radioactivity in the standard SI unit system for the activity rate of a substance is measured in Europe using the Becquerel (Bq). A Becquerel is equal to one nuclide disintegration per second.

Röntgen : The röntgen or roentgen (symbol R) is used as a unit of measurement for ionizing radiation (such as X-ray and gamma rays), which is expressed as the unit charge divided by unit mass (R = C / Kg in SI). In SI units, 1 R = 2.58×10−4 Coulomb / Kg . The röntgen was sometimes used to measure exposure to radiation from other forms than X-rays or gamma rays. To express the different effects of different forms of radiation on biological matter, "Röntgen equivalent man" or rem was also in use. Exposure in rem is equal to the exposure in röntgens multiplied by the Q value, a constant, describing the type of radiation.

Equilibrium Factor

The equilibrium factor has been suggested for the conversion of working level (WL) to Bqm-3 (pCil-1), which is the quantity of value 1.0 for animal studies and 0.5 for occupational epidemiological studies. The equilibrium factor is used to measure the degree of radioactive equilibrium between radon and its short-lived radioactive decay products, and is often assumed to be 0.4 for risk assessment purposes. When short-lived radon daughters exist at the same activity concentration in air as 222Rn, radon is in equilibrium with its progeny, then 1 WL equals 3,700 Bqm-3 (100 pCil-1) 222Rn of air. If the equilibrium factor is 0.5, then 7,400 Bqm-3 (200 pCil-1) 222Rn of air is equivalent to 1.0 WL; if the equilibrium factor is 0.3, then 1 WL corresponds to 333×37 Bqm-3 (333 pCil-1) 222Rn of air.

Absorbed Dose Units

Radiation may be absorbed by materials, which deposits a relatively large amount of energy into a small volume of mass. Electromagnetic radiations (X-rays and gamma photons) are indirectly ionizing; that is, they transfer their energy in various interactions with 7 molecules, and the energy is then used to create a fast-moving charged particle such as an electron. It is possible that the electron obtained enough energy to subsequently cause secondary reactions with a target molecule. Charged

particles, in contrast, strike the tissue or medium and directly react with target molecules, such as oxygen or water.

Gray : The gray was defined in 1975 by Gray (1905-1965). The unit is based on the International System of Units, and one gray is defined as the absorption of one joule of radiation energy by one kilogram of matter.

1 Gy = 1J/kg

Rad : The RAD (Radiation absorbed dose) is expressed as an obsolete unit of absorbed radiation dose, with a symbol R. It was based in the in CGS system of units in 1953. The absorbed dose is defined as 100 ergs of energy absorbed by one gram of tissue mass. It is no longer used and has been replaced in the SI system by the gray;

100 rads are equal to 1 gray.

1 RAD = 100 ergs/gram,

1 Gy = 100 RADs.

Absorbed dose is modified by a qualitative factor related to linear energy transfer and modified absorbed dose is measured in rem.

Dose Equivalent

Sievert : The SI unit for dose equivalent is called the Sievert (Sv). It reflects the biological effects of radiation on the body as opposed to the physical aspects, which are characterised by the absorbed dose, measured in gray. The rem is now superseded by the Sievert. The equivalent dose to a tissue is found by multiplying the absorbed dose, in gray by a dimensionless "quality factor" Q, dependent upon radiation type, and by another dimensionless factor N, dependent on all other relevant factors. N depends upon the part of the body irradiated, the time and volume over which the dose was spread, even the species of the subject. Together, Q and N constitute the total radiation quality factor QF. Beta and gamma radiation have a QF of 1, neutron would have a QF of 3-10, whereas alpha radiation would have a QF of 20. In terms of SI base units:

$$1\ Sv = 1\ J/kg = 1\ m^2/s^2 = 1\ m^2 \cdot s^{-2}$$

1 Sv = 1000 mSv

1 REM = 1 RAD x QF

100 RAD x QF =100 REM=1 Gray=1 Sv=1000 mSv

The sievert is mostly measured in milli sievert in order to easily communicate the amount of dose a person receives. Although the Sievert has the same dimensions as the gray (i.e. joules per kilogram), it shows a different thing. To prevent any risk of mistake between the absorbed dose and the equivalent dose, one should use the corresponding special units, namely the gray instead of the joule per kilogram for absorbed dose and the Sievert instead of the joule per kilogram for the dose equivalent. For a given amount of radiation (measured in gray), the biological effect (measured in Sievert) can vary considerably as a result of the radiation weighting quality factor QF . This variation in effect is attributed to the Linear Energy Transfer (LET) of the type of radiation, creating a different relative biological effectiveness for each type of radiation under consideration.

Rem : The REM (roentgen-equivalent-man) absorbed dose can be expressed to account for the amounts of biological damage a particular type of radiation causes. This is known as dose equivalent. The first unit for dose equivalent is called the REM. An absorbed dose describes the amount of energy from ionizing radiation absorbed by any kind of matter.

1 REM = 100 erg/g

The SI unit for dose equivalent is called the Sievert (Sv).

1 Sv = 100 REM.

1 Sv = 1000 mSv = 1 Gy = 100 REM = 100 RAD x QF

1.8. Scenario of Natural radioactivity studies in Mizoram:

Monitoring of natural radionuclide in Mizoram is still at an initial stage. Most of the studies were mainly in relation to indoor and outdoor air. Natural radionuclide measurement was done long back in 1996 by Srivastava *et al*(1996). They conducted measurements of potential alpha energy of radon and its progenies in some regions of Aizawl, Kolasib, Saiha and Khawlian. Later, measurement of radon, thoron and their progeny concentrations were conducted in 17 dwellings (Ramachandran *et al*, 2003). In 2009, measurement of radon and thoron concentrations in Aizawl, Champhai and Kolasib districts of Mizoram were done by Rohmingliana *et al* (2009) and Vanchhawng *et al* (2009).

The concentration of ^{222}Rn can be felt with earthquake. Jaishi *et al* (2015) had carried out soil gas radon and thoron concentration measurements using LR-115 type-II detectors in seismic areas. They found out a positive correlation between radon/thoron data and seismic activities that occurred around the measuring site. Not so long ago, Chhangte (2018) carried out an intensive analysis of radon and thoron in dwellings, with special reference to Saiha and Lawngtlai districts of Mizoram as well.

Intensive study of radon gas in Mizoram is still a challenge. In this research work, within Mizoram, chosing all the existing six oil exploration areas, study of radon gas abundance beneath the ground surface at different baptism depth is done. Once the baseline datas are collected, comparison in any form and kind for further studies is evident.

Soil radioactivity, radon in water, Uranium in water, calculation of radon mass exhalation rate, an *in*-situ measurement of radon concentration in earth was conducted. Lattitudinal and longitudinal coordinates of each sampling sites were marked by Global Positioning System (GPS) device and at the time of sampling, background gamma radiation level were taken at two level, one at the ground surface and the other at a height of 1 meter above the ground at each spots using a Gamma Survey Meter PM 1405. For measurement of radon concentration in water and radon mass exhalation rates, a scintillation based radon detector, Smart RnDuo (developed

by BARC, Mumbai) was employed. Measurement of uranium concentration in water was also conducted using a device called LED Fluorimeter, LF-2a, which works on the principle of detection of fluorescence produced by uranyl complexes in water samples. Soil radioactivity measurement was carried out by measuring the activity concentration of three specific prominent primordial radionuclide; namely; ^{238}U, ^{232}Th and ^{40}K. A gamma ray spectrometer, i.e., Sodium Iodide (NaI) detector, doped with thallium (Tl) and coupled with a personal computer based 1K multi-channel analyzer;GSPEC-SA was employed for this purpose. An *in-situ* measurement of radon at different baptism dept of 10cm, 30cm, 50cm and 70cm is corried out with a soil probe specially designed for the purpose and a smart RnDuo.

Objectives of the study

The study of this work will determine the variation of Radon gas concentration in soil of oil field area in Mizoram to the world average radon concentration. To achieve our goal the objectives of the study will include the following:

1. To determine the radon mass exhalation rate of the soils collected from all the six oil exploration areas by using Smart RnDuo (Radon detector), and to draw a graph between Slope of radon concentration and radon mass exhalation rate.

2. To measure the soil radioactivity of soil samples collected from oil field area.

3. To measure the background gamma radiation and GPS coordinate.

4. To identify soil type and find the grain size of the soil samples collected.

5. To measure the uranium content in water and radon content in water from all the nearby runing water source and to correlate the same.

6. To perform an *in-situ* measurement of radon concentration at different baptism depth of all the six oil exploration areas in Mizoram and to study the nature of radon gas concentration.

7. To draw the correlation graph between rodon concentration at different depth with ground level background gamma radiation of all thestudy area.

This research work may be helpful in learning the radon concentration in soil of all the oil field areas of mizoram. This will also help in finding the health safety levels of the general public of the study area. The result will also be compared with the findings by other researchers. Depending upon the level of radon concentration observed, further studies may also be conducted.

2

Theory, Instruments And Experimental Methodology

This section of the research work covers the entire theories involved. Firstly, the description of the present study area is highlighted followed by the instruments engaged, its specifications and detail functioning are discussed. Necessary procedure involved in the measurements is highlighted as well. This will provide a comprehensive insight and technique of detectors, equipment, and measurement principle of the instruments used for the measurement of Radon and Uranium from drinking water and soils.

To measure the radon gas in soil and water, a Smart RnDuo detector is used. The radon concentration in water and exhalation from the soil is calculated from the obtained experimental data. The measurement of activity concentration in the soil is carried out using a Thallium (Tl) activated 5"× 4" Sodium Iodide (NaI) detector. By detecting and measuring trace quantities of uranium present in aqueous samples, uranium concentration in water is easily measured using LED Fluorimeter LF-2a. Background gamma detection is carried out with Gamma Survey Meter PM 1405 based on Geiger-Muller counter by a transformation of photon to electro-pulses and Sieve shaker is used to analyze the soil type and grain sizes of the soil samples collected from each location of a particular oil exploration areas.

2.1 Study area

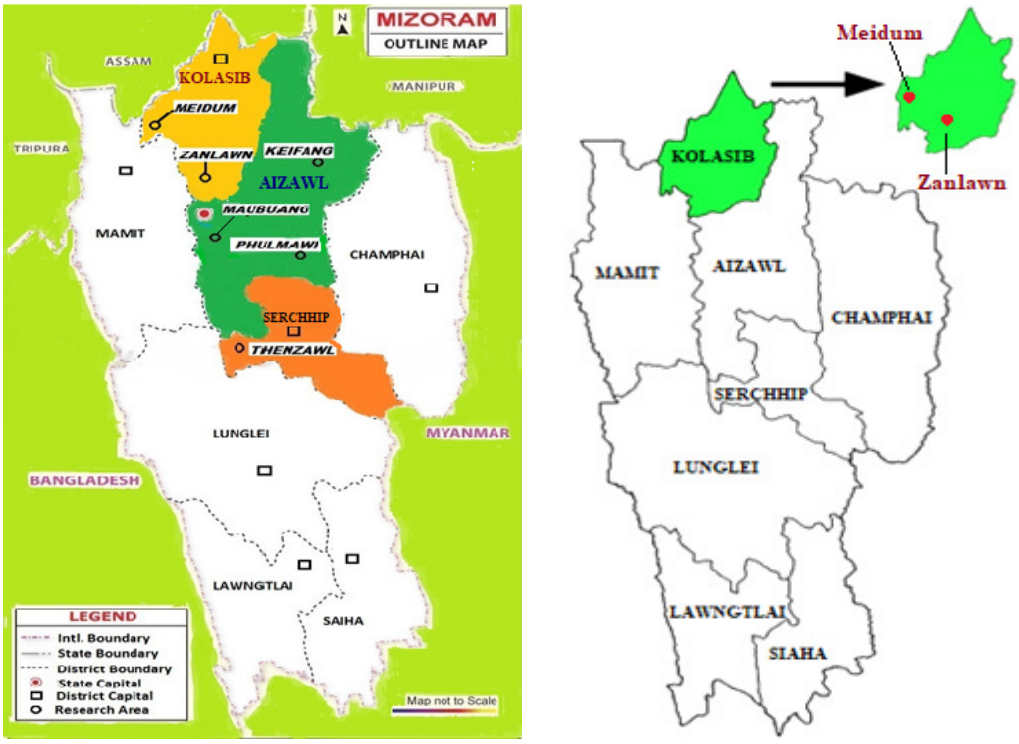
Mizoram is located in the North Eastern part of India neighbouring the states of Manipur, Tripura and Assam. It has an international boundary with Bangladesh and Myanmar as well. Eighteen different spots are chosen from the existing six oil

exploration areas in Mizoram. These oil exploration areas are located at three different districts.

The detailed description of the chosen spots against their respective districts are discussed below.

2.1.1. Kolasib district:

Two oil fields are chosen from Kolasib district for the present study. The two chosen oil fields are situated at Meidum and Zanlawn villages respectively. Meidum oil field area stretches from 24º10'11.8"N to 24º10'12.9"N and between 92º35'55.4"E to 92º35'58.8"E with an elevation range of 291ft to 331ft from sea level. And that of Zanlawn oil field area stretches from 23º59'01.0"N to 23º59' 02.6"N and between 92º42'47.8"E to 92º42'50.8"E with an elevation range of 2110 ft and 2900 ft from sea level. Fig.3.1 shows the location map of all the oil exploration areas in Kolasib district.



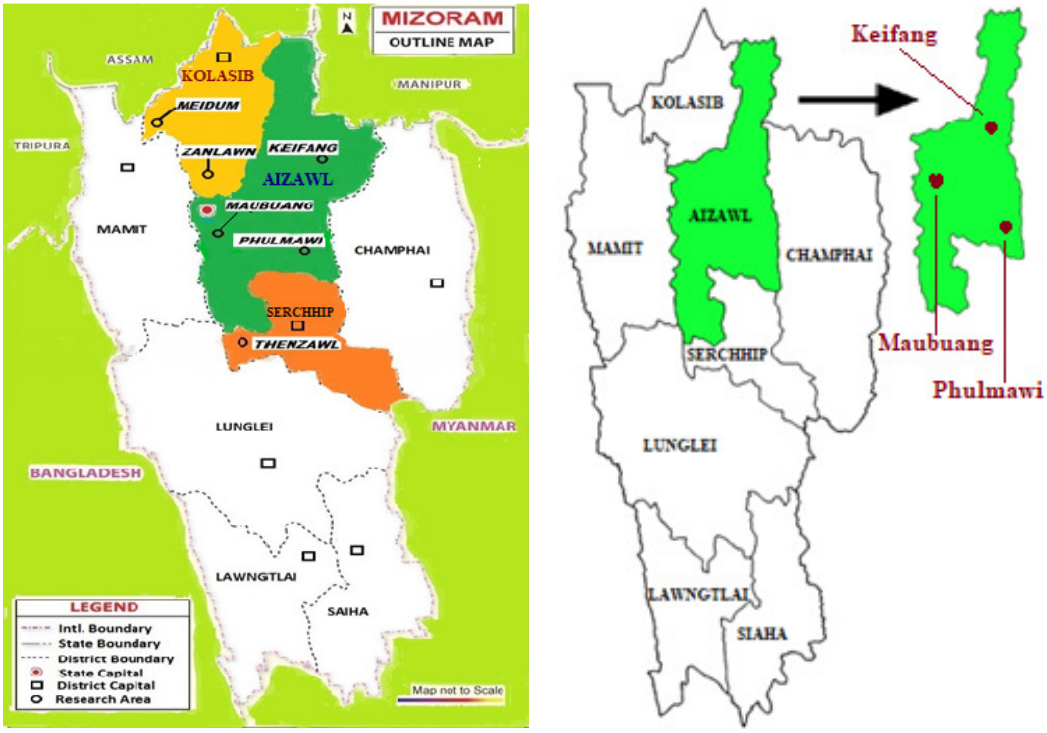
(a) (b)

Fig. 2.1.(a): Map of all the oil exploration areas in Mizoram

2.1.(b): Location of oil exploration areas in Kolasib district

2.1.2. Aizawl district:

Three oil fields are chosen from Aizawl district for the present study. The three chosen oil fields are situated at Phulmawi, Maubuang and Keifang villages respectively. Phulmawi oil field area stretches from 23º35'29.9"N to 23º35'33.1"N and between 92º51'23.0"E to 92º51'25.0"E with an elevation range of 2900 ft and 2956 ft from sea level; that of Maubuang oil field area stretches from 23º29'42.7"N to 23º29' 47.3"N and between 92º42'3.6"E to 92º42'5.8"E with an elevation range of 2870 ft and 2885 ft from sea level and that of Keifang oil field area stretches from 23º39'12.5"N to 23º39'14.2"N and between 92º57'0.9"E to 92º57'1.7"E with an elevation range of 2915ft to 2927ft from sea level. Fig.3.2 shows the location map of all the oil exploration areas in Aizawl district.



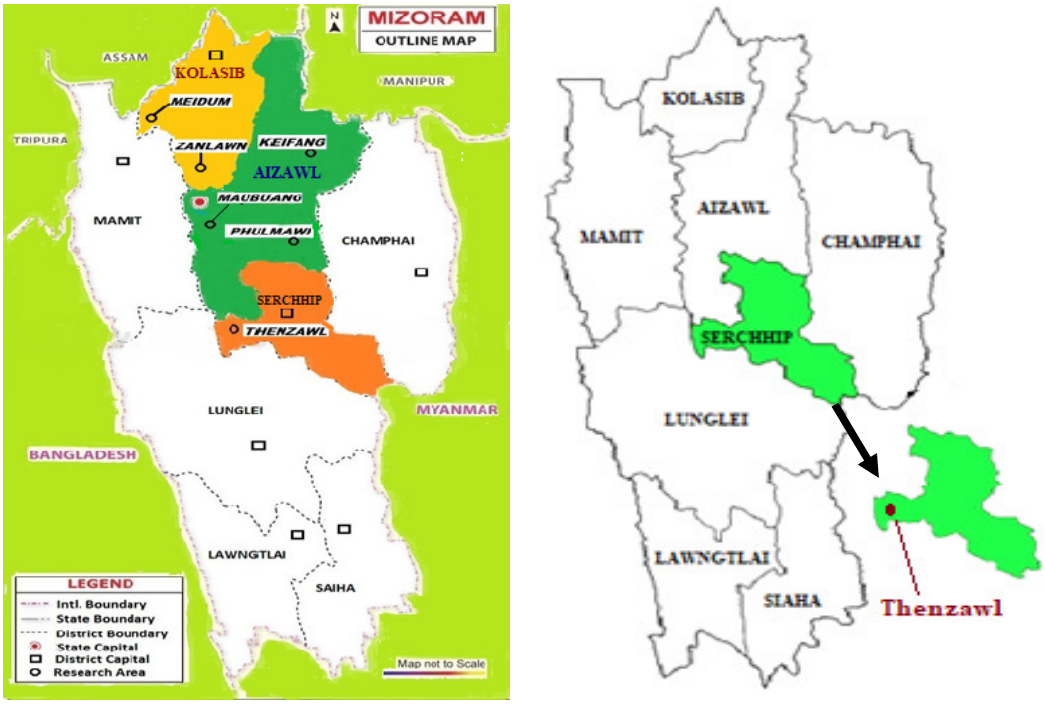
(a) (b)

Fig. 2.2.(a): Map of all the oil exploration areas in Mizoram

2.2.(b): Location of oil exploration areas in Aizawl district

2.1.3. Serchhip district:

One oil field was chosen from Serchhip district for the present study, namely the Thenzawl oil field area. Thenzawl oil field area stretches from 23º18'08.3"N to 23º18'12.4"N and between 92º42'5.8"E to 92º47'11.9"E with an elevation range of 2454 ft and 2483 ft from sea level. Fig.3.3 shows the location map of the oil exploration area in Serchhip district.



(a) (b)

Fig. 2.3.(a): Map of all the oil exploration areas in Mizoram
2.3.(b): Location of oil exploration area in Serchhip district

2.2. Measurement of background Gamma radiation:

The background gamma radiation detection is carried out with Gamma Survey Meter PM 1405 on the basis of Geiger-Muller counter by a transformation of photon to electro-pulses. The instrument is manufactured by a Russian based company called Polimaster who specializes in manufacturing radiation measurement and detection

devices. Survey Meter analyses the level of beta radiation flux from contaminated areas of gamma and X-ray equivalent ambient exposure levels. Instrument warns the operator with audible warnings when the preset radiation levels are reached, and records each detected count in a search mode with an audio signal. A large energy-compensated GM tube for accurate measurement of the ambient equivalent dose rate of X-ray and gamma radiation in the range from background to 100 mSv / h (10 R / h) is integrated into the Survey Meter.

Fig. 2.4: Gamma Survey Meter PM 1405

After opening the special screen-filter and selecting beta-radiation flux density measurement mode, the instrument enables to estimate the surface exposure level of different environmental objects from beta radiation sources. The instrument is compact in size and has a lightweight, large LCD backlight display, audible warning, and non-volatile memory.

2.2.1. Technical Specification:

Detector	: Geiger-Muller counters
Dose equivalent rate (DER) measurement range	: 0.1 μSv/h – 100 mSv/h
DER indication range	: 0.01 μSv/h – 130 mSv/h

DER measurement accuracy	: ± (20 + K/H) %, where Ḣ – dose rate, μSv/h K - coefficient 1.0 μSv/h
Dose equivalent (DE) measurement range	: 1.00 μSv – 10.0 Sv
DER indication range	: 0.01 μSv – 10.0 Sv
DE measurement accuracy	: ± 20 %
PC communication	: USB interface

Actual Measurements is carried out at ground level as well as at 1 meter above the ground level so that background gamma radiations coming from cosmic and terrestrial sources are detected. The instrument's operating algorithm ensures continuity of the measurement process, static handling of measurement results, fast adaptation to radiation rate changes and effective output of the information obtained on the LCD. The measurement range for gamma radiations is between the ranges of $0.1\mu Svh^{-1}$to $100mSvh^{-1}$. Latitudinal and Longitudinal coordinates is also carried out by Global Positioning System (GPS) device at each sampling site.

2.3. Surveillance of location using Global Positioning System (GPS) :

Global Positioning System (GPS) is a navigation revolution. It is a technology that pinpoints a user's location anywhere in the world, 24 hours a day, regardless of the weather.

GPS consists of a constellation of 24 satellites orbiting some 12,000 miles above the earth. These satellites transmit signals containing time and orbital data to calculate satellite position and almanac data. Meanwhile, receivers used on the ground, sea and air search the sky for the satellites. The GPS unit needs to acquire good signals from at least three satellites to determine a position on the surface of the earth. A fourth signal is required to get three-dimensional positioning which determines elevation or altitude.

Fig. 2.5: Garmin GRB 21 GPS tracking device

2.3.1. Technical Specifications:

Physical:

Case	:	Fully-gasketed, high-impact plastic alloy, waterproof to IPX7 standards (waterproof to 1 meter for 30 minutes)
Size	:	4.4”H x 2”W x 1.2”D
Weight	:	Approx. 5.3 ounces(150g) w/batteries

Temperature Range: 5^{o} to 158^{o} F (-15^{o} to 70^{o}C)[3] (operating)

Performance

Receiver	:	Differential-ready, 12 parallel channel
Acquisition time	:	Approx. 15 seconds (warm start) Approx. 45 seconds (cold start) Approx. 5 minutes (First Time/AutoLocate^{TM})
Update Rate	:	1/second, continuous
Position Accuracy	:	0.1 knot RMS steady state
Dynamics	:	Performs to specifications to 6 g’s

Interfaces	:	NMEA 0183 (versions 2.00-2.30), RTCM 104 (for DGPS corrections) and RS-232 for PC interface
Antenna	:	Built-In
Power		
Input	:	Two 1.5-volt AA batteries[3]

Specifications subject to change without notice.

1) With optional Garmin Differential Beacon Receiver Input (such as Garmin GRB 21).
2) Subject to accuracy degradation to 100m 2DRMS under the U.S. DOD0 imposed Selective Availability program.
3) The temperature rating for the eTrex may exceed the usable range of some batteries. Alkaline batteries can rupture at high temperatures. External power can only be applied using the Garmin Auto Power Adapter or PC Interface Cable with Auto Power Adapter (This cable contains a voltage regulator). Modifications or other applications will void the product warranty.
4) Alkaline batteries lose a significant amount of their capacity as temperature decreases. Use lithium batteries when operating the eTrex in below-freezing conditions. Extensive use of screen backlighting will significantly reduce battery life.

2.4. Soil Type and Grain Size Determination using Sieve Shaker

Radon mass exhalation rate is found to be greatly affected by the soil moisture content. Different types of soil have different grain size, and the grain size determines the ability for soil to retain moisture. Therefore, identification of soil type and grain size determination is an important factor in this regard.

For identification of soil type using the process of sieving, a Mechanical Sieve Shaker was employed to enable quality assurance of the result (Figure 2.6(c)). This is because mechanical parameters such as sieving time, speed and amplitude are carried out with exact reproducibility in a Mechanical Sieve Shaker.

Fig. 2.6: Dressing of soil samples for Soil type and Grain size study-
(a) Drying of soil samples, (b) Different sieves with digital balance
(c) Mechanical sieve shaker, (d) Different sieves

Collected soil samples were dried and placed in the uppermost sieve in a set of stacked sieves. The stack of sieves was arranged in order so that the coarsest sieve is at the top with finer ones below. A pan was placed at the bottom of the stacked sieves to catch any sediment that passes through the lowest and finest sieve. The stack of sieves was then placed on the shaking machine for about 15 to 20 minutes.

Five different sieves of sieve mesh number, namely, 60 (grain size 0.25 mm which corresponds to medium sand), 120 (grain size 0.125 mm which corresponds to

fine sand), 230 (grain size 0.0625 mm which corresponds to very fine sand), 325 (grain size 0.044 mm which corresponds to silt/mud) and >325 (grain size smaller than 0.044 mm which corresponds to clay) was used to identify the grain size distribution.

The soil that had collected on each sieve was then removed and the weight taken. Percentage of the grain size distribution obtained was then plotted using a triangular plot. The triangle plot consists of three main primary classifications, namely, sand, silt and clay. These three classifications are further divided into 12 classes. A triangular plot, called the USDA triangle was employed for this purpose (García-Gaines *et al*, 2015). The different grain size obtained in this study were named in accordance with the Udden-Wentworth size term (Wentworth, 1922).

2.5. Measurement of soil radioactivity using NaI(Tl) Detector:

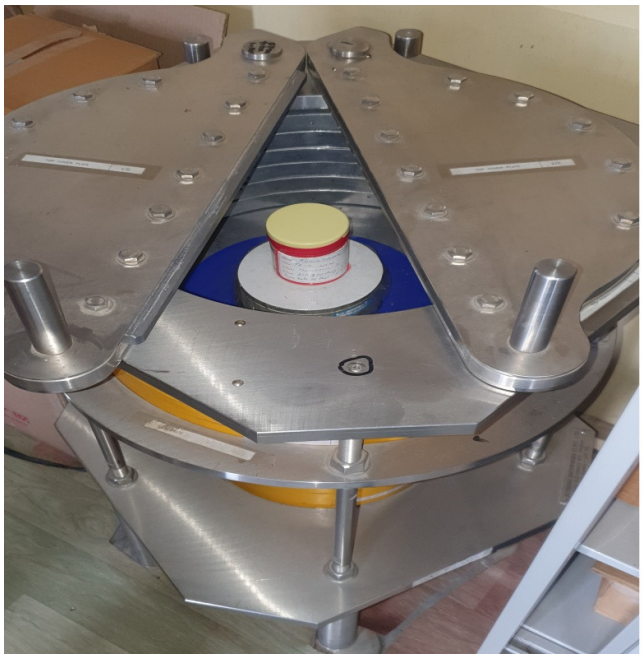
Level of Radium present in the soil is usually defined by activity per dry unit (Bq/kg). The most efficient and precise approach commonly used for the determination of natural radionuclides is by means of gamma spectrometry in previously processed, powdered and sealed individual samples in small plastic containers with a specific orientation (Nazaroff *et al*., 1988). Radioactivity evaluations of the soil samples based on gamma ray spectrometry essentially rely on gamma emissions of different radionuclides in the ^{232}Th and ^{238}U radioactive decay chain. While both of these two series' daughter products are radioactive, they do not all emit strong gamma-rays. Based on its emission capacity, it is possible to easily classify the specific gamma emissions.

Gamma emissions in the series ^{232}Th and ^{214}Bi and ^{214}Pb in those series ^{228}Ac, ^{212}Pb, ^{212}Bi and ^{208}Tl are useful not only to classify radionuclides, but also for their activity estimation. The samples were kept sealed for one month in order to confirm a secular natural equilibrium between ^{226}Ra and ^{228}Th and its components. The logical explanation is that the gaseous daughter products in ^{220}Rn and ^{222}Rn in ^{232}Th and ^{238}U series respectively decay in radionuclides with a half-life of 55 seconds or 3.8 days. The gaseous daughters will be lost, and if the container is not air tight measurements

would have an error. Regardless of this, the sample containers are kept sealed so as to avoid ^{220}Rn and ^{222}Rn leak out. In measurement of soil radioactivity using NaI detector, standard sources required for both efficiency calibration as well as detector energy require special attention. Since the geometry of standard sources affects the attenuation factor for gamma rays, standard sources are required to have similar matrix and geometry with the soil samples for efficiency calibration, but for energy calibration standard sources can be of any matrix. Hence, in specific geometries of known concentration, standard sources were also prepared to minimize the error in the estimation of activity.

Energy calibration is performed to distinguish the various radioisotopes inside a sample. The linear dependence principle is applied between channel number and energy. The gamma-ray spectroscopy system's energy calibration requires the relationship between the energy deposited by the Gamma ray in the detector and the amplitude for the corresponding amplifier pulse. In terms of channel number, the pulse amplitude is calculated with the multichannel analyzer. The calibration of energy is also used to establish the photo peak resolution and the location of areas of concern (ROI). The standard ^{137}Cs (661.62 keV) and ^{60}Co (1173.24 keV and 1332.46 keV) sources are used for energy calibration. The standard samples were measured for 500 seconds and the computer program calibrated with the linear fit. Detector efficiency versus energy curve is experimentally developed using standard sources to calculate radioactivity (Bq) of a particular radionuclide. For 10,800 seconds, IAEA standard RGTh-1, RGU-1 and RGK-1 samples with known activity have been counted. The efficiency values for different energy sources have been determined using the formula using known activity and gamma rays for particular energy. In the present work, Gamma Ray Spectroscopy System called GSPEC-SA coupled with NaI (Tl) detector of size 5"× 4" is used to determine the radioactive content of the soil sample and building materials as shown in Figure 2.7.

(a)



(b)

Fig. 2.7. (a). Horizontal view of Sodium Iodide, NaI (Tl) detector
(b). Vertical view of Sodium Iodide, NaI(Tl) detector

GSPEC-SA is a 1K Multichannel Analyzer with HV Supply and Spectroscopy Amplifier instrument.

Fig. 2.8: GSPEC-SA

The GSPEC-SA is the main operated instrument for NaI(Tl) detector based spectroscopy. It contains 1024 channel 48 MHz Wilkinson ADC with Si lab Microcontroller for USB interface with PC for spectrum acquisition and data processing. Data acquisition software is loaded on PC / Laptop and provides spectrum acquisition and display, spectrum analysis software for energy calibration, ROI selection, area calculation, peak search, peak information, spectrum smoothing and spectrum data storage on PC hard disk. High voltage supply necessary to operate scintillation detector is software programmable from 0 to 1200 volts in 256 steps.

2.5.1. Calibration of NaI (Tl) Detector:

The Multi-Channel Analyzer was pre-calibrated with Standard sources Cesium-137 (^{137}Cs) having energies 661.99 keV and Cobalt-60 (^{60}Co) having energies 1173 keV and 1332 keV. The system was calibrated to detect the energies between 0 keV and 3000 keV using the following settings. For efficiency calibration, IAEA standard source of ^{238}U, ^{232}Th and ^{40}K (Figure 2.9) with known activity was analyzed using the GSPEC-SA multichannel analyzer for a period of 10800 seconds (3 hours). This calibration established the detection efficiency of the detector as a function of the energy of radiation. To minimize error due to attenuation of gamma radiation, all the three standard sources were prepared in similar geometry as well as matrix. Also, to

avoid coincidence summing of the gamma rays, a gamma ray standard of the same radionuclide as the one to be monitored was used (Agarwal, 2011).

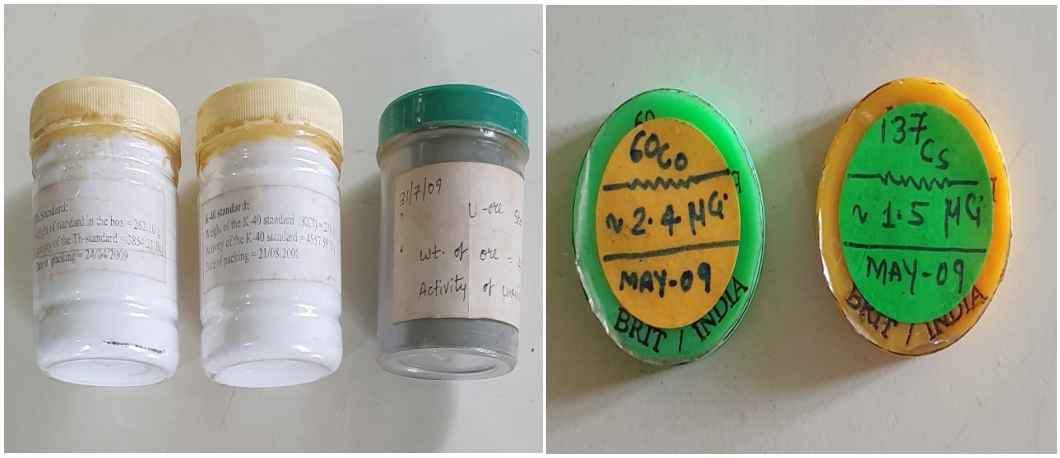


Fig. 2.9: IAEA Standard Sources for Energy and Efficiency Calibration

In order to measure the soil radioactivity, the soil samples are dried and heated using a heater at a temperature of about 110°C. The samples are then grinded into powder size and was sieved using a 500 μm mesh. It is sealed inside an air-tight container (about 250 ml) and kept undisturbed for a minimum period of 30 days to attain radioactive equilibrium. The measurement of activity concentration of ^{238}U, ^{232}Th, and 40K in the soil samples collected is carried out by using Thallium (Tl) activated 5" X 4" Sodium Iodide (NaI) detector. The detector will be connected to a GSPEC-SA (Version 2.5 X).

Table 2.1 shows the initial settings of the Gamma Ray Spectroscopy Sample Analyzers instrument.

Table 2.1: Initial settings of GSPEC-SA instrument

Gain	HV	LLD	^{137}Cs		^{60}Co		^{60}Co	
			Channel	Energy (keV)	Channel	Energy (keV)	Channel	Energy (keV)
6	650	1	231	661.9	403	1173	455	1332.01

2.5.2. Efficiency calibration of NaI (Tl) Detector:

The gamma ray photon emitted from the radioactive decay chain of the standard sources undergo various types of interactions with the detector, thus leading to a complex detector response of continuous energy distribution, having certain full energy peaks. This continuous energy distribution is due to part absorption of the photon energy inside the detector volume, while the remaining photon energy escapes from the detector. The full energy peaks arise due to the complete absorption of gamma photons within the detector, either by the photoelectric effect or by various multiple interactions. For the gamma energy peak obtained, the efficiency was calculated using the formula:

$$\eta(\%) = \frac{Area/\sec}{dps} \times \frac{100}{Ab\%} \times 100 \qquad (2.1)$$

Where,

$\eta(\%)$ = Percent Efficiency

$Area/sec$ = Net peak area second (back-ground subtracted)

dps = Source strength

$Ab\%$ = Gamma ray abundance factor

Before measuring the natural radioactivity present in a sample, a three-point energy calibration was carried out using sources containing a mixture of radionuclide (ISO 18589-3:2007(E)). In this study, the energy calibration is achieved by counting given standard sources of ^{60}Co and ^{137}Cs for a period of 500 seconds. This calibration allows the establishment of the relationship between the channel numbers of the analyzer and the known energy of the photons (BIPM, 2004). Three photo peak areas were obtained and after analysis of the region of interests (ROI's), the necessary calibration was performed by inputting the obtained data into the computer software.

2.5.3. Determination of soil radioactivity:

The weights of the samples were measured and the activity concentration (A) was obtained (in Bq/kg) for each samples using the formula:

$$A = \frac{N}{T} \times \frac{100}{\gamma\%} \times \frac{100}{\eta\%} \times \frac{1}{Wt} \quad (2.2)$$

where,

$\frac{N}{T}$ = Background subtracted net photo peak counts in time 'T'

γ = abundance of gamma ray under consideration

η = absolute detection efficiency obtained from the energy efficiency calibration

Wt = weight of the sample

2.5.4. Determination of Radium Equivalent Activity:

The Uniformity of natural radioactivity in soil with respect to exposure to radiation has been defined in terms of Radium equivalent activity (Ra_{eq}) to compare the specific activity of materials containing different amounts of 226Ra, 232Th and 40K. The activities of these elements have been measured using the NaI (Tl) detector. Using the activity calculated of these elements radium equivalent activity is calculated using the following equation (Mehra *et al.,* 2009).

$$Ra_{eq} = C_{Ra} + 1.43C_{Th} + 0.07C_K \quad (2.3)$$

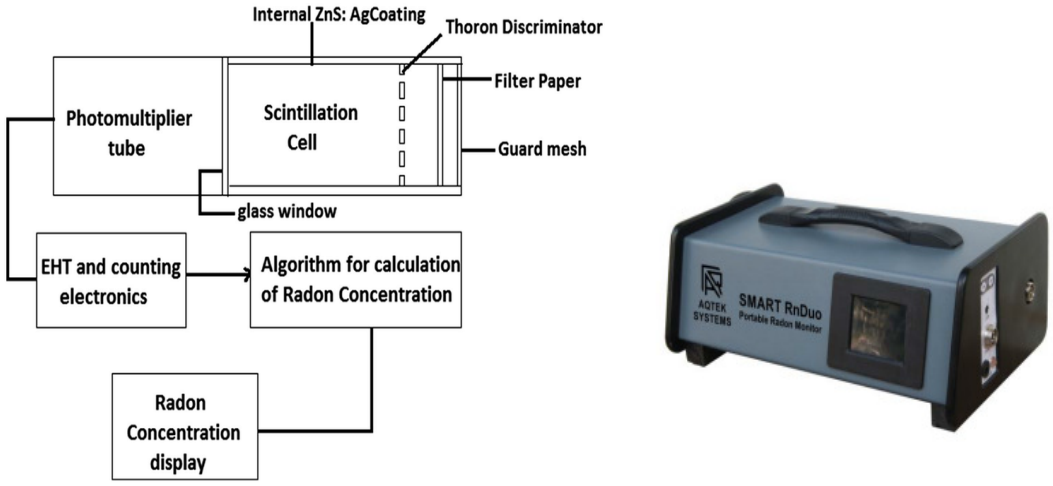
Where, C_{Ra}, $C_{Th,}$ and C_K represents the activity concentrations of ^{226}Ra, ^{232}Th, and ^{40}K (Bq/kg) respectively. While defining Ra_{eq} activity, it has been assumed that 370 Bq/kg for ^{226}Ra or 259 Bq/kg for ^{232}Th or 4810 Bq/kg for ^{40}K produces the same gamma dose rate.

2.6. The Smart RnDuo:

The advanced Smart RnDuo is manufactured by Bhabha Atomic Research Centre, Mumbai, India for the measurement of radon (^{222}Rn) and thoron (^{220}Rn) concentration in air, water, and soil. It is an advanced continuous portable detector designed for multiple purposes of ^{222}Rn and ^{220}Rn analyses and hence the name RnDuo (Duo since it is capable for two purposes). The measurement of radon in RnDuo is based on the detection of alpha particles emitted from radon and its decay products formed within the volume of the scintillation cell. The PMT and corresponding counting electronics continuously count the alpha scintillations from radon and its decay products produced within the cell.

For the assessment of radon, the sample gases are stored in a scintillation cell (150cc) by diffusion. During diffusive sampling, the gas passes through the "progeny filter" and "thoron discriminator" which removes radon/thoron progeny and thoron. The measurement of radon in RnDuo is based on the detection of alpha particles emitted from radon and its decay products formed within the volume of the scintillation cell. The PMT and corresponding counting electronics continuously count the alpha scintillations from radon and its decay products produced within the cell.

Due of varying radon concentrations, the build-up and degradation of radon decay products within the scintillation cell is complex and they never attain equilibrium with radon. As a result, automatic continuous monitoring of radon was not feasible without taking into account the activities of the decay product.



(a) (b)

Fig. 2.10. (a) Schematic diagram of the Smart Radon Monitor (SRM)
(b) Photograph of the Smart Radon-Thoron Monitor (RnDuo)

For the efficient implementation of scintillation technology to continuously calculate radon concentration a sublime algorithm was developed at BARC. The technique is based on the conceptual decay and development of radon decay products during the on-going cycle of measurement and from previous radon concentration. The alpha counts acquired are interpreted by a microprocessor unit to show the radon concentration according to the established algorithms. The thoron discriminator based on the "diffusion-time delay" does not allow the short-lived thoron (half-life of 55.6 s) to pass through extensively.

It may also be pointed out that RnDuo has several advantages over the existing solid-state alpha-spectroscopy (AST) technique with its alpha scintillation technology. With radon the procedure is more sensitive than the procedure of alpha spectroscopy. More specifically, the measurements using the scintillation detector are unaffected by the quantities of humidity and trace gas present in the sample air. The RnDuo technical specification is given in the table.

Technical specifications of RnDuo:

Detector type	: Scintillation cell
Scintillation coating	: Internally coated ZnS:Ag

Scintillation cell active volume	: 153 cm^3
Radon sensitivity	: 1.2 CPH/(Bq/m^3), 44.5 CPH/(pCi/L)
Thoron sensitivity	: 0.8 CPH/(Bq/m^3), 30 CPH/(pCi/L)
Sampling type	: Diffusion / Flow
Sampling flow rate	: 0.5 to 0.7 L/min with inbuilt pump
Measurement cycle time	: 15 / 30 / 60 min
Response time	: 15 minutes for attaining 95% of radon / thoron

Minimum detection limit

Radon	: 8 Bq/m^3 at 1 σ and 1 h cycle
Thoron	: 15 Bq/m^3 at 1 σ and 1 h cycle
Upper detection limit	: 50 MBq/m^3
Effect of sample humidity and trace gases on sensitivity	: Practically nil until humidity is not condensed on scintillation surface.
Thoron interference	: < 5% with sniffing mode of sampling
Power	: Ext. 110- 240 V AC 50/60 Hz ,Internal 6 V DC Battery
Dimension	: 37 cm x 20 cm x 12 cm

RnDuo is used for measurements and reports of radon concentration in real-time and makes use of alpha from radon and also it's decay products fraction 218Po and 214Poformed inside detector volume originated from current radon activity. ZnS:Ag scintillation screens are easily replaceable. There is no effects of humidity and trace gas content in sample gas on measurements and sample drying not required even in the case of radon in water measurement. No electronic component or high voltage in detector volume. There is also no chance of damage to PMT or electronics by the entry of water or chemical vapours in scintillation cell volume. The scintillation cell can be replaced quickly and at ease. Data can be transferred using USB port of PC over a short distance or long distances using RS485 which is used for high speed data transfer.

2.7. Measurement of Radon Mass Exhalation rate from soil using Smart RnDuo:

The measurement of radon mass exhalation rate in collected soil samples was carried out by using a scintillation based radon monitor Smart RnDuo. RnDuo is an advanced portable continuous radon/thoron monitor, whose detection principle is based on detection of alpha emitted from radon and its decay products formed inside a scintillation cell volume, and has multiple applications in radon and thoron studies (Amanjeet *et al,* 2018*)*. The instrument consists of a progeny filter and a thoron discriminator which eliminates radon/thoron progenies and thoron from entering the scintillation chamber. The alpha scintillations from radon and its decay products formed inside the cell are continuously counted by the PMT and the associated counting electronics. The instrument has an in-built algorithm to continuously measure radon concentration. The measured radon concentration is then processed by a microprocessor unit as per the developed algorithm to display the concentration of radon (Fig. 2.11 & Fig. 2.12).

Fig. 2.11: Mass exhalation chamber

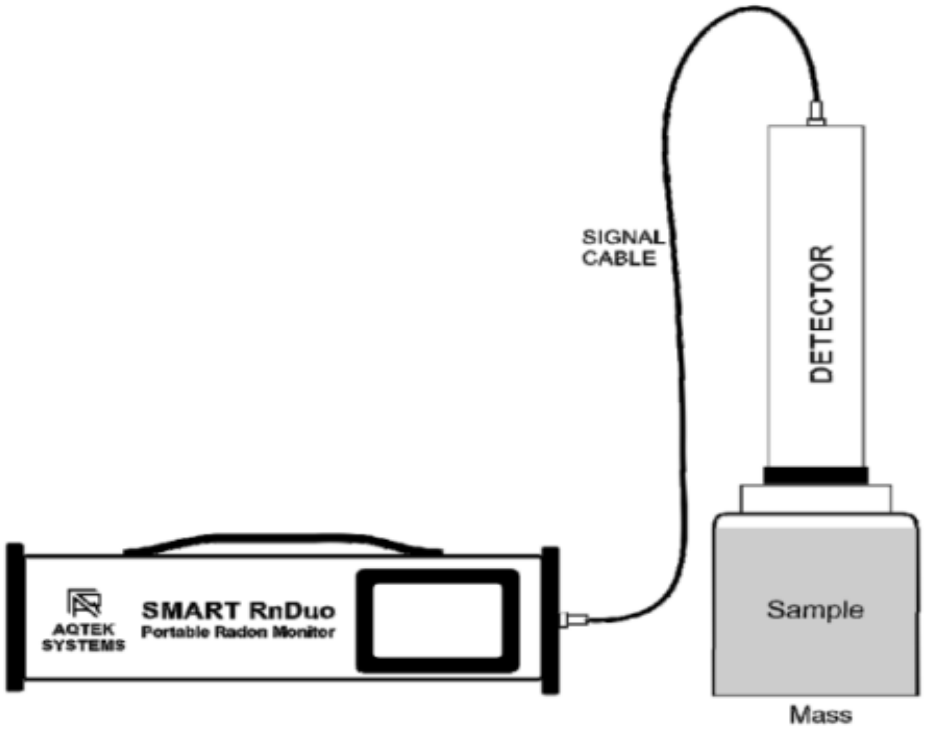


Fig. 2.12: Measurement of radon mass exhalation from soil

2.7.1. Protocol for measurement of Radon Mass exhalation:

1) 'Mass Exhalation Chamber' provided with the Smart RnDuo measurement device is used for measurement of mass exhalation volume.
2) The used scintillation cell is replaced with a scintillation cell which is retained for at least 3 hours after radon flushing so that it is free from background.
3) The Smart RnDuo is put on, The cycle is set to 1 hour and for Diffusion Mode the Pump is switch off.
4) The Smart RnDuo and the mass exhalation chamber connected and linked using the signal cable as seen in Figure 2.10 for diffusion mode.
5) The quantity of soil in the accumulation chamber should be at the maximum level.
6) After enclosing the soil, the radon concentration build-ups are measured for 1 hour cycle for span of 24 hours.

Radon data is retrieved and the least square fit to equation 2.4 was done using Origin software and the exhalation rate was determined from the curve slope. The first

data was discarded to preclude interaction with the residual radon concentration present in the accumulator.

For measuring radon mass exhalation rate, the sample was first weigh and its volume taken, and then put inside the radon mass exhalation chamber. The detector is then mounted on top of the exhalation chamber (Fig. 2.12), and build up data of radon was retrieved every 60 minutes for a period of about 10- 24 hours. Least square fitting of the data obtained was carried out using the equation (Lekshmi *et al,* 2018):

$$C(t) = \left(\frac{J_m M}{V}\right) t + C_o \qquad (2.4)$$

Where C (t) is ^{222}Rn concentration (Bq m^{-3}) at time t, C_o is the ^{222}Rn concentration (Bq m^{-3}) present in the chamber volume at t = 0, M is the total mass of the dry sample (Kg).

V is the effective volume (volume of detector + porous volume of sample + residual air volume of mass exhalation chamber) (m^3).

Equation 2.4 is nothing but a simple linear equation where $\left(\frac{J_m M}{V}\right)$ is the slope of the graph plotted between the experimentally measured radon concentration, *C(t)* and the measurement time, *t*.

The porous volume (V_p) can be estimated using the following equation

$$V_P = V_s - \left(\frac{M}{\rho_g}\right) \qquad (2.5)$$

Where V_s is the sample volume in the mass exhalation chamber, ρ_g is the specific gravity of the sample and t is the measurement time (h).

On least square fitting of the experimental data using equation 2.4, the slope of the graph is obtained. Using this result, one may obtain the mass exhalation rate, J_M, using the equation:

$$J_m = \frac{(slope)\times V}{M} \quad (2.6)$$

2.8. Smart RnDuo for Radon content in Water:

In the present research work, water sample is collected from any kind of water source available in the nearby area of Oil exploration areas where the main research work is done. The study is conducted by measuring radon content in water by using an instrument Smart Rnduo (Radon Detector). Radon measurement in liquid samples are important for ingestion dosimetry and other studies such as adsorption and partition coefficient determination.

2.8.1. Protocol for measurement of radon concentration in water:

Sampling protocol:

1) Water sample is collected in a leak tight sampling bottle provided with Smart RnDuo system.
2) While sampling into the bottle, caution must be taken to avoid formation of bubble/agitation in the liquid. This is carried out by gently transferring the sample by putting one end of sampling tube inside the tap (or open end of the flowing water) and other end put at the bottom of the sampling bottle held in a bucket or other container.
3) The bottles is filled completely without leaving any air volume, and close tightly avoiding any leakage.
4) The time of sampling was noted and measurement of dissolved radon was done within 4-5 hours after the sampling. The radon gas setup including detector volume was flushed for about 5 minutes with the pump before starting the experiment. After flushing, the sample is attached and the pump is ON again for 2-3 minutes. Then a delay of 5 minutes after turning the pump off and then measurement can be done with a 15 minutes cycle for 1 hour in which the first reading was ignored.

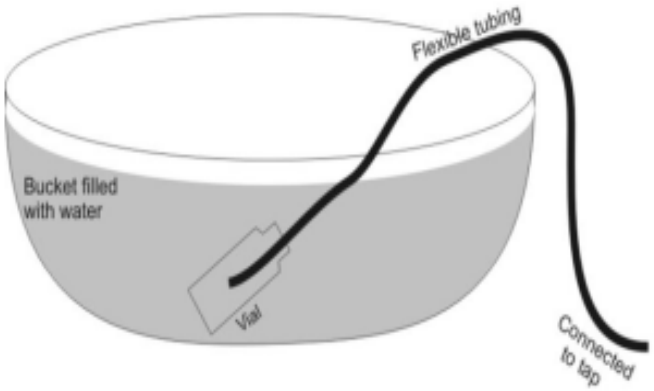


Fig. 2.13. Schematics of water sample collection

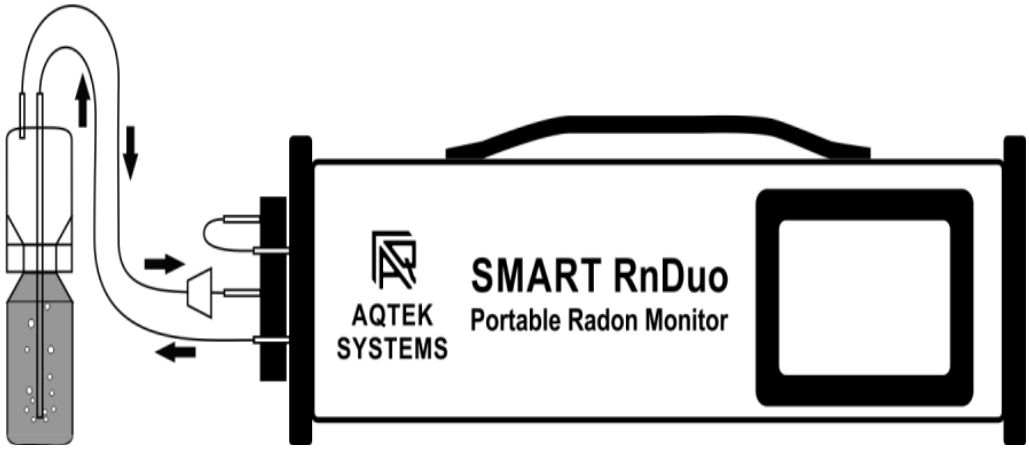


Fig. 2.14. Measurement of Radon content in water using Smart RnDuo

Measurement Protocol:

1) The radon gas in setup including detector volume are flushed for about 5 minutes by putting Pump setting = On in Rn222 mode in open loop.
2) RnDuo is connected with bubbler attachment and to the sampling bottle using flexible tubings.

3) Pump is turned on for 2-3 minutes by putting Pump setting = On in Rn222 mode in closed setup.

4) Measurement is done with 5 minutes delay after the pump is turned off with following configuration in RnDuo

   Mode = Rn222 Pump Settings = Off

   Modify cycle = 15 minutes

5) Measurement was done for a period of about 1 hour. The first reading was ignored and the average values of the later reading were taken as C_{air}.
6) When more than one samples were analyzed continuously, instead of stopping the measurement at the end of 1 hour, the sampling bottle was removed and the set up was flushed for about 5 minutes in open loop (by putting "ON" the pump in RnDuo).
7) After flushing the cell for 5 minutes, the pump was then again turned "OFF" and the measurement procedure described above was repeated for subsequent sample analysis.

After taking measurements for 1 hour a series of four readings for C_{air} was obtained. The first reading is discarded such that any background radon counts from the previous samples does not interfere, the average of the readings were then calculated. The volume of the liquid samples used and also the volume of air enclosed in the closed loop system were then manually measured.

The relation to estimate the radon concentration in liquid (C_{liq}) (Bq/ m^3) from the concentration measured in air (C_{air}) with RnDuo is given by:

$$C_{liq} = C_{air}\left(K + \frac{V_{air}}{V_{liq}}\right) \tag{2.7}$$

where K is partition coefficient of radon in liquid with respect to air (=0.25 for water), V_{air} is volume of air enclosed in the closed loop setup (Bubbler volume + tubing volume + detector volume) and V_{liq} is volume of liquid in sampling bottle.

The radon concentration in the water sample was then calculated using Equation 2.7.

2.9. Measurement of Uranium in water using LED Fluorimeter:

The uranium concentration in water will be measured using LED Fluorimeter LF-2a. The Fluorimeter is an instrument used for detecting and measuring trace quantities of uranium present in aqueous samples such as water. It works on the principle of measurement of fluorescence of uranium complexes in the aqueous sample. Uranium complexes, on excitation with UV light of suitable wavelength, produce green fluorescence, which can be measured by PMT. The Fluorimeter uses, as an excitation source, pulsed UV LEDs emitting at 400nm using suitable filters.

2.9.1. Procedure for determination of uranium concentration in water using LED Fluorimeter:

1) Cuvette chamber, where the cuvette with sample is inserted.
2) Intense pulse UV LEDs, which excite fluorescence in uranium complexes in the sample. A suitable sharp cut off filter transmits only light of wavelengths shorter than 440 nm from the LEDs. Lenses appropriately arranged to focus the LED light on the sample in the cuvette.
3) Detection chamber houses the photomultiplier tube and suitable filters which transmit the fluorescence, but do not transmit the LED light. The photomultiplier tube is kept in off mode when the LEDs are on and is automatically switched on after a delay for a period of about 50 microseconds.
4) The electronics perform the following functions such as precision timing circuits for producing precisely timed pulses in the LEDs. PMT pulser to switch on the photomultiplier tube at the required time for the required duration. Low drift precision Op Amps to process the photomultiplier tube output and LED current monitor output.
5) A Microprocessor based system acquires and process the data. The processing includes averaging of the signals over a large number of pulses, up to 2000pulses, and applying formulae for calculating concentration of uranium from measured fluorescence. The microprocessor also permits recording the temperature of the instrument and date of measurement.

Fig. 2.15: LED Fluorimeter LF-2a.

The LED Fluorimeter LF-2a is capable of measuring uranium concentrations from 0.5 ppb to 1000 ppb with an accuracy of +10% or 0.05 ppb whichever is greater and repeatability of better than +/- 5%.

2.9.2. Technical Specifications:

Analytical Technique	: Fluorescence of uranium salt
Element Analyzed	: Uranium in aqueous medium
Excitation Source	: Light Emitting Diode (LED)
Detector	: Photomultiplier tube
Analyte volume	: Minimum 6 ml
Cuvette	: External size- 12.5mm x 22.5mm x 45mm Made from ultra-low fluorescence fused silica Open top with PTFE lid
Minimum concentration	: 0.5 microgram uranium per litre i.e., 0.5 ppb
Dynamic range	: 0.5-1000 ppb
Accuracy	: 10% or 0.05 ppb whichever is larger
Modes of operation	: Standard Addition Method Calibrated Fluorescence Mode Uncalibrated Fluorescence Mode
Measurement time	: About 1 second for an average of 256 pulses taken five times.

Power Requirements : The unit operates on 12V DC

Power required : About 8 Watts

Firstly the Standard solution prepared by diluting ICP Uranium Standard (ICP-MS-66N-0.01X-1), manufactured by Accu Standard, Connecticut, United States of America. The uranium standard is 100 µg/ml uranium concentrations in 2-5% Nitric acid. The required uranium standard is obtained by diluting standard to about 500 ppb standard using doubled distilled water, the procedures are shown along the observations and result sections. A blank solution is prepared to eliminate effects of any fluoroscencing compounds present in buffer solution. A blank solution is essentially a sample with zero uranium concentration. Blank solution is taken along with each batch during processing of the sample and concentrations observed in the blank solutions were subtracted from each batch of the samples.

The water samples are first filtered using filter paper in order to measure the Uranium concentration. 5 ml of water sample was taken and then 0.5 ml of 5 % Fluren or Buffer solution was added. Fluren or buffer solution in prepared by adding Sodium Pyrophosphate in double distilled water. Orthophosphoric acid is added till the pH level becomes 7. The procedure for preparing Fluren or Buffer solution is given in the result and discussion sections. Buffer solution is added to the samples to increase the fluorescence yields by order of magnitude. This resulted in the formation of the uranyl complex, which was then excited by pulsed lasers and the fluorescence are measured by a photo multiplier tube. All the samples were measured by the standard addition technique. A solution with a 500 (µg/l) mass concentration of uranium was used as the standard for analysis. The concentration of uranium in the sample is calculated using the following formula.

$$U = \frac{D_1}{D_2 - D_1} \times \frac{V_1 C}{V_2} \qquad (2.8)$$

where, D_1 is the fluorescence due to sample alone, D_2 is the fluorescence due to sample and U-standard, V_1 is the volume of U-standard added (ml), V_2 is the volume of sample used for analysis (ml), C is the concentration of U in U-standard solution (µg/l).

All the time it is important to ensure that any other particles interfering with the solution will result in scattering the lights which will result in error. For accurate measurements samples have to be filtered using filter paper. It is advisable to conduct the experiment under a clean aired station laboratory with controlled temperature. The prepared standard solutions must be used immediately since uranium concentrations in standard solutions decreases with time. The containers and pipettes have to be cleaned thoroughly with organic solvents and soap. Then it has to be rinse with double distilled water till the traces of soap disappears.

2.10. *In-situ* measurement of radon concentration in soil with soil probe:

Radon in the pore space of a soil or a NORM residue (e.g. U tailings) matrix is important for estimation of diffusion length and validation of diffusion model. It can be measured using a soil probe coupled with an online radon monitor. The online monitor should have minimum interference from humidity. In this context, Smart RnDuo based soil gas measurement is a good option. The protocol for the measurement of radon gas at different baptism depth of soil is described below.

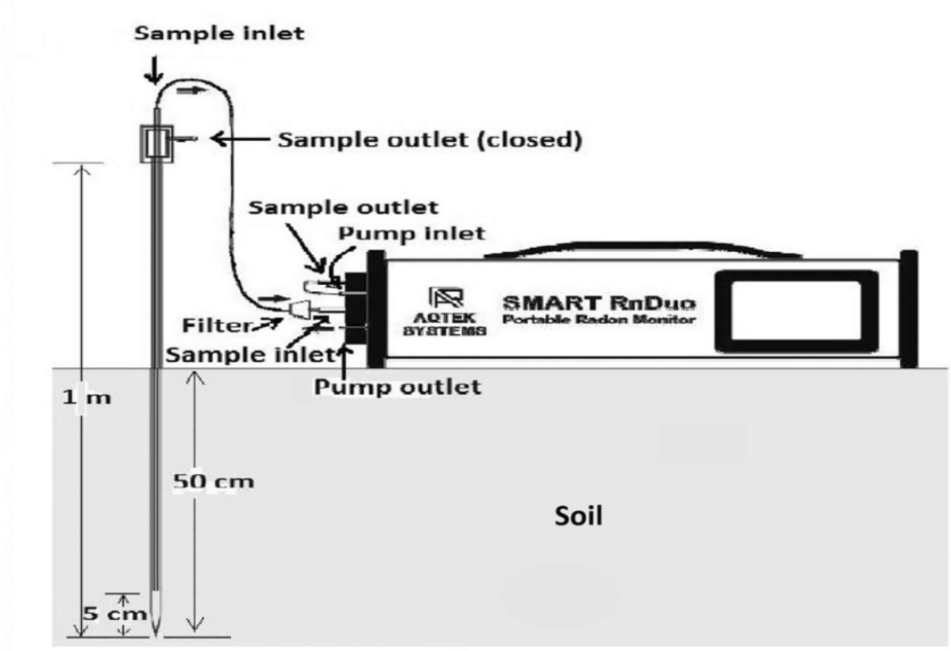


Fig. 2.16: Set-up for *in-situ* measurement of radon in soil

(a) (b)

Fig. 2.17. (a) Soil probe showing the upper end and a wooden hammer.
(b) Soil probe showing the lower end

2.10.1. Protocol for measurement of radon concentration in soil gas:

Deployment Protocol:

1) 'Soil probe' provided with RnDuo system to measure the radon gas concentration in soil pore space is used. Before using the probe we insert the inner pipe in the probe and attach the probe head to it.
2) The soil probe is inserted to the required depth by hammering on the probe head. If the probe faces a greater resistance, there is a possibility of encountering a rock, in which case the insertion location is changed as the probe tip might get damaged.
3) After the probe is inserted to the required depth, the probe head and the inner pipe is removed. The probe head is replaced with the sampling head which is attached with

the inner pipe. It is ensured that the connection of sampling head with probe is leak proof.

4) RnDuo monitor is connected to the inlet port of the soil probe as shown in fig 2.16 using flexible tubing. The outlet port of the probe is closed with rubber cap to seal it.

Measurement Protocol:

1) The pump is turned on manually for 2-3 minutes by putting pump setting=On in Rn222 mode.
2) For measurement of radon the parameter is set up as below and the measurement is started.
3) Mode = Rn222
4) Modify cycle = 15 minutes
5) Pump Setting = Off
6) The measurement is continued up to 1 hour for each depth. The first reading in each case is ignored while taking average.
7) For measurement at subsequent depths the RnDuo monitor is not turned Off, instead the probe is hammered to the next depths level and the measurement procedure given above are repeated.
8) The sequence of measurement is in an increasing order of depth.
9) Measurement of radon concentration in soil is such gas is performed in such a manner that the difference in two depth levels is at least 15 cm to avoid dilution.
10) Ideally the soil gas measurements should be carried out up to a depth of 120 cm. But in the present study, due to difficulties in inserting the soil probe any further depth, the study is conducted at a maximum depth of 70 cm.

Observation and graphs:

1) The concentration of radon soil gas at different baptism depth of soil is studied.
2) A graph of the radon concentration at different baptism depth is plotted.
3) The correlation of radon concentration at various depth with the ground level background gamma radiation is plotted.

3

Determination Of Radon Mass Exhalation Rate, Soil Radioactivity And Soil Grain Size

This chapter capsule a detail description of the study area adopted for performing the different measurements. The measurements include measurement of the radon mass exhalation rate, the measurement of soil radioactivity using NaI(Tl) detector, measurement of gamma radiation and Global Positioning System (GPS), measurement of soil type and grain size, measurement of radon and uranium content in water. The results and observations of these measurements in the study areas are presented.

3.1. Measurement of Radon Mass Exhalation rate:

The measurement of radon mass exhalation rate of the soil sample collected from eighteen different spots of the six different oil exploration areas was carried out. The soil samples are collected from three different spots from one oil field area to cover the entire area. Radon mass exhalation rate is the rate with which radon is releases into the atmosphere from a given mass of soil.

3.1.1. Result of Radon Mass Exhalation rate:

Figure 3.1., 3.2., 3.3., 3.4., 3.5. and 3.6. shows the graph of radon concentrations vs. time in different oil exploration area namely, Meidum, Zanlawn, Phulmawi, Maubuang, Keifang and Thenzawl areas. Although it is suggested that the measurements are to be taken for a duration of 8 - 10 hours (Handbook on Radon Transport Models and Measurement Method, 2017); to get a more accurate result, in the present study, measurement for radon concentration is done for a duration of 22 hours.

The experimental data are fitted using a linear square fitting equation given by Equation 2.4. From the linear fit it is observed that the slopes of the graph increases with time. This indicates that the graph shows a positive correlation.

Figure 3.1. shows the slope of radon concentrations in Meidum area, namely MD-1, MD-2 and MD-3 of Kolasib district respectively. It can be seen that the radon concentration has a positive correlation with time.

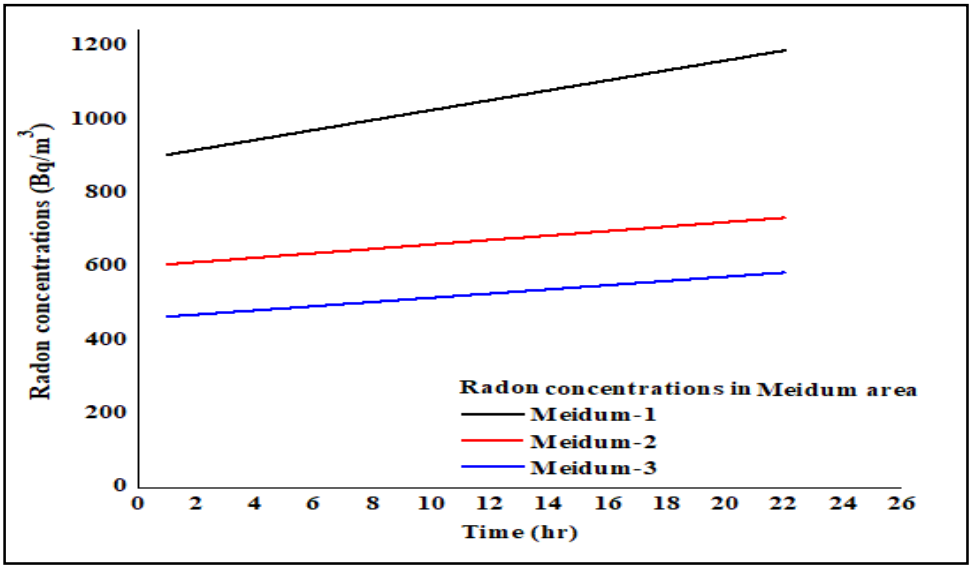


Fig. 3.1. Slope of radon concentration with time of Meidum oil field area.

Figure 3.2. shows the slope of radon concentrations in Zanlawn area, namely ZL-1, ZL-2 and ZL-3 of Kolasib district respectively. It can be seen that the radon concentration has a positive correlation with time.

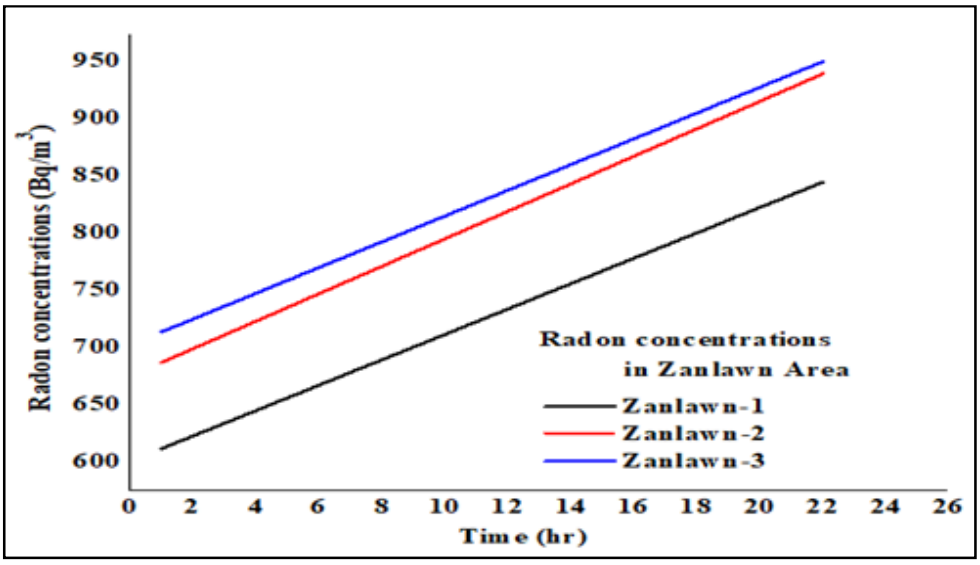


Fig. 3.2. A slope of radon concentration with time in Zanlawn oil field area.

Figure 3.3. shows the slope of radon concentrations in Phulmawi area, namely PL-1, PL-2 and PL-3 of Aizawl district respectively. It can be seen that the radon concentration has a positive correlation with time.

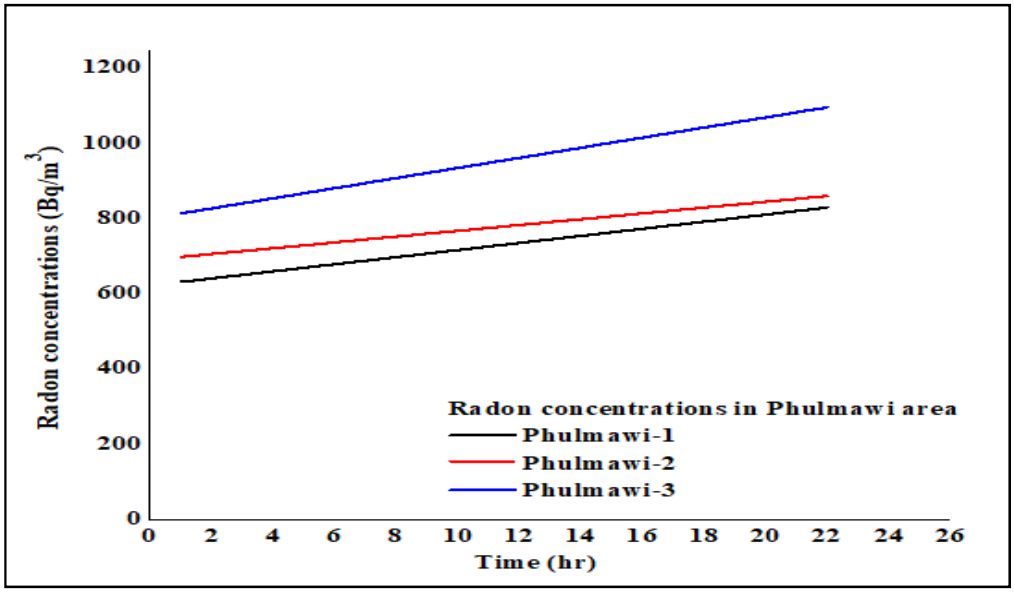


Fig. 3.3. A slope of radon concentration with time in Phulmawi oil field area

Figure 3.4. shows the slope of radon concentrations in Maubuang area, namely MB-1, MB-2 and MB-3 of Aizawl district respectively. It can be seen that the radon concentration has a positive correlation with time.

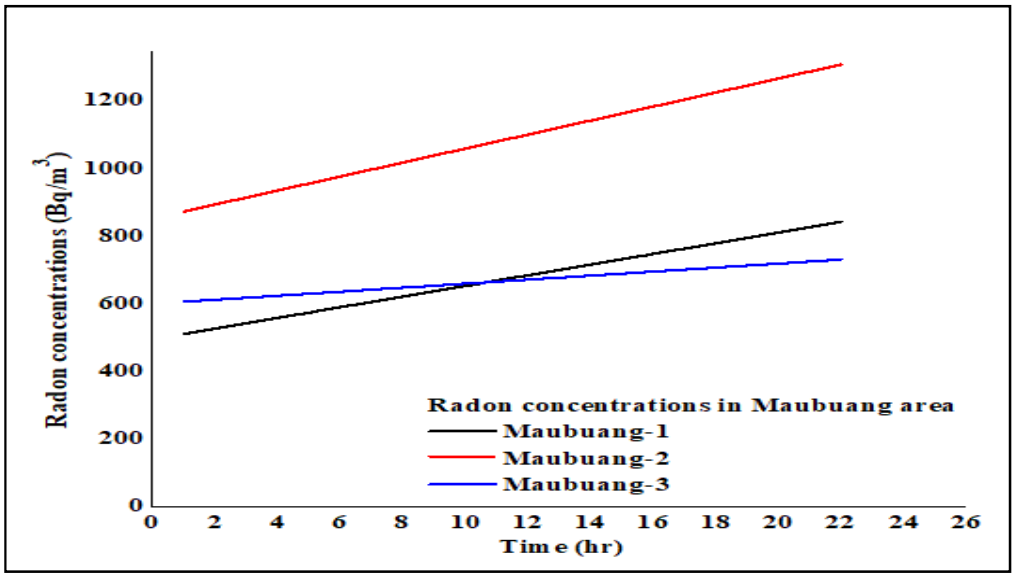


Fig. 3.4. A slope of radon concentration with time in Maubuang oil field area

Figure 3.5. shows the slope of radon concentrations in Keifang area, namely Keifang-1, Keifang-2 and Keifang-3 of Aizawl district respectively. It can be seen that the radon concentration has a positive correlation with time.

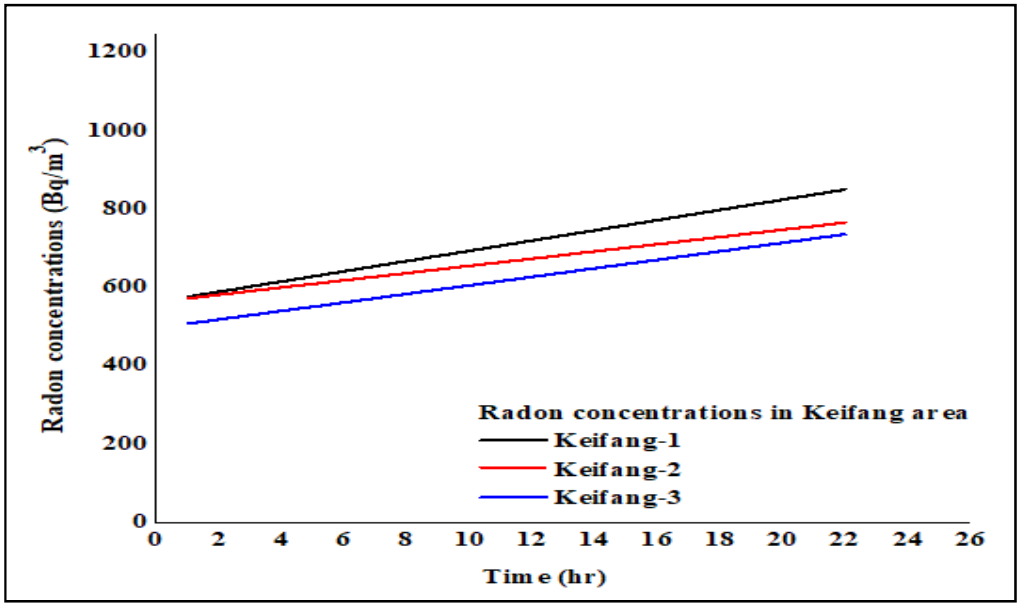


Fig. 3.5. A slope of radon concentration with time in three different spots of Keifang oil field area

Figure 3.6. shows the slope of radon concentrations in Thenzawl area, namely Thenzawl-1, Thenzawl-2 and Thenzawl-3 of Serchhip district respectively. It can be seen that the radon concentration has a positive correlation with time.

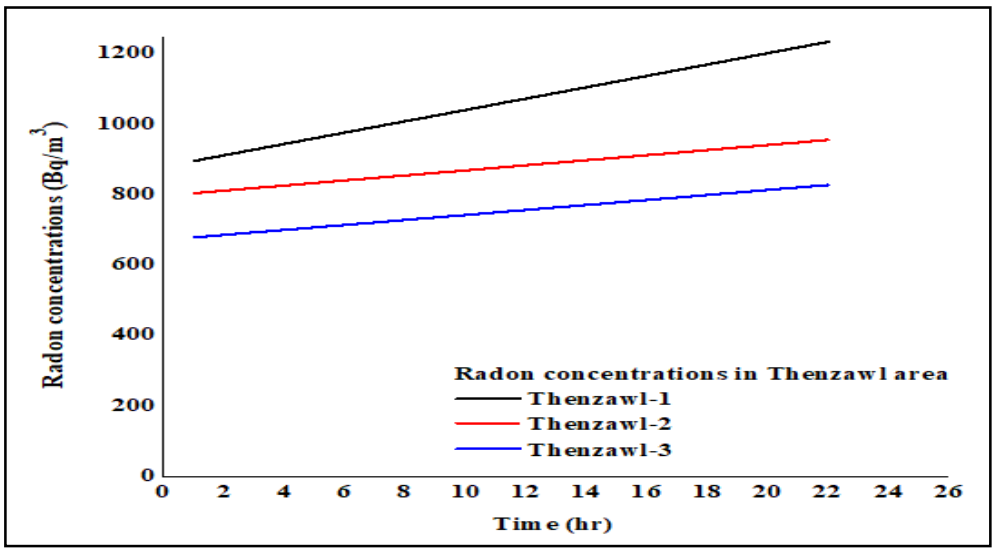


Fig. 3.6. A slope of radon concentration with time in Thenzawl oil field area

3.1.2. Slope of Radon Concentration with Mass Exhalation rate :

The slope of different oil exploration area with respect to time is already observed. Table 3.1. shows the various data of the slope of Radon concentration and the radon mass exhalation rate of soil samples collected from all the oil exploration area.

Table 3.1. Data of the slope of Radon concentration and radon mass exhalation rate from soil samples collected from all the oil exploration areas of Mizoram

Sl. No.	Location	District	Slope of radon concentrations ($Bq/m^3/hr$)	Mass Exhalation Rate, J_M ($mBq/kg/hr$)
1	Meidum-1	Kolasib	13.5432	17.74
2	Meidum-2		12.023	14.07
3	Meidum-3		11.264	13.82
4	Zanlawn-1		11.10164	13.89
5	Zanlawn-2		14.94918	17.88
6	Zanlawn-3		7.82439	9.13
7	Phulmawi-1	Aizawl	9.42857	11.76
8	Phulmawi-2		7.71033	7.62
9	Phulmawi-3		13.43704	16.98
10	Maubuang-1		15.78374	19.12
11	Maubuang-2		20.70807	23.49
12	Maubuang-3		5.94749	7.27
13	Keifang-1		13.05647	15.62
14	Keifang-2		9.22191	9.99
15	Keifang-3		10.87973	11.24
16	Thenzawl-1	Serchhip	16.09938	19.82
17	Thenzawl-2		7.19029	9.42
18	Thenzawl-3		7.07962	9.89

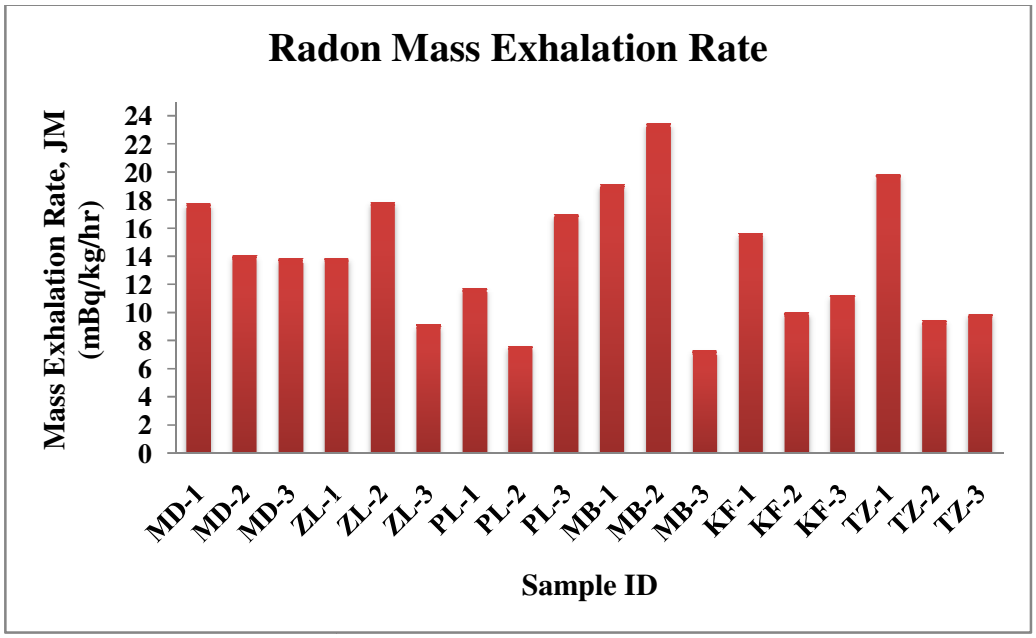


Fig. 3.7. Radon Mass Exhalation Rate of soil samples under study

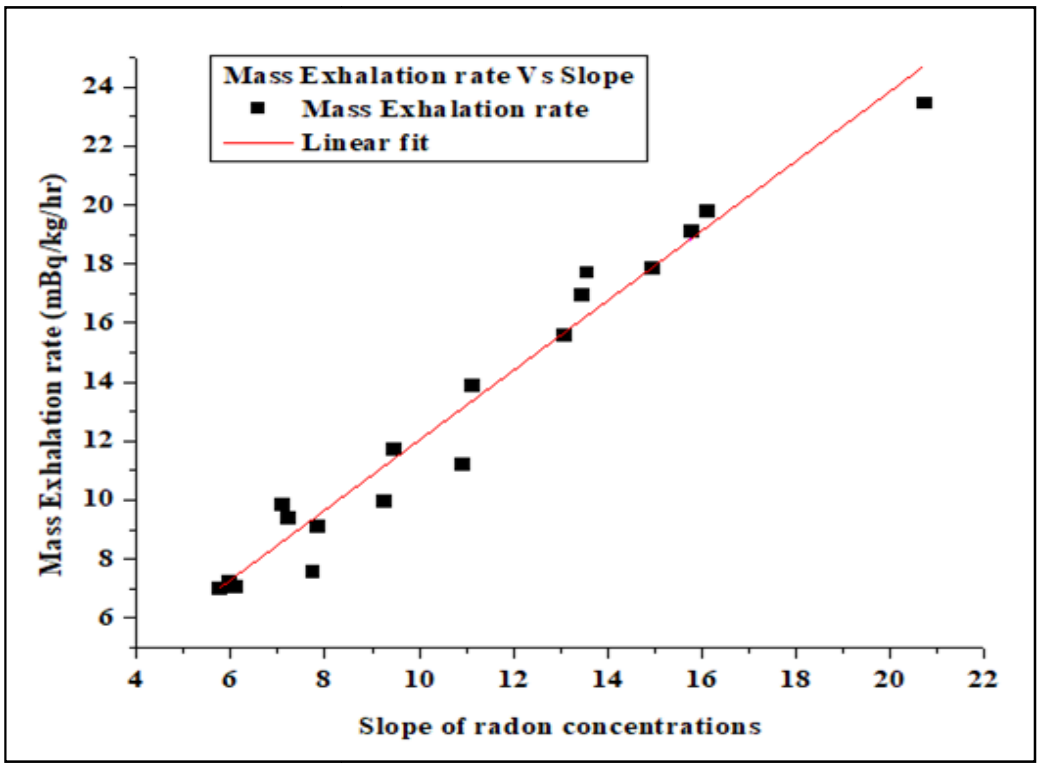


Fig. 3.7a. Slope of radon concentration with Mass Exhalation rate in soil of oil exploration areas

The radon mass exhalation rate of all the study area is shown graphically in fig 3.7 and the graph between the slope of radon concentration with the radon mass exhalation rate is shown in fig 3.7a. It can be seen that the radon concentration has a positive correlation with time.

Table 3.1 shows the various data of the radon mass exhalation rate of soil samples collected from all the oil exploration area. The mass exhalation rate of radon in soil samples ranges from 7.27 mBq/kg/hr in maubuang-3 location to 23.49 mBq/kg/hr in maubuang-2 location with an average of 13.82 mBq/kg/hr. The maximum and minimum radon mass exhalation rate is obtained in maubuang oil field. This may be due to the difference in the moisture content of the two spots.

3.2. Measurement of soil radioactivity using NaI(Tl) detector:

Collected soil samples were made to dry fully by exposing to sunlight for several days and heated using a heater at a temperature of about 110^{o}C. The collected samples were grinded into powdered size and sieved using a 500μm mesh. It was then sealed inside an air-tight container (about 250 ml and weigh between 23.2gm to 24.2gm) and was kept undisturbed for a minimum period of 30 days to attain radioactive equilibrium.

To measure the natural radioactivity within the soil samples, a three-point energy calibration is carried out using sources containing a mixture of several radionuclide (ISO 18589-3:2007(E)). In the present study, ^{60}Co and ^{137}Cs sources were used for energy calibration. This calibration allows the establishment of the relationship between the channel numbers of the analyzer and the known energy of the photons (BIPM-5, 2004).

Radioactivity content of the samples was then obtained by analyzing with GSPEC-SA Multichannel Analyzer for a period of 50,000 seconds. In this analysis, the activity concentrations were determined for ^{238}U, ^{232}Th and ^{40}K after removing the background radiation content. Since secular equilibrium was reached between ^{238}U and ^{232}Th and their decay products, the ^{238}U concentration was determined from the average concentrations of ^{214}Pb and that of ^{232}Th was determined from the average

concentrations of the ^{228}Ac. The average concentration for ^{40}K is obtained from the element ^{40}K itself.

3.2.1. Result of Soil radioactivity:

Table 3.2. gives the results of measurement of efficiency calculation of the given standard source of ^{238}U, ^{232}Th and ^{40}K nuclides whose efficiency were found to be 15.90%, 8.60% and 3.46% for ^{232}Th, ^{238}U and ^{40}K respectively.

Table 3.2. Efficiency Calibration of ^{232}Th, ^{238}U & ^{40}K standard source

Sl. No.	Element	Counting Time(Sec)	Activity (Bq)	Net Area	Ab (%)	Efficiency (η)(%)
1	^{232}Th	10800	3854.21	264723	4	15.90
2.	^{238}U	10800	1636	288823	19	8.60
3.	^{40}K	10800	4557.59	187189.33	11	3.46

Table 3.3. gives the results of measurement of natural radioactivity concentration of ^{238}U, ^{232}Th and ^{40}K radio-nuclides in soil samples under study. The measured values of activity concentration for ^{238}U ranged from 4.89Bq/kg at Thenzawl-1 location to 39.02Bq/kg at Meidum-2 location, with an average value of 17.86Bq/kg, which is much lower to the world average of 30 Bq/kg (UNSCEAR, 2000). For ^{232}Th, the activity concentration ranged from 13.95Bq/kg at Thenzawl-1 location to 111.23Bq/kg at Meidum-2 location, with an average value of 50.92 Bq/kg, which is slightly higher to the world average of 35.00Bq/kg (UNSCEAR, 2000). For^{40}K, activity content ranged from 347.25Bq/kg at Maubuang-2 location to 1122.66Bq/kg at Thenzawl-3 location, with an average value of 644.38 Bq/kg, which is also slightly higher to the world average of 400.00Bq/kg (UNSCEAR, 2000).

Table 3.3: Activity Concentrations of ^{238}U, ^{232}Th & ^{40}K radio-nuclides in soil samples collected from six Oil Exploration Areas.

SAMPLE CODE	LOCATION	ACTIVITY CONCENTRATION (Bq/kg)		
		^{238}U	^{232}Th	^{40}K
MD-1	Meidum	5.75	16.40	426.53
MD-2	Meidum	39.02	111.23	771.57
MD-3	Meidum	14.95	42.61	501.90
ZL-1	Zanlawn	9.57	27.28	524.79
ZL-2	Zanlawn	12.93	36.85	611.15
ZL-3	Zanlawn	12.50	35.63	825.74
PM-1	Phulmawi	13.38	38.13	428.15
PM-2	Phulmawi	11.70	33.35	696.83
PM-3	Phulmawi	13.07	37.25	810.83
MB-1	Maubuang	27.37	78.03	467.38
MB-2	Maubuang	14.69	41.89	347.25
MB-3	Maubuang	36.29	103.45	805.31
KF-1	Keifang	13.27	37.84	603.57
KF-2	Keifang	6.65	18.95	458.35
KF-3	Keifang	16.37	46.66	714.62
TZ-1	Thenzawl	4.89	13.95	528.16
TZ-2	Thenzawl	32.28	92.03	786.67
TZ-3	Thenzawl	36.82	104.97	1122.60
	Average	**17.86**	**50.92**	**644.38**

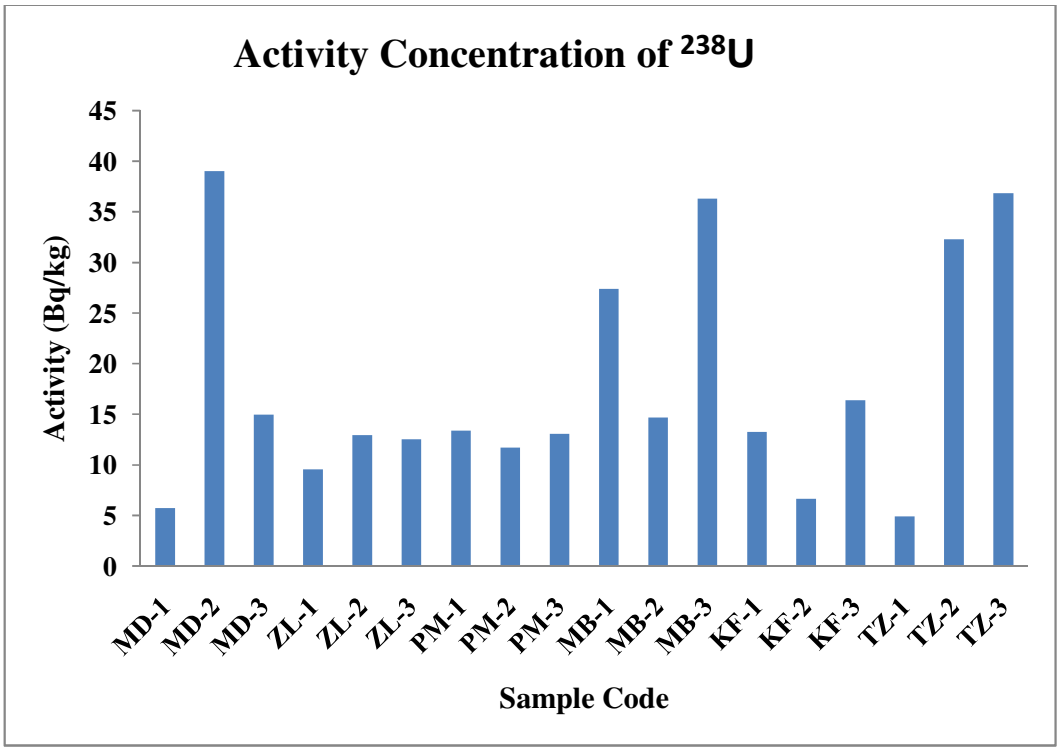


Fig. 3.8a. Activity concentration (Bq/Kg) of ^{238}U

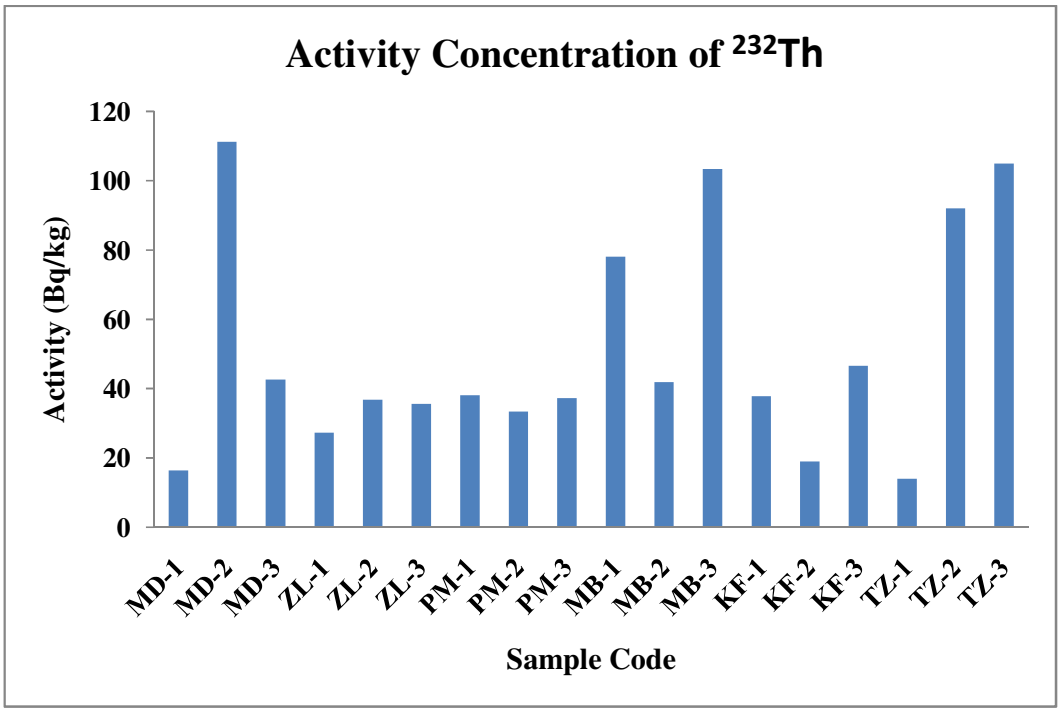


Fig. 3.8b. Activity concentration (Bq/Kg) of ^{232}Th

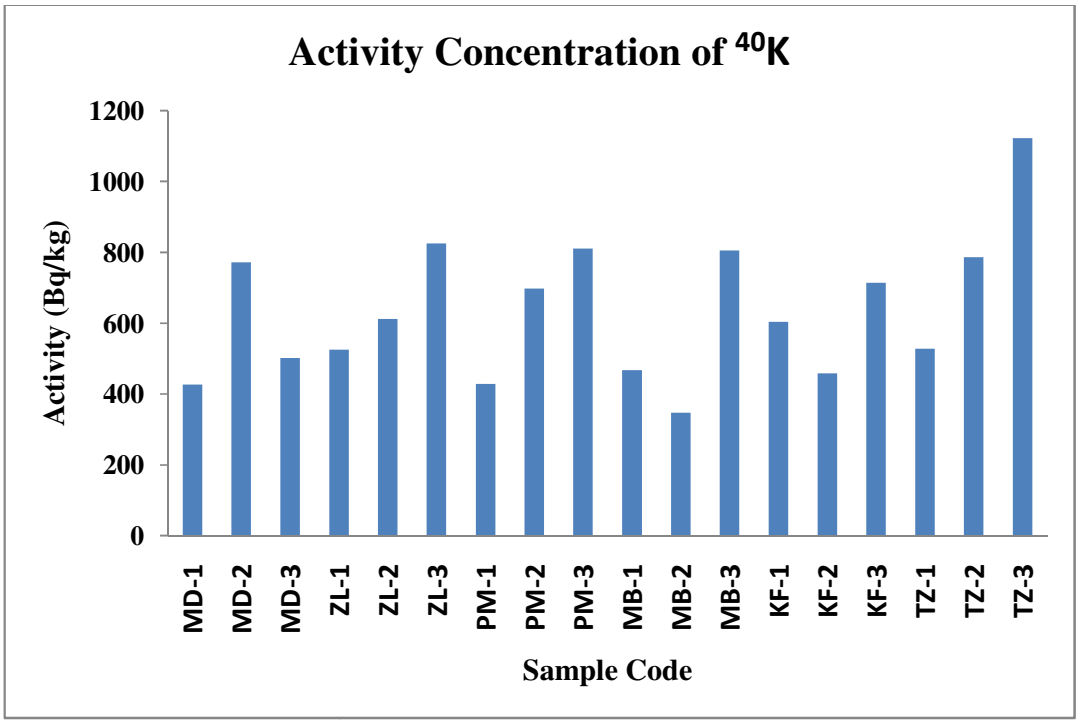


Fig. 3.8c. Activity concentration (Bq/Kg) of ^{40}K

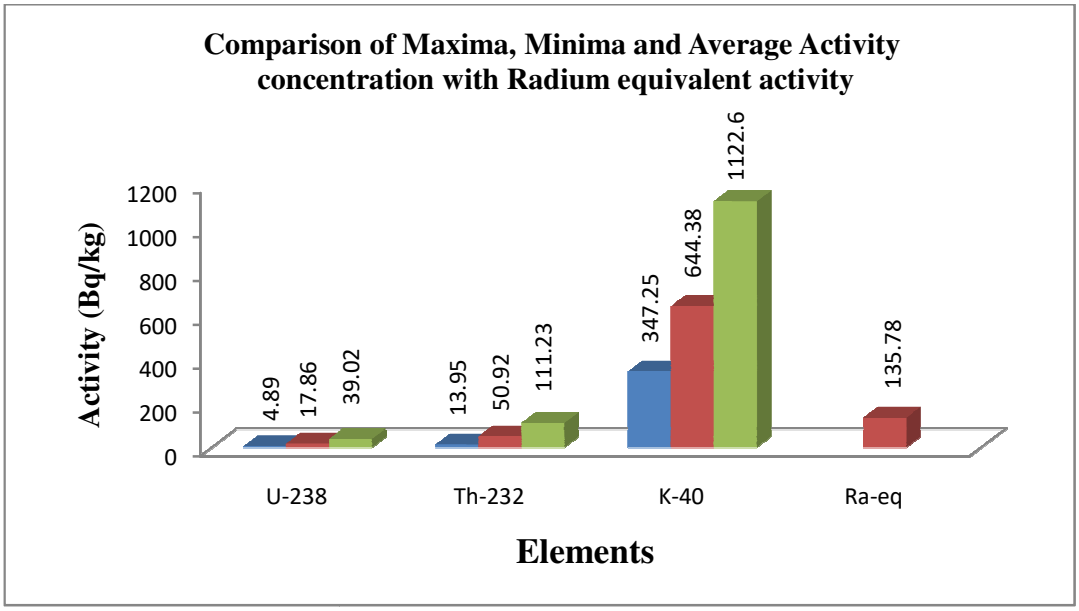


Fig. 3.8d. Comparison of the average values of ^{238}U, ^{232}Th and ^{40}K radionuclides and corresponding radium equivalent of collected samples.

Fig. 3.8a, 3.8b, 3.8c. shows the activity concentration of ^{238}U, ^{232}Th and ^{40}K radio-nuclides comparison of the average values of ^{238}U, ^{232}Th and ^{40}K radio-nuclides in collected samples. It had been found that in almost all of the samples measured, ^{40}K was the most abundant of the three natural radio-nuclides which was taken into account. We are able to calculate the soil radioactivity using the efficiency of each radioactive nuclide. The total effective natural radioactivity in collected soil sample with respect to exposure to radiation is also calculated using equation 2.3 which is the radium equivalent (Ra_{eq}). The radium equivalent activity concentration is found to be 135.78 Bq/kg.

3.3. Measurement of Gamma Radiation and Global Positioning System:

The background gamma radiation is present everywhere on the surface of the earth. The radiation coming from the cosmos as well as from beneath the earth is measured at every spot of the study areas. Global Positioning System at each location is also recorded. Table 3.4. shows the background gamma radiation on ground surface as well as at one meter above the ground.

3.3.1. Observations of Background gamma radiation:

Table 3.4 shows the background gamma radiation at ground surface as well as one meter above the earth surface along with GPS coordinates. This is done to ensure the terrestrial contribution of gamma radiation as well as the cosmic contribution of the background gamma radiation.

Table 3.4: Gamma radiation at ground surface and 1 meter above the ground with GPS coordinates

Sample Area	Longitude North	Latitude East	Ground level (nSv/hr)	One Meter above (nSv/hr)	Variance
MD-1	24^0 10' 12.9"	92^0 35'57.7"	202	176	26
MD-2	24^0 10'12.0"	92^0 35'55.4"	200	160	40

MD-3	24^0 10'11.8"	92^0 35'58.8"	177	140	37
ZL-1	23^0 59'01.3"	92^0 42'47.8"	189	164	25
ZL-2	23^0 59'02.6"	92^0 42'47.9"	176	168	7
ZL-3	23^0 59'01.0"	92^0 42'50.8"	175	146	29
PM-1	23^0 35'33.1"	92^0 51'25.0"	165	155	10
PM-2	23^0 35'32.0"	92^0 51'24.8"	180	152	28
PM-3	23^0 35'29.9"	92^0 51'23.0"	162	148	14
MB-1	$23^0$29'45.5"	$92^0$42'4.3"	183	154	29
MB-2	$23^0$29'47.3"	$92^0$42'5.8"	170	153	17
MB-3	$23^0$29'42.7"	$92^0$42'3.6"	190	155	35
KF-1	$23^0$39'14.2"	92^0 57'1.2"	179	168	11
KF-2	23^0 39'12.5"	92^0 57'1.7"	180	174	6
KF-3	23^0 39'13.7"	92^0 57'0.9"	173	161	12
TZ-1	$23^0$18'08.3"	$92^0$47'04.4"	168	144	24
TZ-2	$23^0$18'10.2"	$92^0$42'5.8"	176	142	34
TZ-3	$23^0$18'12.4"	$92^0$47'11.9"	176	148	28

The ground level background gamma radiation of all the oil exploration area ranges from 162 nSv/hr in phulmawi-3 area to 202 nSv/hr in meidum-1 area. The average ground level background gamma radiation is 179 nSv/hr. The background gamma radiation at 1m (one meter) above the earth surface of all the 18 site ranges from 140 nSv/hr at meidum-3 area to 176 nSv/hr at meidum-1 area. The average background gamma radiation at 1m above the earth surface is 156 nSv/hr. Graphical representation of background gamma level at ground surface and at 1m above the ground surface is shown in fig 3.9a and 3.9b. It is clearly seen that the background gamma radiation at the ground surface is higher than that at 1m above the ground surface. This indicates that the terrestrial contribution of gamma radiation is higher by

a certain amount than the cosmic contribution. The main contributing source of radiation coming from the terrestrial source is uranium.

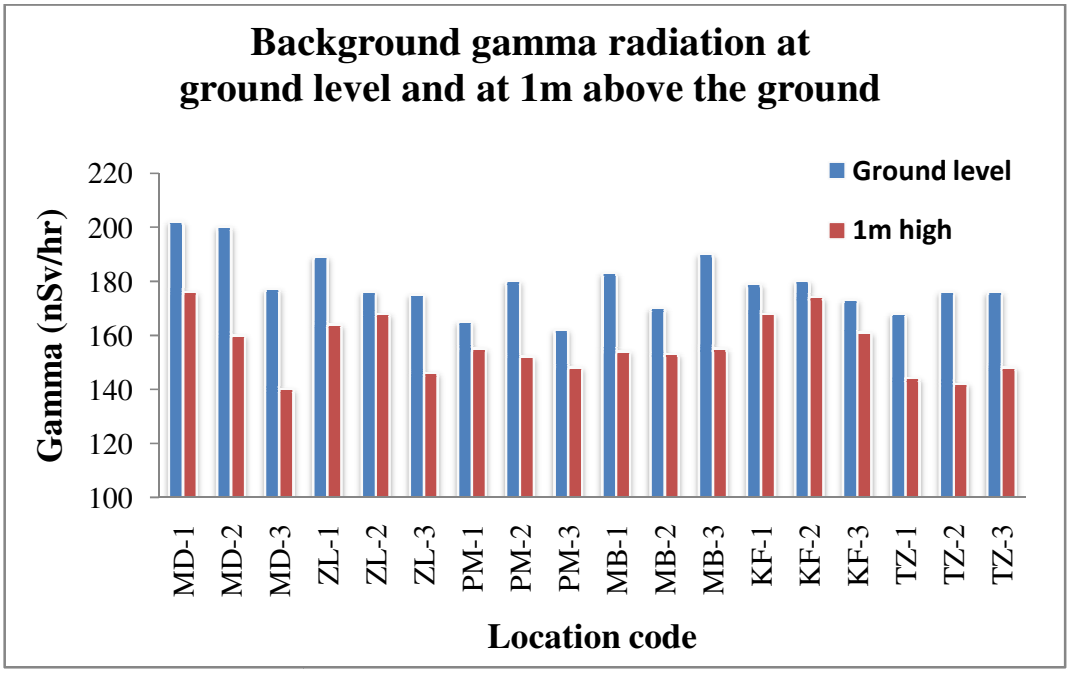


Fig. 3.9a. Gamma radiation at ground surface and at 1m above

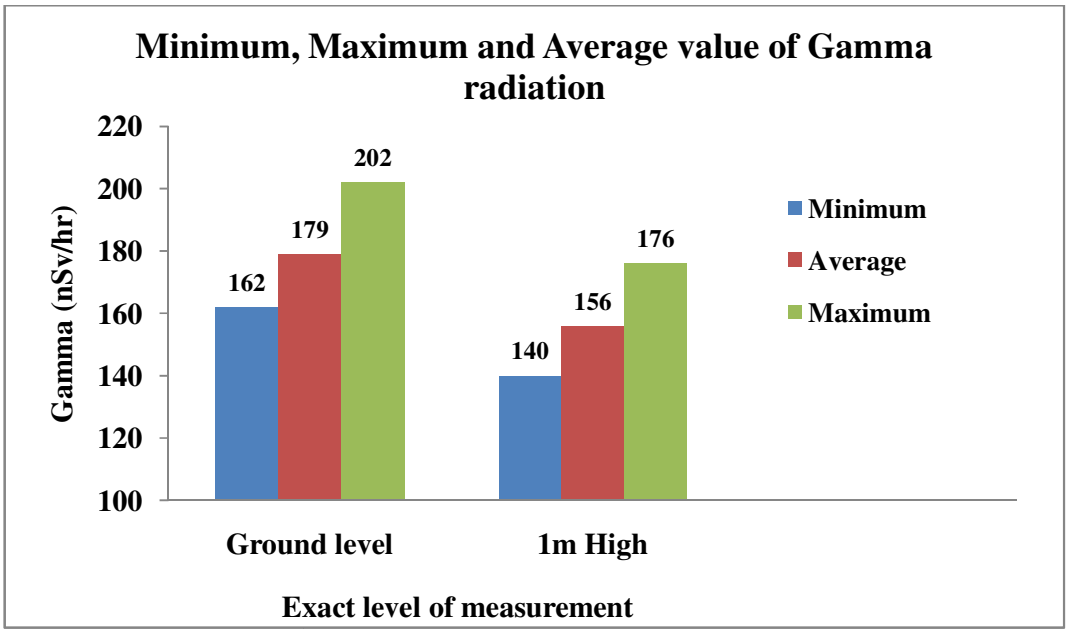


Fig. 3.9b. Average gamma radiation at ground level and at 1m above

The GPS location of all the oil field is recorded with the help of a special device called Garmin GRB 21. The table 3.4 shows the detail GPS location of all the oil field in Mizoram as well as each oil field separately.

3.4. Measurement of Soil type and soil grain size :

Soil type identification and grain size determination of collected soil samples of all the six oil exploration areas within the study area were performed using a mechanical sieve shaker. The ability of soil to retain moisture (which in turn affects the radon mass exhalation rate), as well as the radioactivity content is greatly determined by the soil type and grain size distribution of the soil sample. The soil's ability to attain water largely influenced by the soil type and grain size distribution of the soil. Five different set of sieve, having different mesh number was arranged in an order such that the coarsest sieve is at the top while the finer ones are below. The obtained soil samples were conditioned to the Sieving Machine and the soil was graded into sand, silt or clay from the quantity of grain separate from 'tray' with a scale definition of Udden-Wentworth (Wentworth *et al*., 1922; Lindholm *et al*., 1987).

3.4.1. Observation and discussions:

Table 3.5 shows the measured value of soil grain size in all the six oil exploration areas in Mizoram.

Table 3.5 **:** Determination of soil grain size in oil exploration areas

Sample Code	**Percentage of Soil composition**			**Average J_M**
	Sand	**Silt**	**Clay**	
MD-1	70.40	14.85	14.75	17.74
MD-2	89.97	3.35	6.67	14.07
MD-3	77.61	8.78	13.59	13.82
ZL-1	90.64	2.56	6.8	13.89

ZL-2	85.7	6.36	7.94	17.88
ZL-3	98.64	0.73	0.63	9.13
PM-1	90.81	2.28	6.89	11.76
PM-2	88.26	5.68	6.05	7.62
PM-3	82.45	11.2	6.34	16.98
MB-1	89.04	3.93	7.03	19.12
MB-2	76.48	6.51	17	23.49
MB-3	94.16	1.48	4.36	7.27
KF-1	93.89	2.72	3.37	15.62
KF-2	96.08	1.11	2.79	9.99
KF-3	93.76	2.21	4.01	11.24
TZ-1	76.41	8.64	14.9	19.82
TZ-2	81.86	5.14	13	9.42
TZ-3	85.1	4.55	10.4	9.89
	86.74	**5.11**	**8.14**	**13.82**

From Table 3.5. it is seen that in all the measured collected samples a very high percentage of grain size were found to fall dominantly under “Sand”, which was followed by “Clay” and then a slightly lower percentage of grain size falls under “Slit”. From the grain size distribution obtained, a triangular plotting proposed by USDA (United States Department of Agriculture) was performed using “Origin” computer software to identify the soil type of the collected samples (Garcia *et al*., 2015).

Figure 3.10. shows the United States Department of Agriculture (USDA) Triangular Plot for determination of soil type for oil field in Kolasib district, Aizawl district and Serchhip district respectively. The graph plot indicate that all of the samples soil fall under “sand” and “sand loam”. Table 3.5 also indicates that a higher quantity of smaller grain size does not necessarily indicate the higher exhalation value. From the determination of the soil grain size we have observed that the grain size or distribution of the grains does not necessarily increase the radon mass

exhalation rate, even though the rate of exhalation by radon mass is inversely proportional to the grain size of the soil.

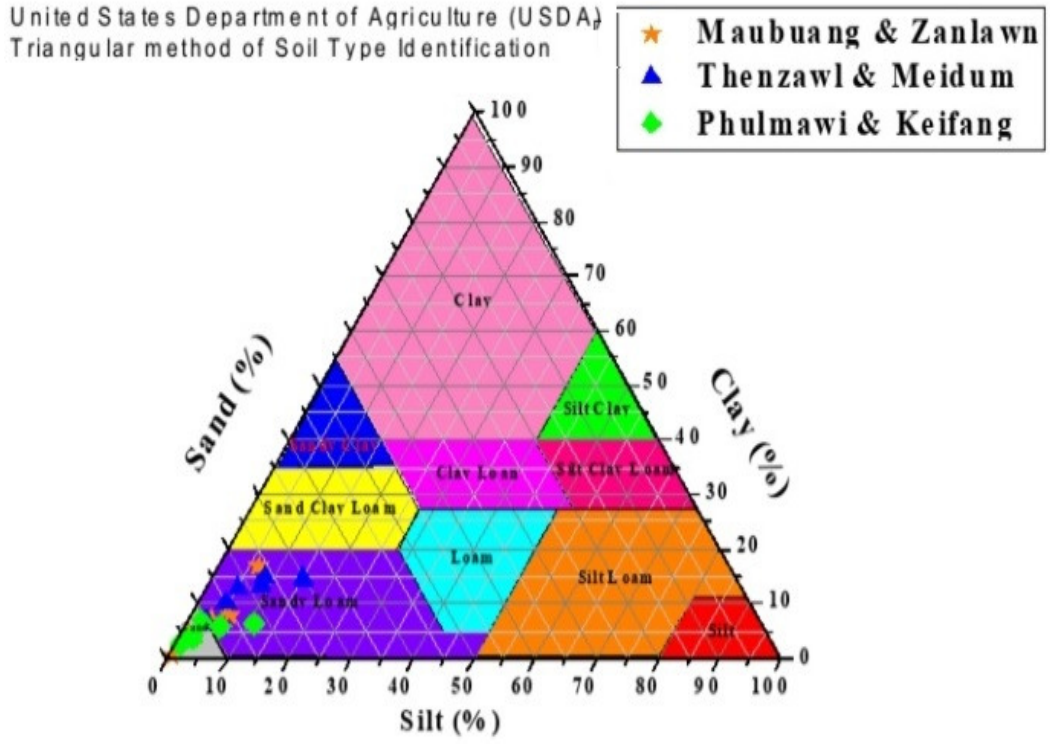


Fig. 3.10. United States Department of Agriculture (USDA) Triangular Plot for determination of soil type

3.5. Measurement of radon content in water using RnDuo:

Smart RnDuo Monitor is used for the determination of radon concentration in water. The principle of measurement of this instrument is based on the detection of alpha particles formed inside the scintillation cell volume, the alpha particles being emitted by radon/thoron contained in the water samples. All the liquid samples collected were from running water and water obtained from road side water source. Samples were stored in a leaked tight glass bottle, and were completely filled to avoid any air trappings inside the bottle.

3.5.1. Result and observations:

Table 3.6 gives the result of radon concentration in water samples collected from 12 different water source (two from each area) within the study area. The water samples were collected during rainy season. The measured values of radon content in water ranged from 0.34 Bq/l in meidum-1 area to 4.33 Bq/l in maubuang-2 area with an average value of 1.26 Bq/l.

Table 3.6: Radon content in water sample of Oil exploration Areas in Mizoram

Sample Code	Water Source	Temperature	pH value	Radon in water (Bq/L)
Meidum-1	Running Water	26.83	6.80	0.34
Meidum-2	Running Water	26.91	7.17	0.41
Zanlawn-1	Running Water	25.71	7.25	0.40
Zanlawn-2	Running Water	26.39	6.88	0.37
Phulmawi-1	Running Water	25.29	7.19	0.41
Phulmawi-2	Running Water	25.15	7.10	0.49
Maubuang-1	Running Water	26.71	7.21	1.02
Maubuang-2	Running Water	25.53	7.05	4.33
Keifang-1	Running Water	26.24	6.95	0.39
Keifang-2	Running Water	25.62	7.15	0.40
Thenzawl-1	Running Water	25.86	6.98	0.41
Thenzawl-2	Running Water	26.13	7.08	0.45

The measured values of radon concentration in water for all the oil exploration areas were found to be well lesser than the safe limit range of 4-40 Bq/L for radon concentration in drinking water as recommended by UNSCEAR (1993). These values were also found to be much lower than the European Commission recommended reference level for radon in drinking water, which is 100 Bq/L (European Commission, 2001). The average value is found to be 1.26 Bq/L, which is also well within the mentioned safe limit range.

Figure 3.11a and 3.11b shows the graphical representation radon concentration in water at various oil exploration areas and the maximum, minimum and average radon concentration in the study area.

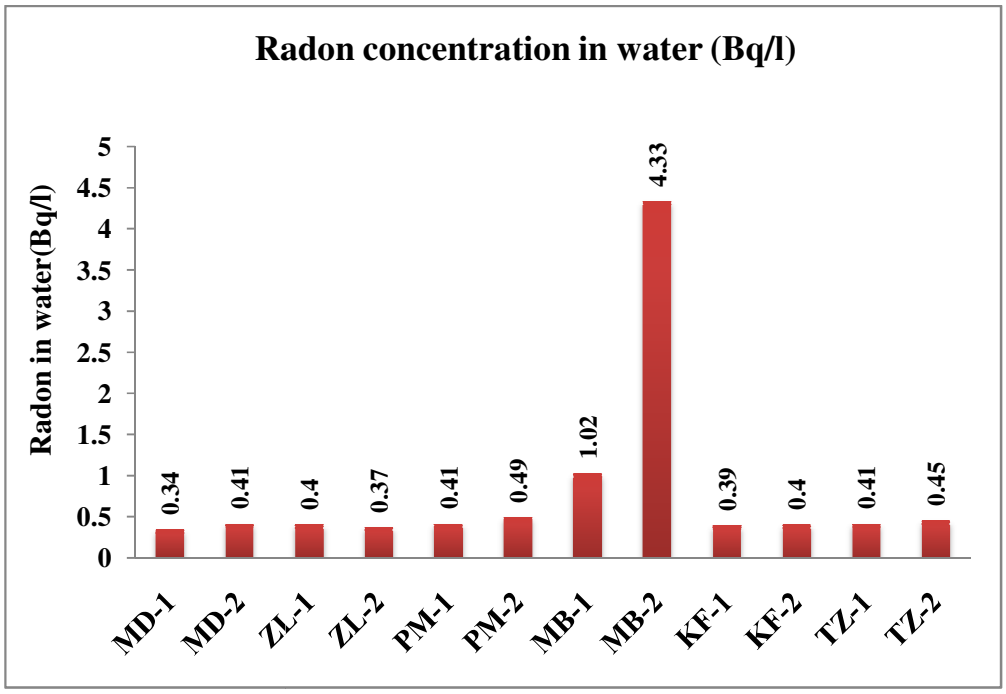


Fig.3.11a. Radon concentration at different oil exploration areas

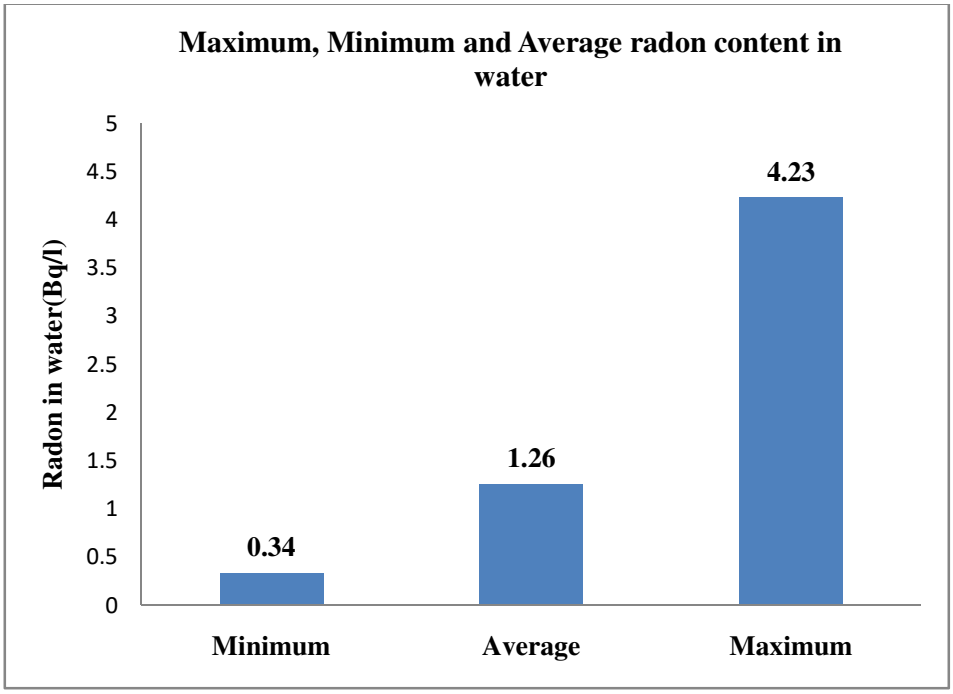


Fig.3.11b. Minimum, Maximum and Average Radon concentration in water

3.6. Measurement of Uranium concentration in water:

The uranium concentration in collected water samples are measured using LED Fluorimeter LF-2a. The Fluorimeter works on the principle of measurement of green uranium fluorescence on the addition of a suitable buffer solution. Standard addition method of measurement was employed for this research work and the uranium fluorescence emitted by the samples were counted in Calibrated Fluorescence mode, i.e. a proper calibration of the instrument was done before each measurement. This is achieved by measuring a blank solution, which is simply a mixture of buffer solution and doubled distilled water (containing zero uranium concentration), using the Fluorimeter before the start of each experiment. Water samples were collected from different sampling sites within the study area using a 60ml Tarsons plastic bottles, and filtering of the samples were done before each measurement using a filter paper to avoid any suspended particles from interfering with the fluorescence.

3.6.1. Preparation of Standard Solution, Buffer Solution and Blank Solution:

ICP Uranium Standard (ICP-MS-66N-0.01X-1), manufactured by Accu Standard, Connecticut, United States of America, is used for preparing the required standard solution used in this research work. The uranium standard is basically a 100 µg/ml uranium concentration in 2-5% Nitric acid. The required uranium standard is obtained by dilution of 100 µg/ml uranium concentration standard to about 500 ppb standard using doubled distilled water in a glass beaker or flask. A precision pipette was used so that accurate required standard concentration is obtained. The freshly prepared standard solution is then put in a plastic bottle for longer storage.

The addition of buffer solution to a sample, while measuring the uranium concentration in liquid samples, not only increases the uranium fluorescence yield of the samples by orders of magnitude, it also convert all the uranium complexes (having different fluorescence yield) into a single valence state U (IV), thus emitting only one type of fluorescence. For measurements, it is recommended that 1 part of buffer solution is added to 10 parts of uranium solution / sample. The buffer solution is prepared by taking 5 grams of Sodium Pyrophosphate into a flask / plastic bottle and adding 100 ml of double distilled water to it. The flask / plastic bottle was shook until all the Sodium Pyrophosphate salts dissolves. Ortho-phosphoric Acid was then added drop by drop while monitoring the pH value of the solution, and the required buffer is obtained when a pH of 7 is reached. While measuring the uranium concentration using a Fluorimeter, a blank solution is always required to eliminate the possible effects of any fluorescing compounds present in a buffer solution. The blank solution is prepared by take 1 ml of Buffer solution and adding 10 ml of double distilled water to it. The blank solution is essentially a sample with zero uranium concentration. Fluorescence of blank solution is always measured when calibrating the detector/instrument and also when measuring unknown uranium concentration samples. The uranium concentration in the water sample was then calculated using Equation 2.6

3.6.2. Result and observations:

Table 3.7 gives the results of uranium concentration in water samples collected from 12 different locations within the study area. All the samples collected were from running water and water obtained from road side water source. The water samples were collected during rainy season. The measured values of uranium concentration in water ranged from 0.213 μg/l to 0.643 μg/l, with an average value of 0.323 μg/l. The measured pH values ranged from 6.80 to 7.25, with an average value of 7.025. The pH value of all collected samples were found to be well within the safe limit value of 6.5- 8.5 for drinking water, as recommended by BIS (1991).

Table 3.7: Uranium content in water samples of Oil exploration Areas in Mizoram

Sample Code	Water Source	Temperature	pH value	Uranium in water (μg/l)
Meidum-1	Running Water	26.83	6.80	0.231
Meidum-2	Running Water	26.91	7.17	0.643
Zanlawn-1	Running Water	25.71	7.25	0.215
Zanlawn-2	Running Water	26.39	6.88	0.213
Phulmawi-1	Running Water	25.29	7.19	0.289
Phulmawi-2	Running Water	25.15	7.10	0.251
Maubuang-1	Running Water	26.71	7.21	0.316
Maubuang-2	Running Water	25.53	7.05	0.308
Keifang-1	Running Water	26.24	6.95	0.216
Keifang-2	Running Water	25.62	7.15	0.419
Thenzawl-1	Running Water	25.86	6.98	0.409
Thenzawl-2	Running Water	26.13	7.08	0.362
	Average	**26.03**	**7.07**	**0.323**

The Uranium concentration in water ranges from 0.213µg/l in zanlawn-2 area to 0.643µg/l in meidum-2 area with an average value of 0.323µg/l which is found to be a quite lower than the safe limits for drinking water, i.e. 30µg/l as prescribed by WHO (2011). The pH value ranges from 6.80 in meidum-1 area to 7.25 in zanlawn-1 area with an average pH value of 7.07.

Figure 3.12a and 3.12b shows the graphical representation of Uranium concentration at various oil exploration areas and the minimum, maximum and average radon concentration from the study areas.

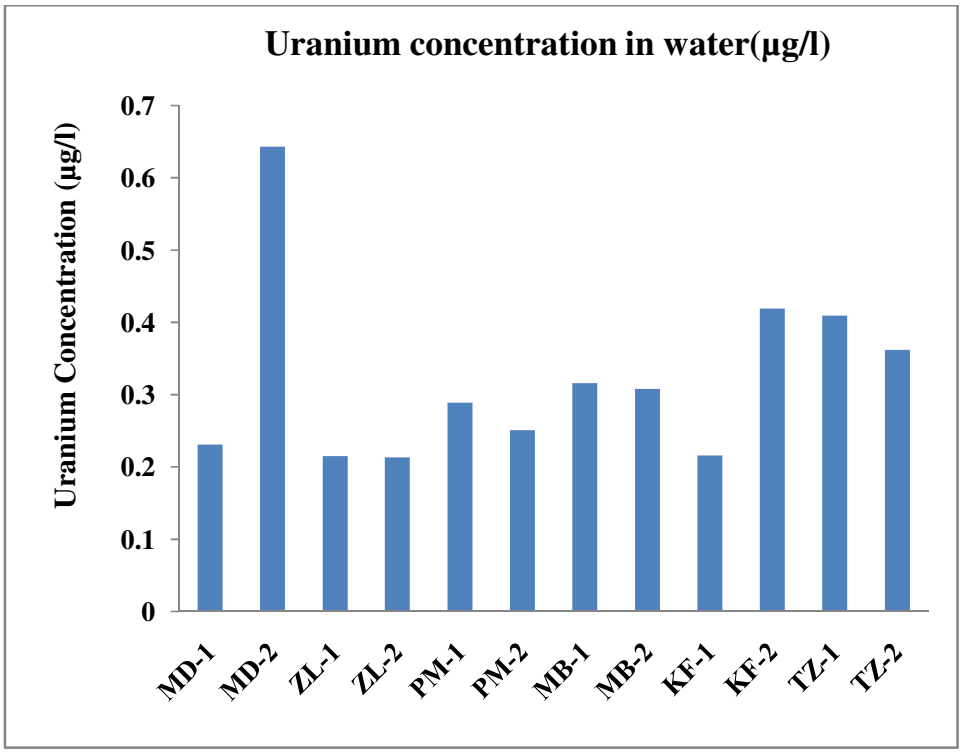


Fig. 3.12a. Uranium Concentration in Water of al the oil field area

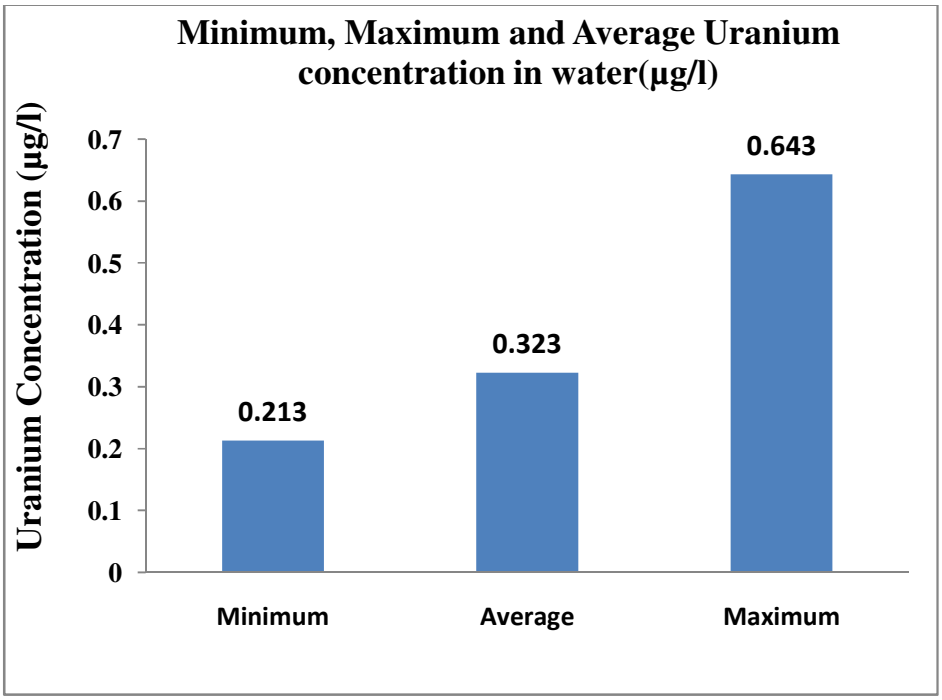


Fig. 3.12b. Minimum, Maximum and Average Radon concentration of study area

3.7. Correlation between radon and uranium concentration in water:

The correlation between radon concentration in water from table 3.6 and uranium concentration in water taken from table 3.7 is plotted. Fig.3.13. shows the correlation graph between radon content in water and uranium content in water. Looking at the decay series of uranium, the percentage of radon that is present in water is definitely coming from uranium via radium. A correlation graph plotted between radon concentration in water and uranium content in water also indicate a correlation graph between radon concentration in water and radium content in water.

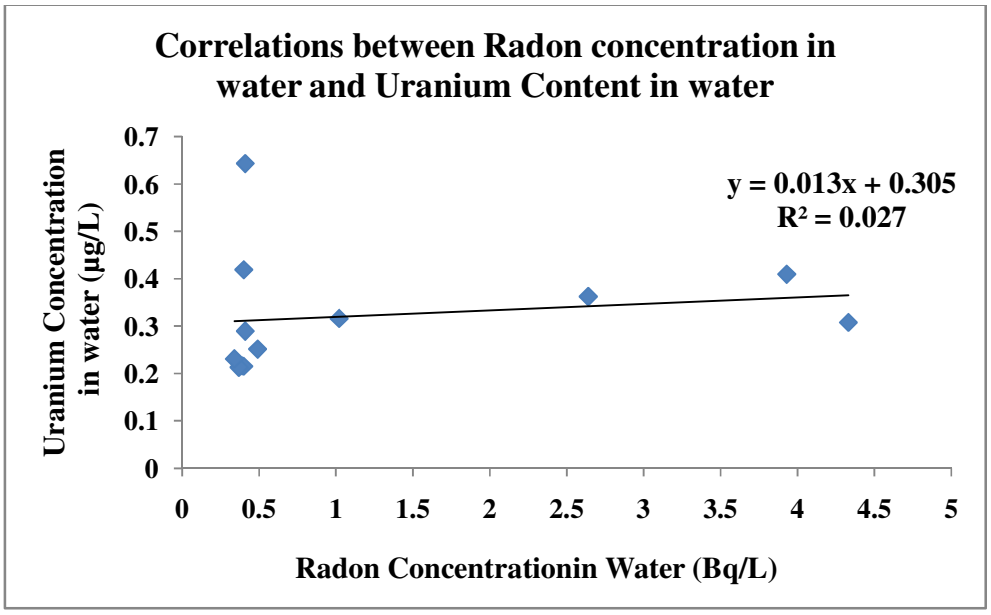


Fig. 3.13. Correlation between radon content in water and uranium content in water

The correlation coefficient thus obtained is $R^2 = 0.027$. The correlation could have been better if the radon concentration is immediately studied on the spot itself. It could also be better if radon gas concentration loss in the atmosphere is not possible even though the water samples are transported with air tight glass container.

4

In-situ Measurement of Radon Concentration In Soil With Soil Probe

An *in-situ* measurement of radon concentration in soil at different baptism depth is studied. Since the condition of soil at different oil exploration areas is different the depth at which the soil probe could be inserted is different. We are interested in studying the radon concentration at the same depth. As such we choose the baptism depth of 10cm, 30cm, 50cm and 70cm respectively.

4.1. *In-situ* measurement of radon concentration in soil with soil probe:

Radon concentration at different depths was studied in the specified study areas. Although 'soil probe' of various lengths are available the soil probe used in the present measurement is 1m long. Even though our intension is to baptize the soil probe to at least 100cm deep, but in actual practice it was not possible to baptize deeper than 70cm. There is a high chance of damage to the soil probe. This happen in all the locations within Thenzawl oil field area. Thus 70cm depth is taken as the maximum depth for this research work. To maintain uniformity in the study, the soil probe is baptized to a maximum of 70cm in all other oil field area as well.

The soil probe is first baptized to 10cm deep and the radon concentration at 10cm deep is noted. The probe is further baptized to 30cm deep and the radon concentration noted. Then the probe is further baptized to 50cm deep and the concentration recorded. Finally, the probe is further baptized to 70cm deep and the concentration noted. It is observed that the radon concentration increases as we baptize the soil probe deeper and deeper. This is true for all the oil field. The soil probe is baptized with the help of a wooden block specially prepared for hammering and inserting the probe inside the ground. The density of the earth is different in different oil field areas. Whereas in some location the probe is easily baptized into the

earth, but in some other field it is quite difficult to baptize. It takes a minimum of two to three persons to baptize the soil probe. While one person do the hammering part, others hold the probe tight to maintain safety as well as straight entrance of the probe. Even with three person working together in the field, in locations like Thenzawl oil exploration area it is not possible to baptize the probe deeper than 70cm.

Mizoram is a hilly area and all the oil field available are constructed by lowering and leveling the earth. This is achieved by cutting tons and tons of earth and then leveling it. The original earth surface is lowered by around 7m to 20m in all the field to make it level. The soil probe, thus can be considered not baptized from the top original earth but from deep inside the earth. The soil density is high and creates difficulties for the soil probe to penetrate so deep as well. It give immense retarding force to penetrate the soil probe to our desired depth.

Soil probe provided with RnDuo system is utilized for the measurement of radon gas concentration in soil. The soil probe is made of stainless steel with hollow inside for the passage of gas. An inner pipe can be inserted in the probe which is further fitted with the head. The head is utilized for safe hammering point. The soil probe could then be hammered with a wooden block on the head till it reaches the required depth. The head is then removed and RnDuo monitor is connected to the inlet port of the soil probe thus enabling the completion of the set up and ready for reading.

4.1.1. Measurement protocol:

1) The pump is turned on manually for 2-3 minutes by putting Pump setting = On in Rn222 mode
2) For measurement of radon, the parameters are set up as below and the measurements start.

   Mode = Rn222

   Modify cycle = 15 minutes

   Pump Settings = Off

3) The measurements are continued up to 1 hour for each depth. While taking average, the first readings in each case are ignored. The mean of the three readings gives the final reading for that depth.
4) For measurements at subsequent depths the RnDuo monitor are not turned Off. Instead the probe is hammered to the next depth level and the measurement procedure given above is repeated.
5) The sequence of measurement performed was in an increasing order of depth.
6) Measurement of radon concentration in soil gas was performed at four different depths 10 cm, 30 cm, 50 cm and 70 cm.

   Fig. 3.2. shows the block diagram of the mentioned smart RnDuo.

4.1.2. Results and Discussion:

Table 4.1. shows the result and observation of Radon Concentration in soil gas of all the oil exploration areas in Aizawl, Serchhip and Kolasib district of Mizoram respectively.

Table 4.1. Radon Concentration in soil gas at various baptism depth of all the oil exploration areas in Mizoram

Sl. No	**Sampling Location**	**Sampling ID**	**GPS Location (Latitude/Longitude)**		**Baptism Depth**	**Radon Concen-tration kBq/m^3**
1	Meidum	MD-1	Elev(ft)	: 331	10cm	0.22
			North	: 24^0 10' 12.9"	30cm	0.24
			East	: 92^0 35'57.7"	50cm	0.26
					70cm	0.31
2	Meidum	MD-2	Elev(ft)	: 329	10cm	0.12
			North	: 24^0 10' 12.0"	30cm	0.13
			East	: 92^0 35'55.4"	50cm	0.14
					70cm	0.15
3	Meidum	MD-3	Elev(ft)	: 291	10cm	0.10
			North	: 24^0 10'11.8"	30cm	0.13

			East	: 92^0 35'58.8"	50cm	0.15
					70cm	0.18
4	Zanlawn	ZL-1	Elev(ft)	: 2900	10cm	0.15
			North	: 23^0 59'01.3"	30cm	0.16
			East	: 92^0 42'47.8"	50cm	0.18
					70cm	0.19
5	Zanlawn	ZL-2	Elev(ft)	: 2110	10cm	0.12
			North	: 23^0 59'02.6"	30cm	0.13
			East	: 92^0 42'47.9"	50cm	0.15
					70cm	0.16
6	Zanlawn	ZL-3	Elev(ft)	: 2119	10cm	0.12
			North	: 23^0 59'01.0"	30cm	0.14
			East	: 92^0 42'50.8"	50cm	0.17
					70cm	0.19
7	Phulmawi	PM-1	Elev(ft)	: 2900	10cm	0.40
			North	: $23^0$35'33.1"	30cm	0.42
			East	: 92'51'25.0"	50cm	0.47
					70cm	0.52
8	Phulmawi	PM-2	Elev(ft)	: 2901	10cm	0.11
			North	: $23^0$35'32.0"	30cm	0.16
			East	: 92'51'24.8"	50cm	0.18
					70cm	0.24
9	Phulmawi	PM-3	Elev(ft)	: 2956	10cm	0.13
			North	: $23^0$35'29.9"	30cm	0.14
			East	: 92'51'23.0"	50cm	0.15
					70cm	0.18
10	Maubuang	MB-1	Elev(ft)	: 2875	10cm	0.15
			North	: 23^0 29'45.5"	30cm	0.23
			East	: 92^0 42'4.3"	50cm	0.35
					70cm	0.42

11	Maubuang	MB-2	Elev(ft)	: 2870	10cm	1.23
			North	: 23^0 29'47.3"	30cm	1.25
			East	: 92^0 42'5.8"	50cm	1.55
					70cm	1.60
12	Maubuang	MB-3	Elev(ft)	: 2885	10cm	0.80
			North	: $23^0$29'42.7"	30cm	0.86
			East	: $92^0$42'3.6"	50cm	1.19
					70cm	1.35
13	Keifang	KF-1	Elev(ft)	: 2927	10cm	0.11
			North	: $23^0$39'14.2"	30cm	0.13
			East	: $92^0$57'1.2"	50cm	0.15
					70cm	0.16
14	Keifang	KF-2	Elev(ft)	: 2915	10cm	0.10
			North	: $23^0$39'12.5"	30cm	0.13
			East	: $92^0$57'1.7"	50cm	0.16
					70cm	0.19
15	Keifang	KF-3	Elev(ft)	: 2918	10cm	0.14
			North	: $23^0$39'13.7"	30cm	0.28
			East	: $92^0$57'0.9"	50cm	0.34
					70cm	0.40
16	Thenzawl	TZ-1	Elev(ft)	: 2460	10cm	0.15
			North	: $23^0$18'08.3"	30cm	0.26
			East	: 92'47'04.4"	50cm	0.49
					70cm	0.72
17	Thenzawl	TZ-2	Elev(ft)	: 2454	10cm	0.81
			North	: $23^0$18'10.2"	30cm	1.08
			East	: 92'42'05.8"	50cm	1.23
					70cm	1.37
18	Thenzawl	TZ-3	Elev(ft)	: 2483	10cm	0.14
			North	: $23^0$18'12.4"	30cm	0.15

			East	: 92’47’11.9”	50cm	0.20
					70cm	0.22

4.2. Oil field wise Graphical representation of Radon concentration:

Radon concentration at different baptism depth is represented by a graph as shown below. The radon concentration at 10cm, 30cm, 50cm and 70cm deep of the three spot each in all the oil field area are not the same. This is due to the difference in the porosity of the soil. Higher total soil porosity can provide larger possibility for radon to escape the grain surface and then lead to higher soil radon concentration (Kainan SUN *et al.,*2004).

Radon concentration in Meidum area:

Meidum oil exploration area has a maximum radon concentration of 0.31 kBq/m^3 at 70 cm deep and a minimum of 0.1 kBq/m^3 at a 10cm deep.

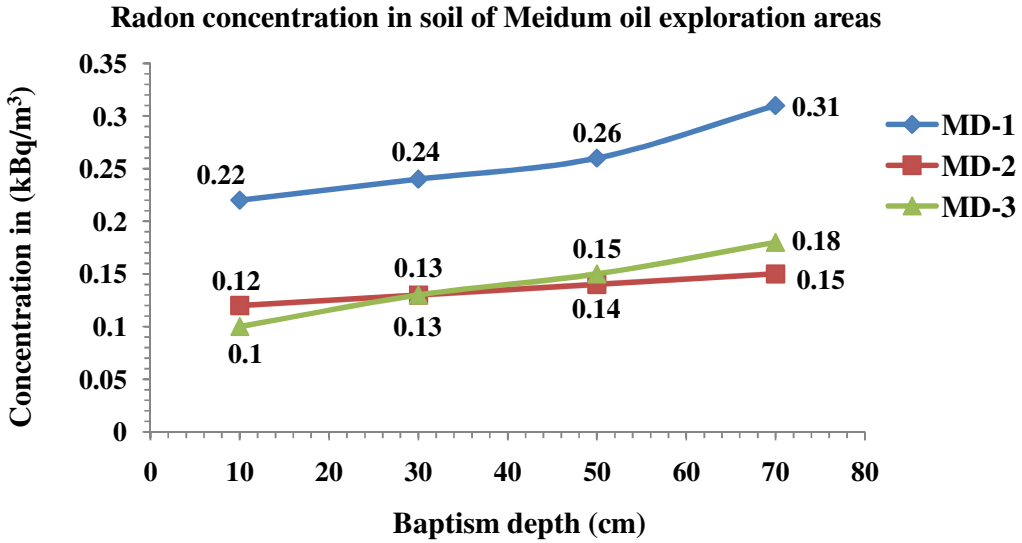


Fig. 4.1: Radon concentration in soil at different spot of Meidum oil field area

Radon concentration in Zanlawn area:

Zanlawn oil exploration area has a maximum radon concentration of 0.21 kBq/m^3 at 70 cm deep and a minimum of 0.12 kBq/m^3 at a 10cm deep.

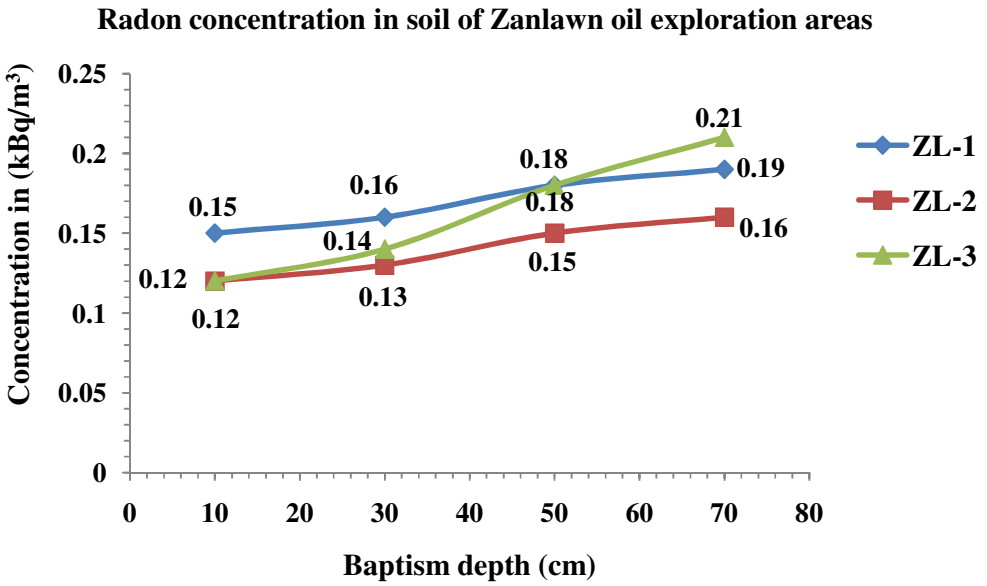


Fig. 4.2: Radon concentration in soil at different spot of Zanlawn oil field area

Radon concentration in Phulmawi area

Phulmawi oil exploration area has a maximum radon concentration of 0.52 kBq/m^3 at 70 cm deep and a minimum of 0.11 kBq/m^3 at a 10cm deep.

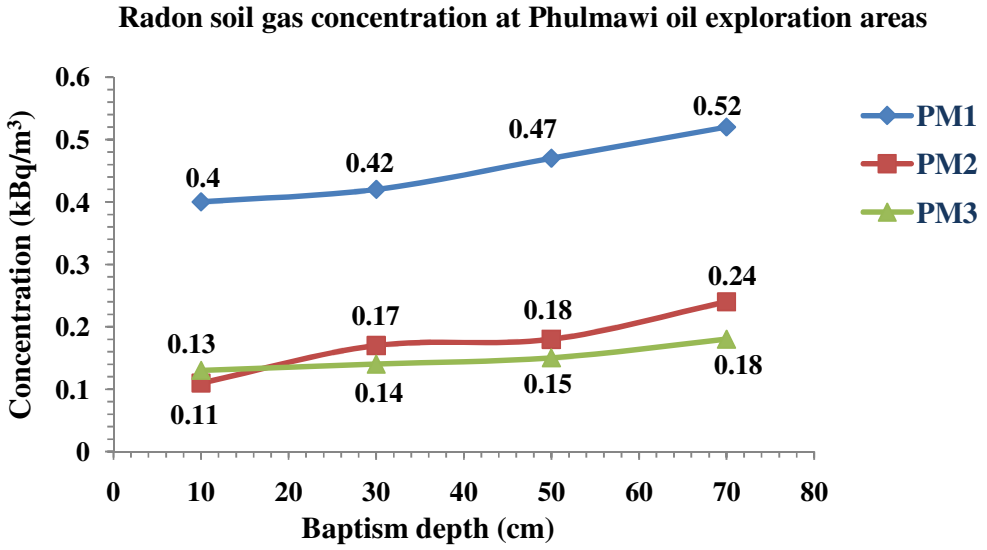


Fig. 4.3: Radon concentration in soil at different spot of Phulmawi oil field area.

Radon concentration in Maubuang area

Maubuang oil exploration area has a maximum radon concentration of 1.6 kBq/m^3 at 70 cm deep and a minimum of 0.15 kBq/m^3 at a 10cm deep.

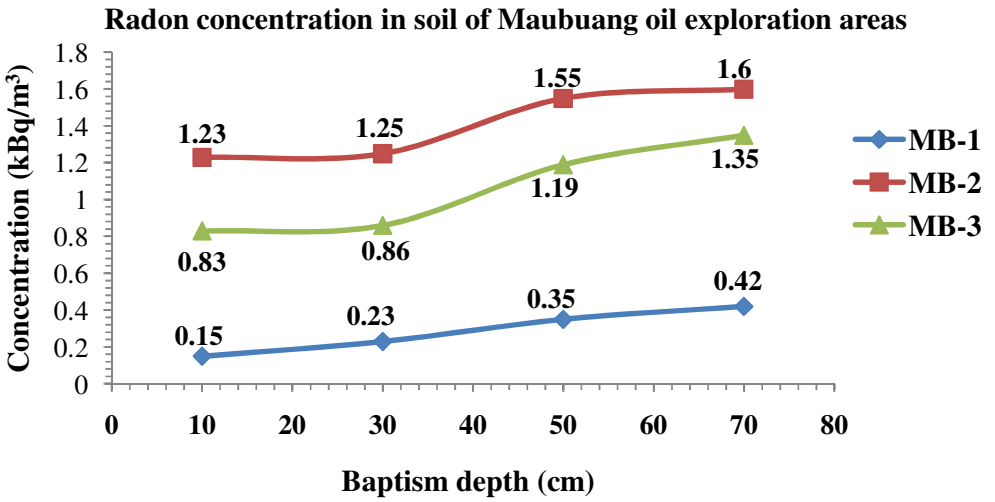


Fig. 4.4: Radon concentration in soil at different spot of Maubuang oil field area.

Radon concentration in Keifang area:

Keifang oil exploration area has a maximum radon concentration of 0.4 kBq/m^3 at 70 cm deep and a minimum of 0.1 kBq/m^3 at a 10cm deep.

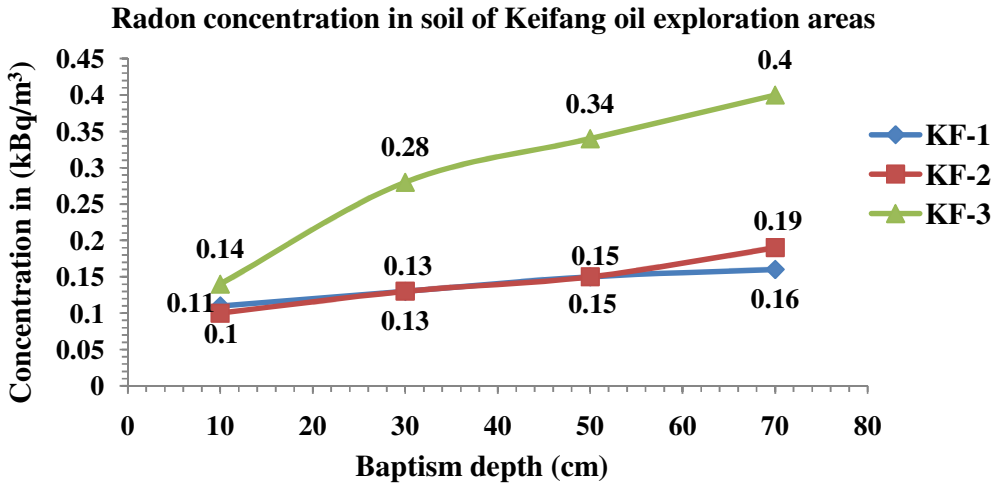


Fig. 4.5: Radon concentration in soil at different spot of Keifang oil field area.

Radon concentration in Thenzawl area:

Thenzawl oil exploration area has a maximum radon concentration of 1.37 kBq/m^3 at 70 cm deep and a minimum of 0.14 kBq/m^3 at a 10cm deep.

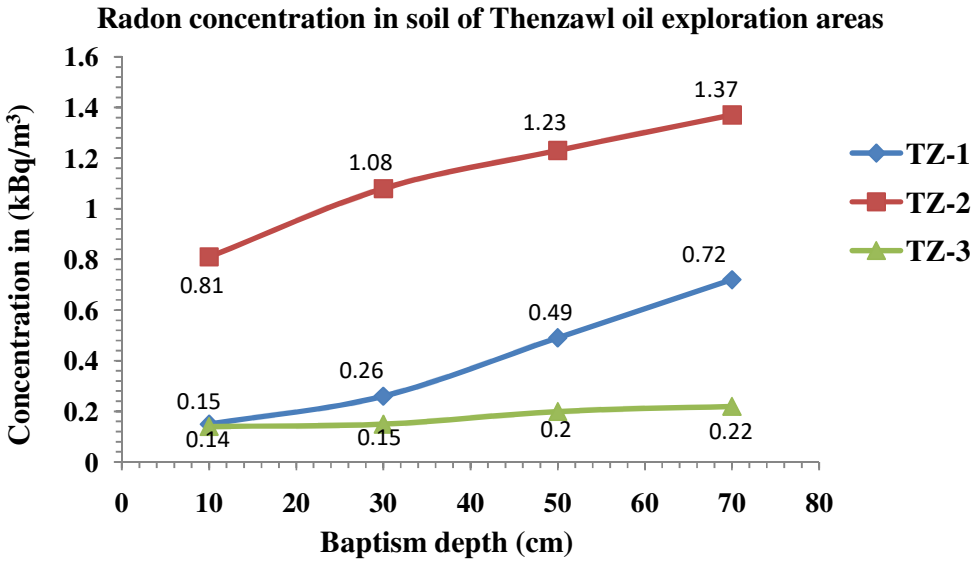


Fig. 4.6: Radon concentration in soil at different spot of Thenzawl oil field area.

Average Radon Concentration at different Baptism depth:

The average radon concentration at 10cm deep of all the oil exploration area is 0.28 kBq/m^3; at 30cm deep it is 0.325 kBq/m^3, at 50cm deep it is 0.42 kBq/m^3 and at 70cm deep it is 0.475 kBq/m^3. The average radon concentration at 10cm deep is lowest and the average radon concentration at 70cm deep is highest.

4.3. Oil field wise correlation between ground level Gamma Radiation and Radon concentration at 10cm, 30cm, 50cm and 70cm respectively:

Table 4.2 shows the ground surface background gamma radiation of all the oil field area which is taken from Table 3.4. It also shows the radon concentration at various baptism depth of 10cm, 30cm, 50 cm and 70cm of all the oil exploration areas taken from Table 4.1. A correlation graph between the two is drawn for all the oil field area separately. In each oil field area the graph shows a similar pattern. The

correlation coefficient R^2 is higher at 10cm deep and lower at 70cm deep. The background gamma radiation at ground level is higher than the gamma radiation measured at 1m above the ground at the same spot. This indicates that the gamma radiation is coming from the terrestrial source than from cosmic radiation.

Table 4.2. Gamma Radiation at ground level and Radon Concentration in soil gas at various baptism depth of oil exploration areas in Mizoram, India

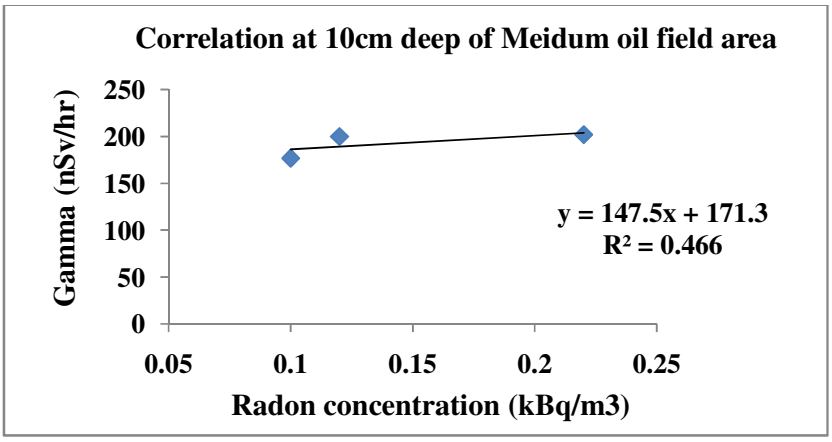
Sl. No	**Sampling Location**	**Sampling ID**	**Gamma ground level (nSv/hr)**	**Baptism Depth**	**Radon Concen-tration kBq/m^3**
1	Meidum	MD-1	202	10cm	0.22
				30cm	0.24
				50cm	0.26
				70cm	0.31
2	Meidum	MD-2	200	10cm	0.12
				30cm	0.13
				50cm	0.14
				70cm	0.15
3	Meidum	MD-3	177	10cm	0.10
				30cm	0.13
				50cm	0.15
				70cm	0.18
4	Zanlawn	ZL-1	189	10cm	0.15
				30cm	0.16
				50cm	0.18
				70cm	0.19
5	Zanlawn	ZL-2	176	10cm	0.12
				30cm	0.13
				50cm	0.15
				70cm	0.16
6	Zanlawn	ZL-3	175	10cm	0.12

				30cm	0.14
				50cm	0.17
				70cm	0.19
7	Phulmawi	PL-1	165	10cm	0.40
				30cm	0.42
				50cm	0.47
				70cm	0.52
8	Phulmawi	PL-2	180	10cm	0.11
				30cm	0.1
				50cm	0.18
				70cm	0.24
9	Phulmawi	PL-3	162	10cm	0.13
				30cm	0.14
				50cm	0.15
				70cm	0.18
10	Maubuang	MB-1	183	10cm	0.15
				30cm	0.23
				50cm	0.35
				70cm	0.42
11	Maubuang	MB-2	170	10cm	1.23
				30cm	1.25
				50cm	1.55
				70cm	1.60
12	Maubuang	MB-3	190	10cm	0.80
				30cm	0.86
				50cm	1.19
				70cm	1.35
13	Keifang	KF-1	179	10cm	0.11
				30cm	0.13
				50cm	0.15

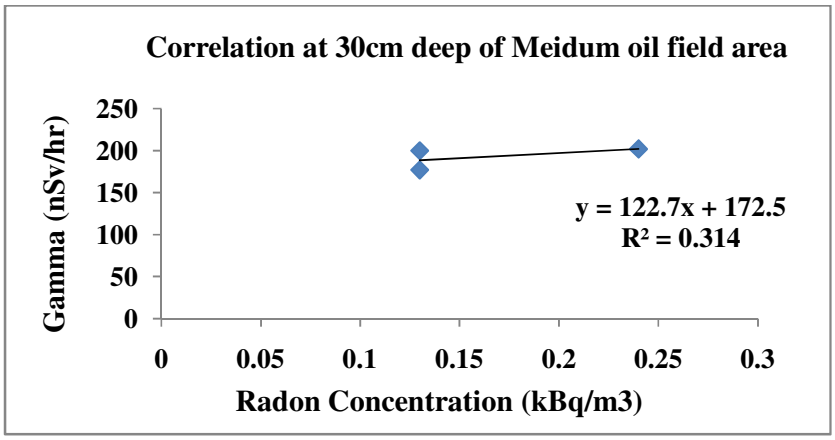
				70cm	0.16
14	Keifang	KF-2	180	10cm	0.10
				30cm	0.13
				50cm	0.16
				70cm	0.19
15	Keifang	KF-3	173	10cm	0.14
				30cm	0.28
				50cm	0.34
				70cm	0.40
16	Thenzawl	TZ-1	168	10cm	0.15
				30cm	0.26
				50cm	0.49
				70cm	0.72
17	Thenzawl	TZ-2	176	10cm	0.81
				30cm	1.08
				50cm	1.23
				70cm	1.37
18	Thenzawl	TZ-3	176	10cm	0.14
				30cm	0.15
				50cm	0.20
				70cm	0.22

Correlation at Meidum oil field area:

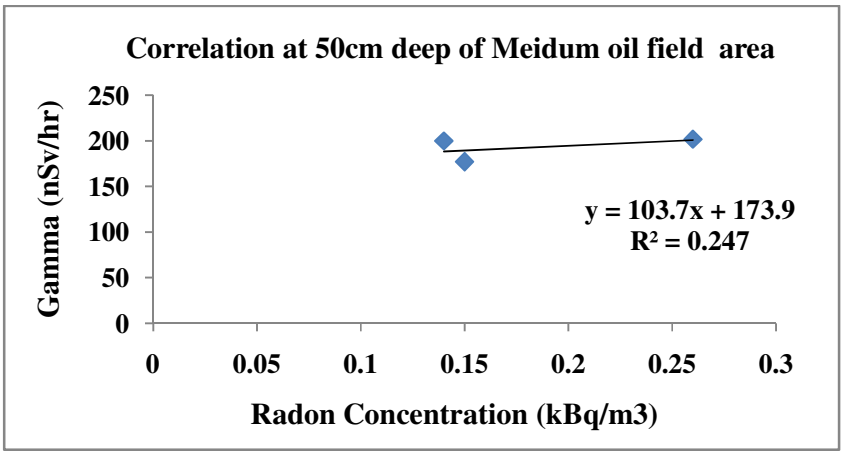
The figure 4.7. shows the correlation graph between Ground level gamma radiation and average radon concentration at 10cm, 30cm, 50cm and 70cm deep of Meidum oil exploration area respectively.


Correlation at 10cm deep of Meidum oil field area
Gamma (nSv/hr)
250
200
150
100
50
0
0.05
0.1
0.15
0.2
0.25
Radon concentration (kBq/m3)
y = 147.5x + 171.3
R² = 0.466

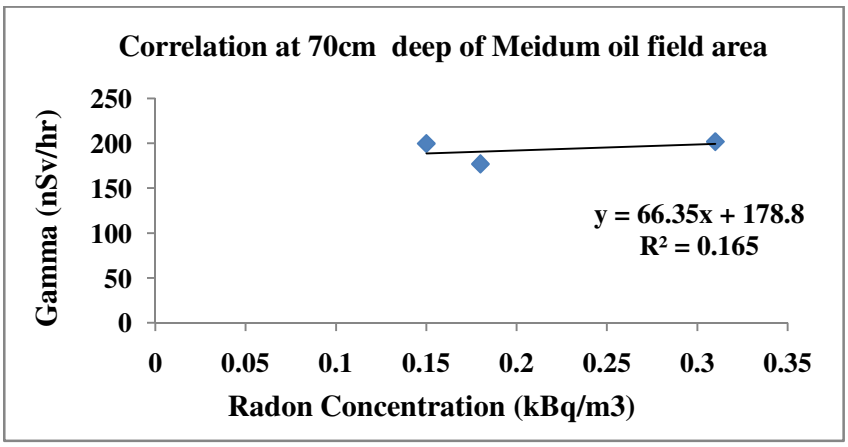
(a)


Correlation at 30cm deep of Meidum oil field area
Gamma (nSv/hr)
250
200
150
100
50
0
0
0.05
0.1
0.15
0.2
0.25
0.3
Radon Concentration (kBq/m3)
y = 122.7x + 172.5
R² = 0.314

(b)


Correlation at 50cm deep of Meidum oil field area
Gamma (nSv/hr)
250
200
150
100
50
0
0
0.05
0.1
0.15
0.2
0.25
0.3
Radon Concentration (kBq/m3)
y = 103.7x + 173.9
R² = 0.247

(c)



(d)

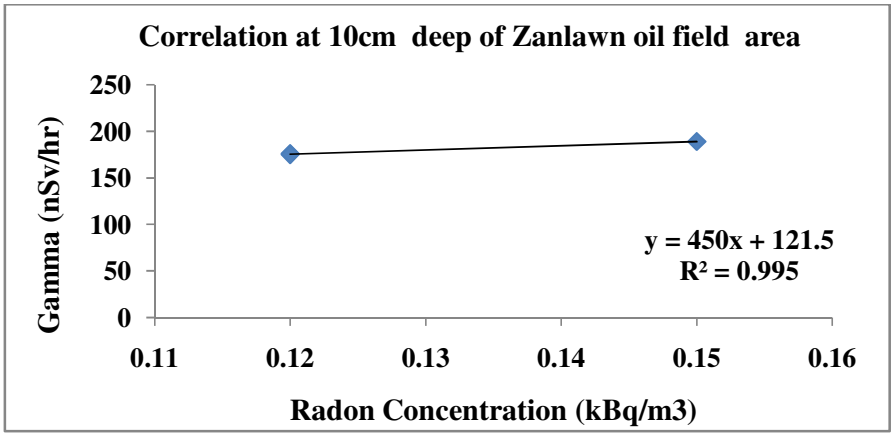
Fig. 4.7. Correlation between Ground level gamma radiation and Radon concentration at different depth of Meidum oil field.

(a). Correlation at 10cm deep. (b). Correlation at 30cm deep

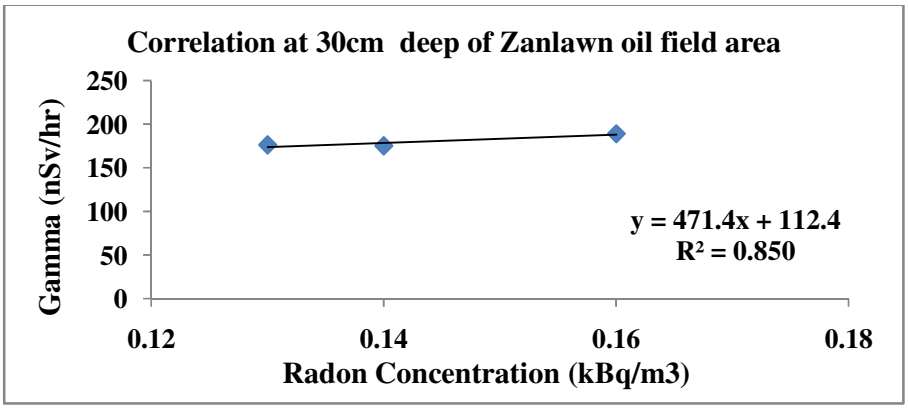
(c). Correlation at 50cm deep (d). Correlation at 70cm deep.

Correlation at Zanlawn oil field area:

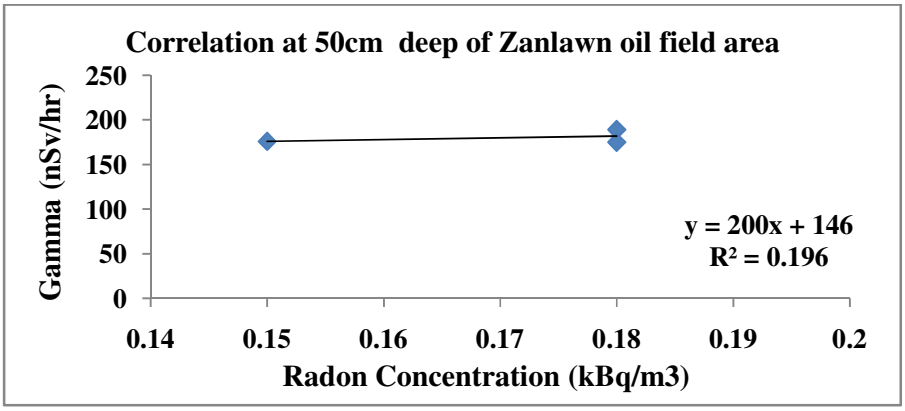
The figure 4.8. shows the correlation graph between Ground level gamma radiation and average radon concentration at 10cm, 30cm, 50cm and 70cm deep of Zanlawn oil exploration area respectively.



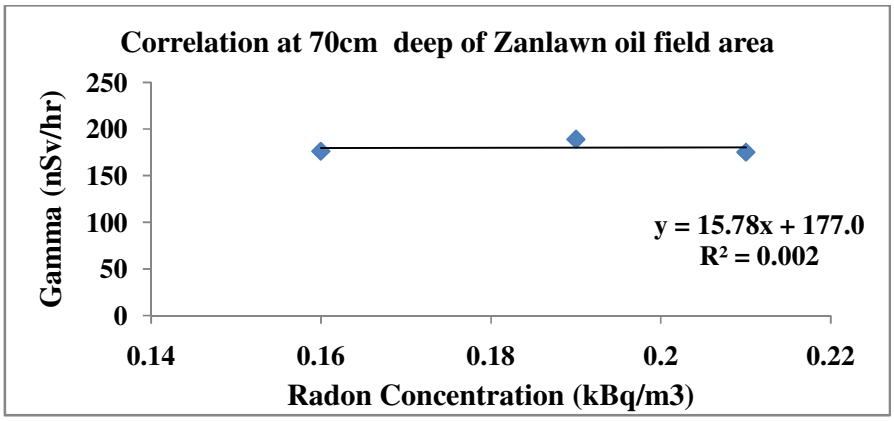
(a)



(b)



(c)



(d)

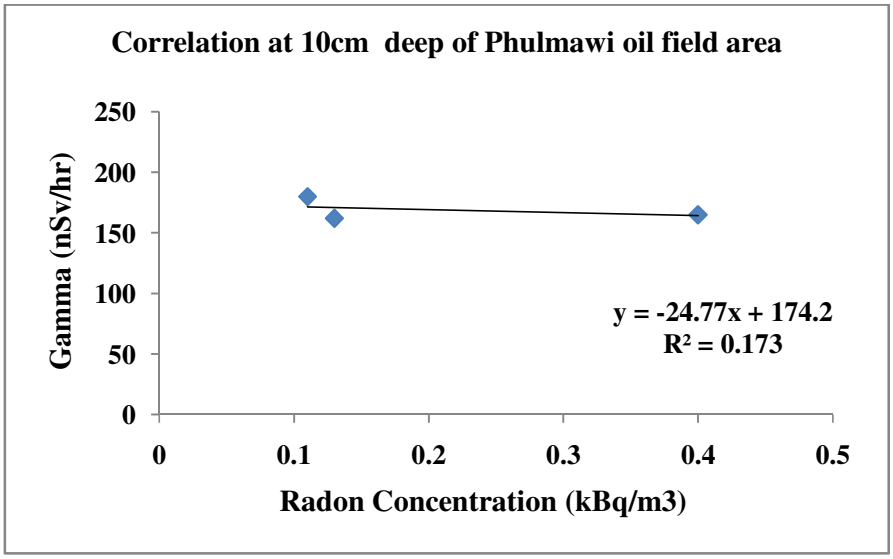
Fig. 4.8. Correlation between Ground level gamma radiation and Radon concentration at different depth of Zanlawn oil field.

(a). Correlation at 10cm deep. (b). Correlation at 30cm deep

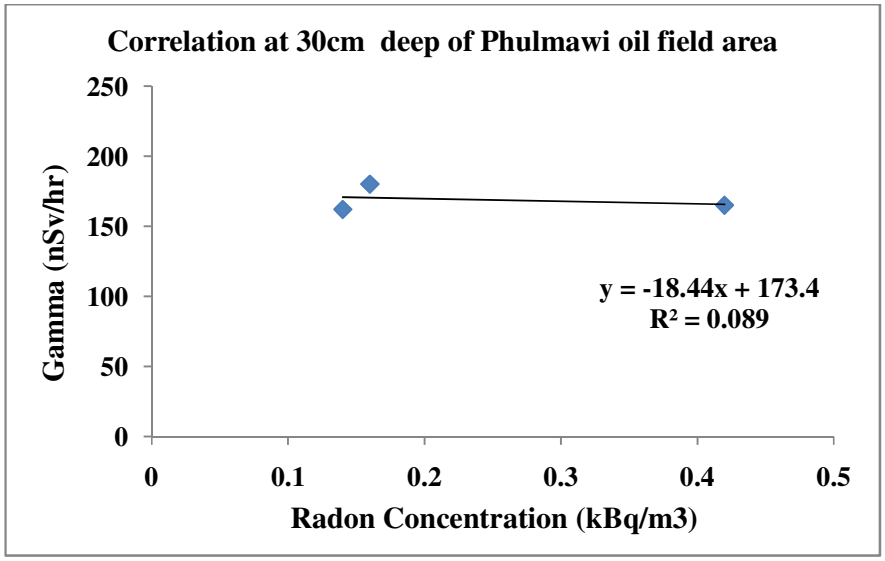
(c). Correlation at 50cm deep (d). Correlation at 70cm deep.

Correlation at Phulmawi oil field area:

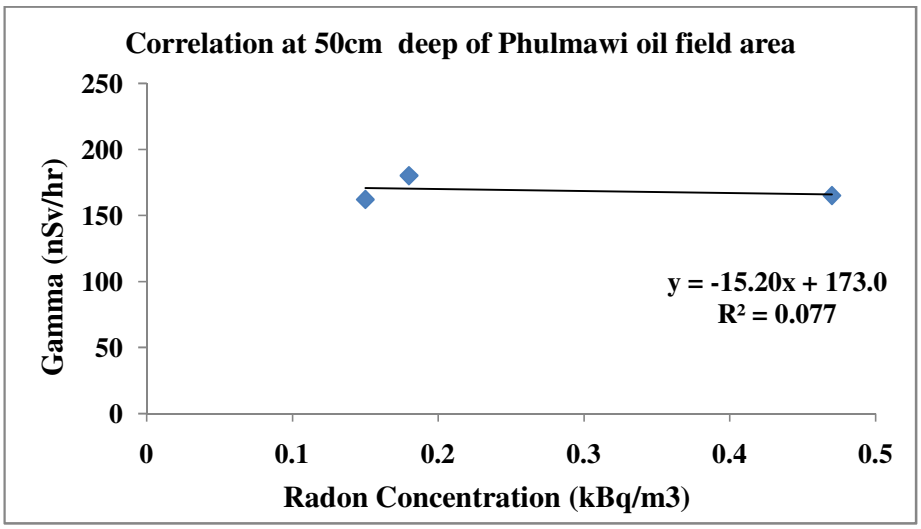
The figure 4.9. shows the correlation graph between Ground level gamma radiation and average radon concentration at 10cm, 30cm, 50cm and 70cm deep of Phulmawi oil exploration area respectively.



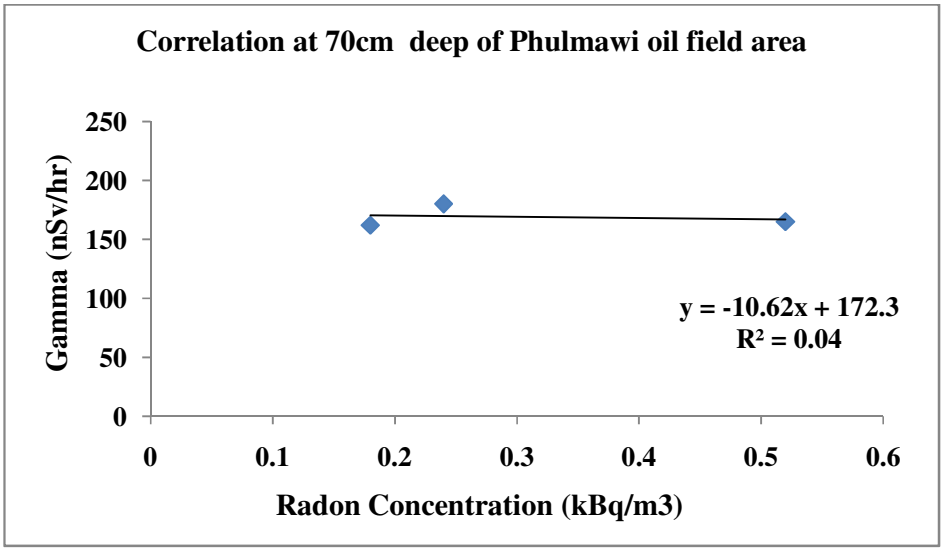
(a)



(b)



(c)



(d)

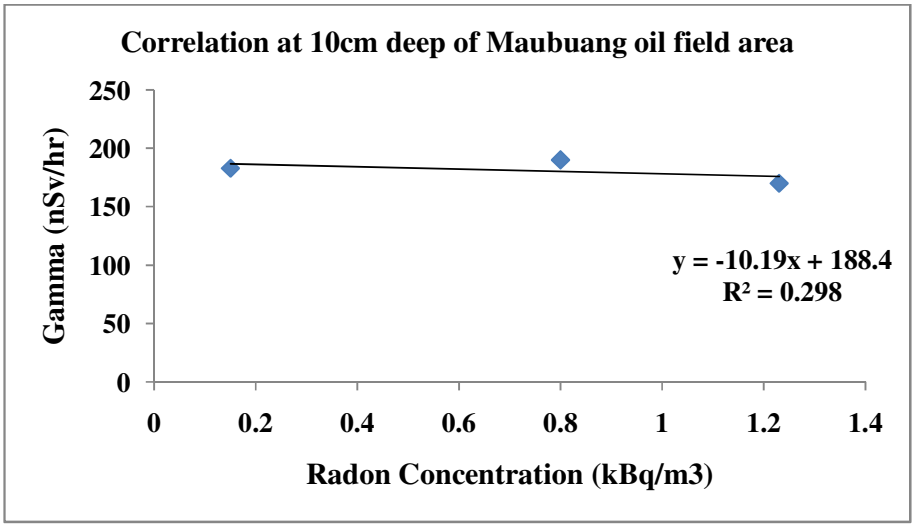
Fig. 4.9. Correlation between Ground level gamma radiation and Radon concentration at different depth of Phulmawi oil field.

(a). Correlation at 10cm deep. (b). Correlation at 30cm deep

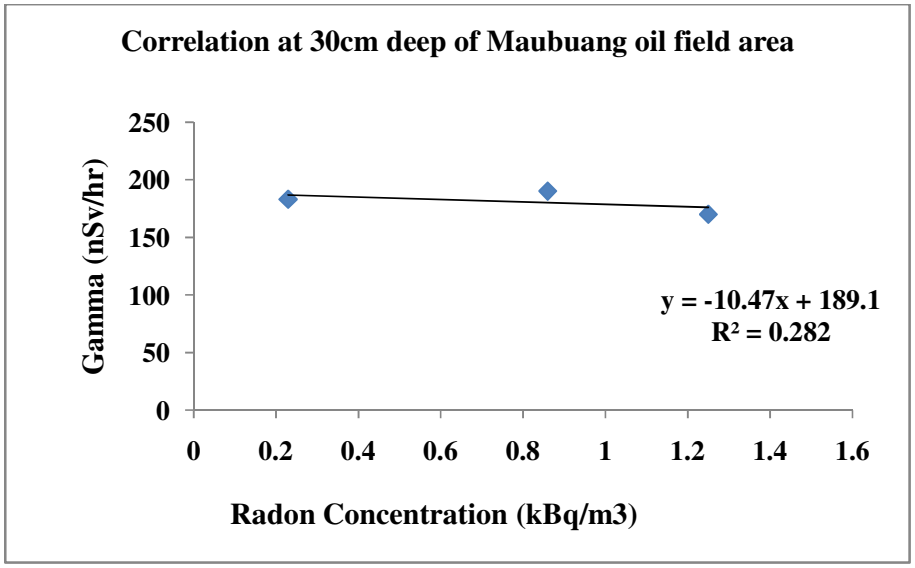
(c). Correlation at 50cm deep (d). Correlation at 70cm deep.

Correlation at Maubuang oil field area:

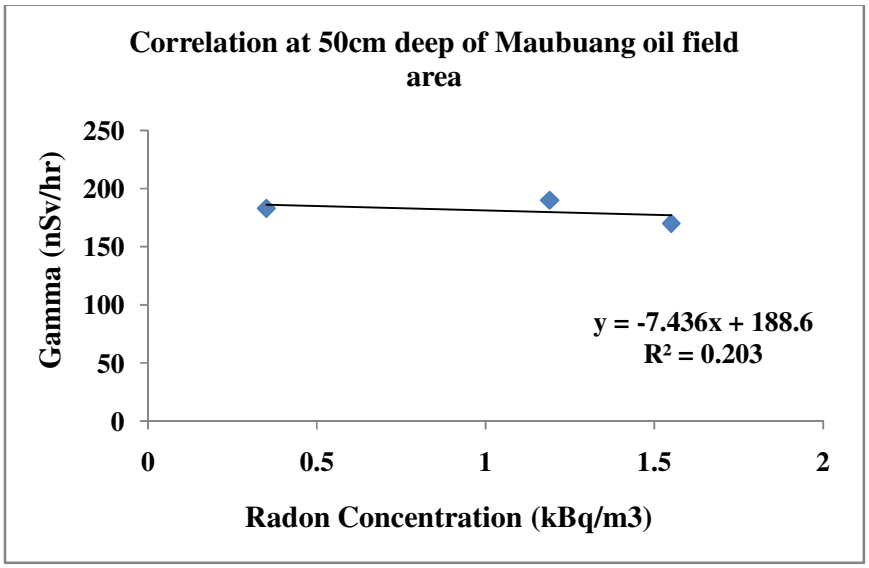
The figure 4.10. shows the correlation graph between Ground level gamma radiation and average radon concentration at 10cm, 30cm, 50cm and 70cm deep of Maubuang oil exploration area respectively.



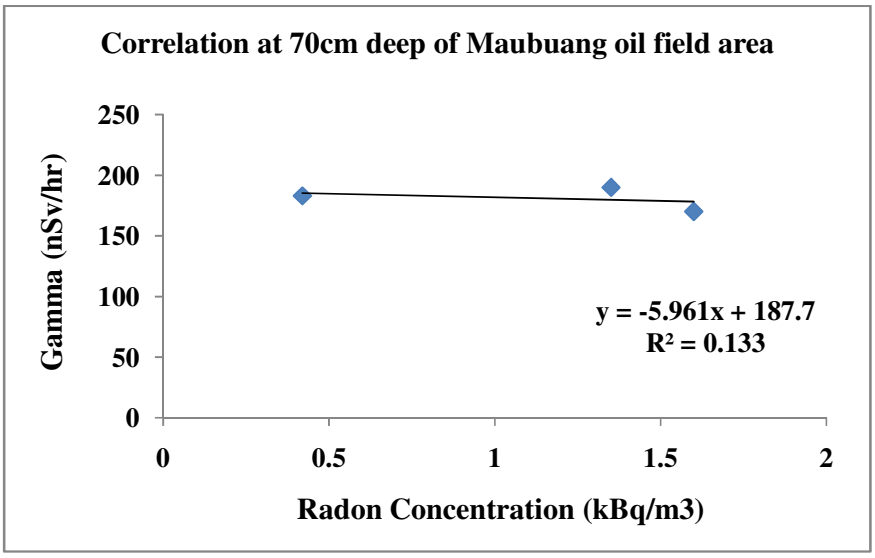
(a)



(b)



(c)



(d)

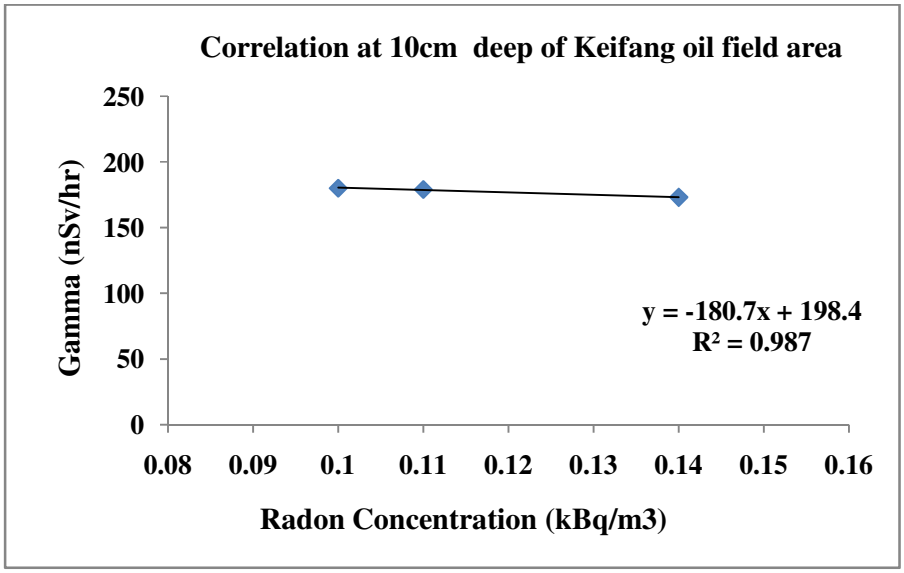
Fig. 4.10. Correlation between Ground level gamma radiation and Radon concentration at different depth of Maubuang oil field.

(a). Correlation at 10cm deep. (b). Correlation at 30cm deep

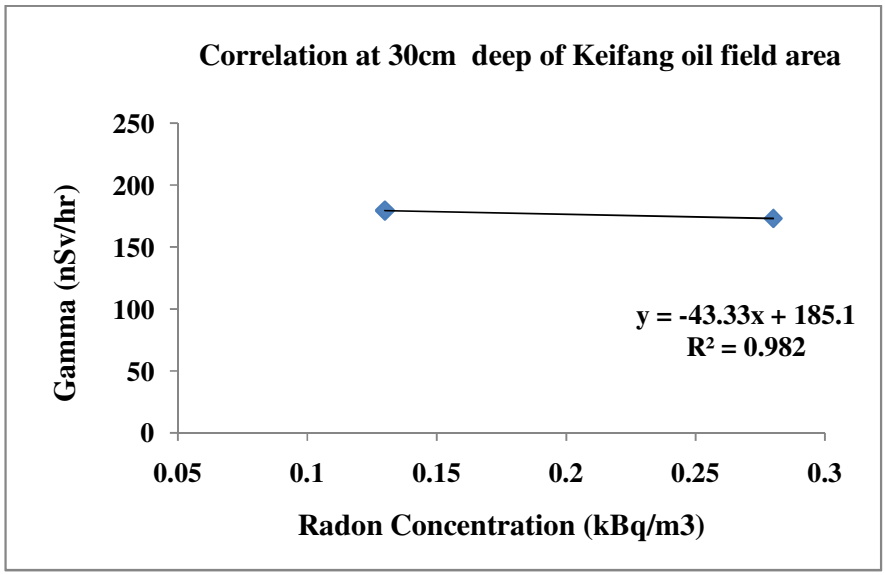
(c). Correlation at 50cm deep (d). Correlation at 70cm deep.

Correlation at Keifang oil field area:

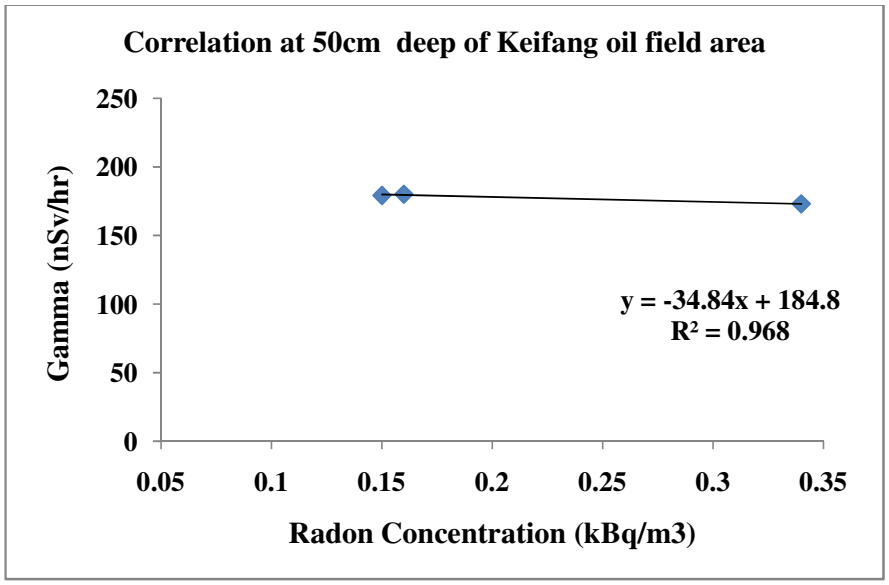
The figure 4.11. shows the correlation graph between Ground level gamma radiation and average radon concentration at 10cm, 30cm, 50cm and 70cm deep of Keifang oil exploration area respectively.



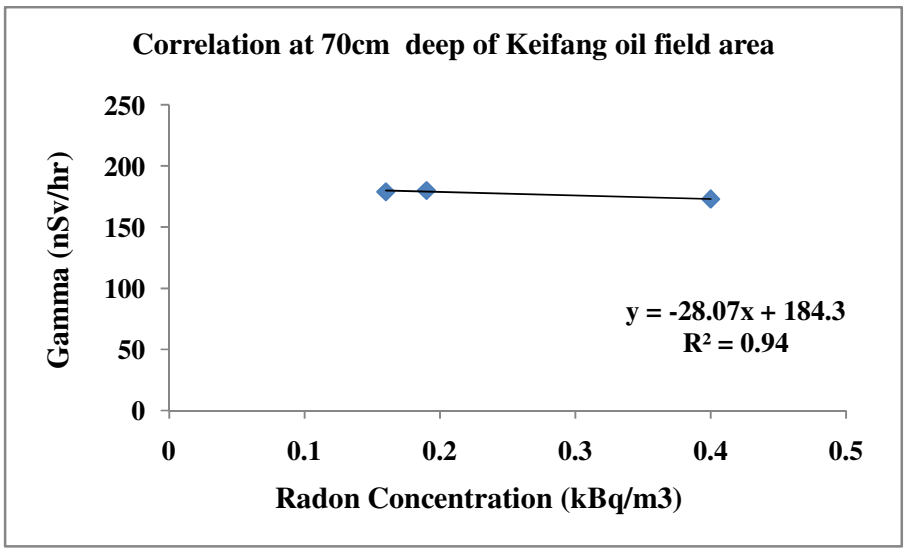
(a)



(b)



(c)



(d)

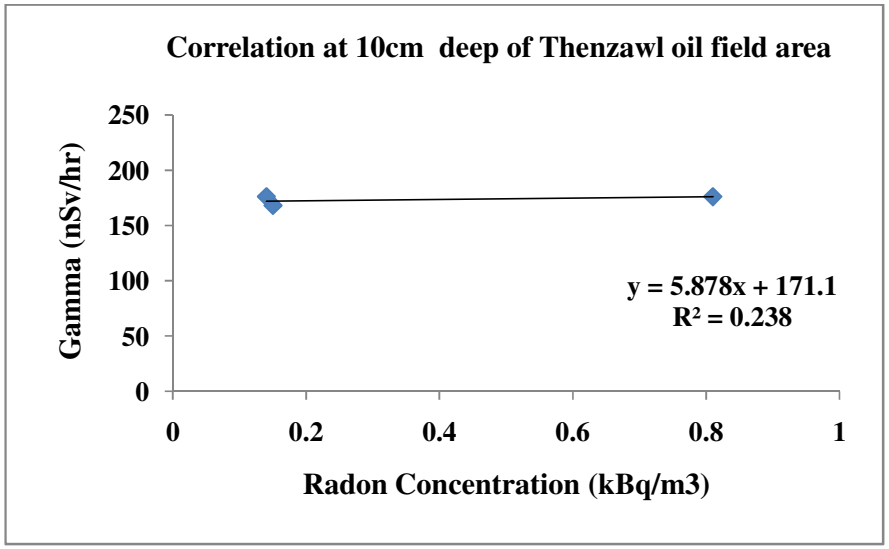
Fig. 4.11. Correlation between Ground level gamma radiation and Radon concentration at different depth of Keifang oil field.

(a). Correlation at 10cm deep. (b). Correlation at 30cm deep

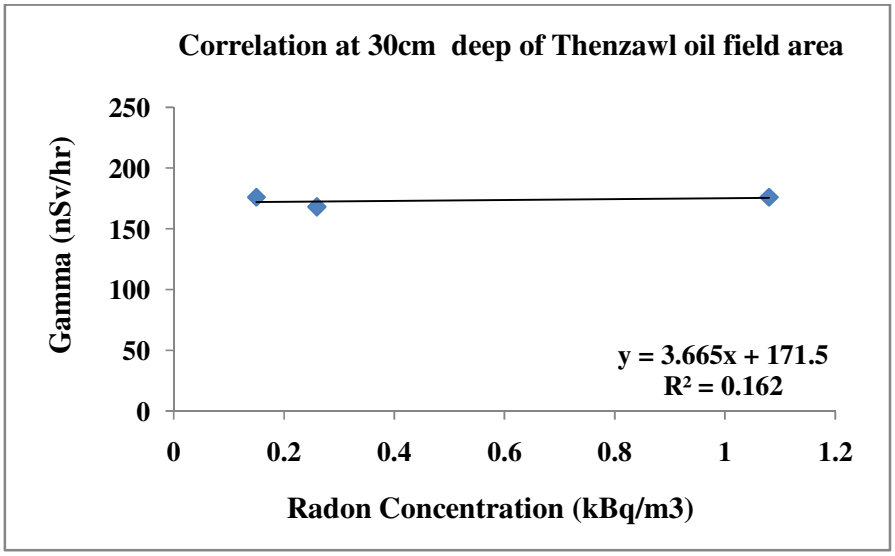
(c). Correlation at 50cm deep (d). Correlation at 70cm deep.

Correlation at Thenzawl oil field area:

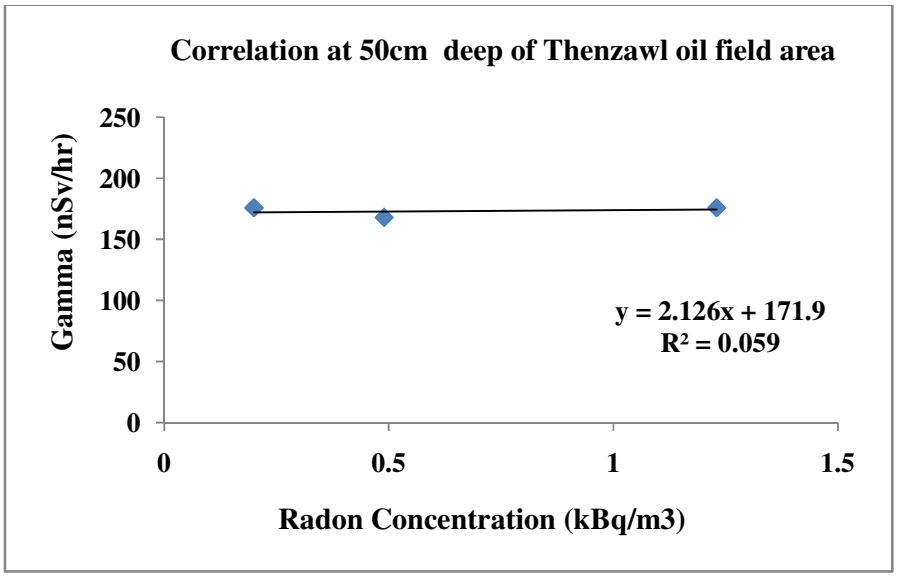
The figure 4.12. shows the correlation graph between Ground level gamma radiation and average radon concentration at 10cm, 30cm, 50cm and 70cm deep of Thenzawl oil exploration area respectively.



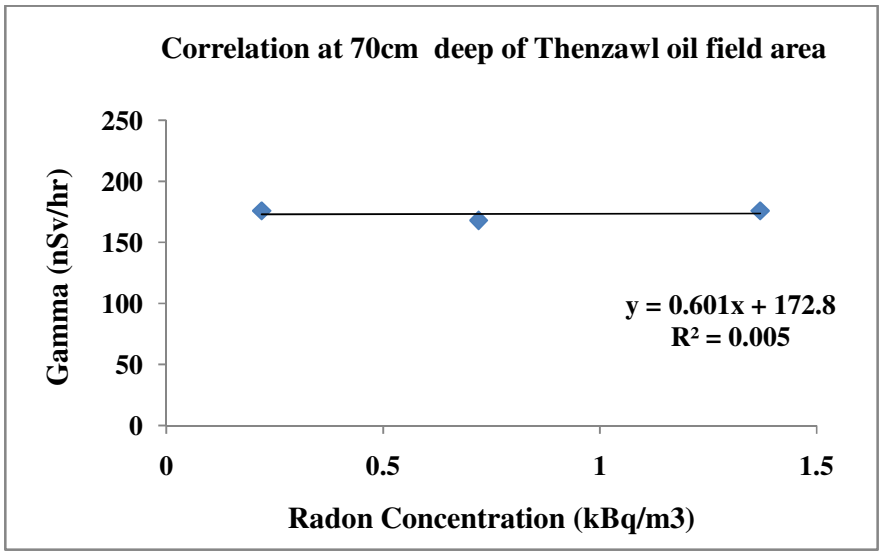
(a)



(b)



(c)



(d)

Fig. 4.12. Correlation between Ground level gamma radiation and Radon concentration at different depth of Thenzawl oil field.

(a). Correlation at 10cm deep. (b). Correlation at 30cm deep

(c). Correlation at 50cm deep (d). Correlation at 70cm deep.

4.3.1. Observations drawn from the correlation graph between gamma radiation and radon concentration:

In all the correlation graph plotted between the background gamma radiation at ground surface and the radon concentration in soil at different baptism depth it is clearly determined that the correlation coefficient decreases as we go deeper and deeper. This means that the correlation coefficient is best at 10cm deep in all the cases and started to decrease slightly at 30cm deep; followed by 50cm and minimum at 70cm deep. This indicates that the background gamma radiation has significant correlation with the radon concentration in soil. The background gamma radiation and the radon concentration nearer to the ground surface have a better correlation as compared to the correlation deeper inside the ground. Both the gamma radiation and the radon gas emanates from terrestrial sources. It is evident that both have a better correlation at the point closest to each other, i.e, at the ground surface area. In the present work the radon concentration closest to the point where the gamma radiation is counted is 10cm deep.

In this research work radon concentration below the ground surface is taken only up to 70cm deep and the radon gas concentration in soil continue to increase.

The correlation graph shows that there is a good correlation between the gamma radiation and the radon concentration at 10cm but a weak correlation at 70cm deep. The best correlation coefficient of 0.995 is seen at 10cm deep in Zanlawn area; whereas the least correlation coefficient of 0.04 is observed at 70cm deep in Phulmawi area. It is thus concluded that the correlation decreases with depth. In the present study between 10cm deep and up to 70cm deep it has been observed that there is a good correlation which decreases as the soil probe is inserted deeper and deeper. This is due to their same parent source of origin, their terrestrial origin.

4.3.2. Depth wise variation of correlation coefficient between gamma radiation and radon concentration of the study areas:

The table 4.3. shows the depth wise correlation coefficient thus obtained between ground level background gamma radiation and radon concentration at different baptism depth of 10cm, 30cm, 50cm and 70cm of each oil exploration areas. As

discussed above, the correlation coefficient at different oil exploration area is maximum at 10cm deep and minimum at 70cm deep.

Table 4.3. Depth wise correlation coefficient of different oil field.

Sl.No	**Study area**	**Baptism Depth (cm)**	**Correlation coefficient (R^2)**
1	Meidum	10	0.466
2	Meidum	30	0.314
3	Meidum	50	0.247
4	Meidum	70	0.165
5	Zanlawn	10	0.995
6	Zanlawn	30	0.850
7	Zanlawn	50	0.507
8	Zanlawn	70	0.196
9	Phulmawi	10	0.173
10	Phulmawi	30	0.089
11	Phulmawi	50	0.077
12	Phulmawi	70	0.04
13	Maubuang	10	0.298
14	Maubuang	30	0.282
15	Maubuang	50	0.203
16	Maubuang	70	0.133
17	Keifang	10	0.987
18	Keifang	30	0.982
19	Keifang	50	0.968
20	Keifang	70	0.940
21	Thenzawl	10	0.239
22	Thenzawl	30	0.162
23	Thenzawl	50	0.059
24	Thenzawl	70	0.005

Fig. 4.13. shows a graph between the correlation coefficient and different study area. From the graph it is clear that there is a good correlation and there is a specific trends of correlation between the ground level background radiation and radon concentration at different baptism depth.

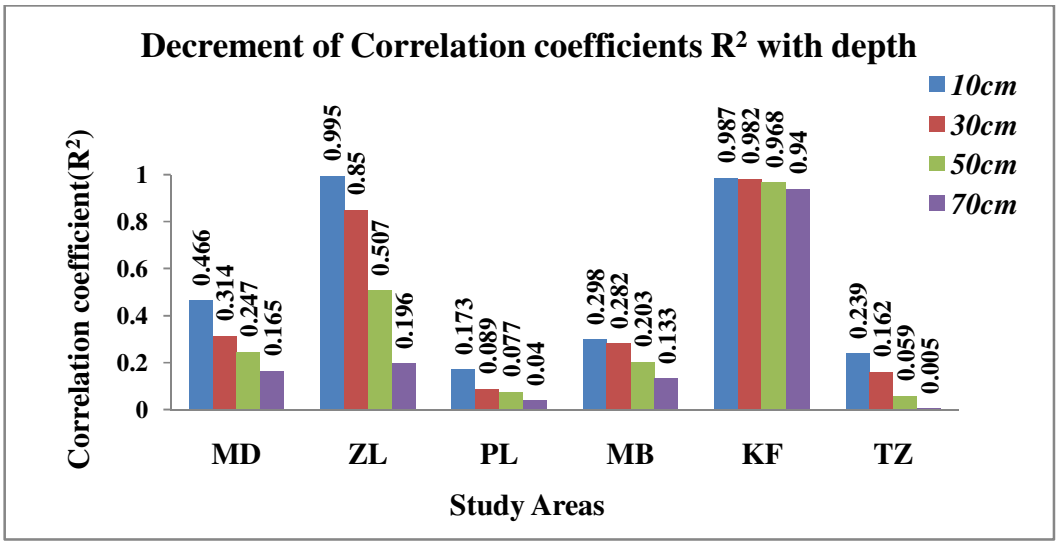


Fig. 4.13. Decrement of R^2 of radon concentration at different depth of study area

4.3.3. Comparison with studies from other areas in India and Pakistan

The study to determine the radon concentration in soil gas and in surrounding dwellings is also carried out at various places in India. The concentration was found to vary between 1.10kBq/m^3 to 31.80kBq/m^3 in the Budhakedar area of Tehri, Garhwal (Prasad *et al.* 2008). In Tusham ring complex Haryana the radon concentration in granitic soil region varies between 42.80kBq/m^3 to 71.50kBq/m^3 and that for non granitic soil region it varies from 17.4kBq/m^3 to 49.7kBq/m^3 17.4 (Bajwa *et al.* 2010). In Tusham ring complex dwelling areas of granitic region the radon concentration vary between 109 Bq/m^3 to 1006 Bq/m^3 whereas in non granitic areas of dwellings it varies from 60 Bq/m^3 to 235 Bq/m^3 (Bajwa *et al.* 2010). The radon concentration in soil gas also ranges from 0.01 kBq/m^3 to 2.33 kBq/m^3 in Garhwal, Himalaya (Bourai *et al.* 2013). The radon concentration as reported from Hamirpur district, Himachal Pradesh, India varies between 0.03kBq/m^3 to 2.28kBq/m^3 (Mehra and Bala 2013). In Kangra district, Himachal Pradesh the radon soil gas

concentration varies from 1.10kBq/m^3 to 82.20kBq/m^3 (Singh *et al.* 2006) and in Gangadhar district of Rajasthan the radon gas concentration varies between 0.09kBq/m^3 to 10.40kBq/m^3 (Duggal *et al.* 2014). The radon gas concentration in Malwa belt, Punjab is found to vary between 1.90kBq/m^3 to 16.40kBq/m^3 (Kumar *et al.* 2011). The soil radon concentration in Upper Siwaliks ranger from 11.50kBq/m^3 to 78.47kBq/m^3; whereas the indoor radon concentration in the study area varies between 71.7 Bq/m^3 to 421.7 Bq/m^3 (Singh *et al.* 2010). Most of the Radon Concentration in Soil Gas and dwellings as obtained from various other locations falls within the range of the present investigation except those in the granitic soil and non-granitic soil of Tusham ring complex of Haryana and radon concentration in soil of Upper Siwaliks, India.

Radon concentration in soil is also carried out in some part of Pakistan. The radon concentration in Islamabad, Pakistan ranges from 17.34kBq/m^3 to 72.52kBq/m^3 (Ali *et al.* 2010). In Murree, Pakistan it ranges from 0.61kBq/m^3 to 3.59kBq/m^3 (Ali *et al.* 2010), and in Southern Punjab, Pakistan it ranges from 0.42kBq/m^3 to 3.56kBq/m^3 (Mujahid *et al.* 2010) respectively.

Dwelling place radon concentration is also carried out at non-oil exploration areas in Aizawl district, Kolasib district and Serchhip district respectively. The minimum, maximum and geometric mean value of radon concentration in Aizawl district ranges from 26.91 Bq/m^3, 84.81 Bq/m^3 and 47.56 Bq/m^3 respectively. In Kolasib district it is 21.16 Bq/m^3 , 93.54 Bq/m^3 and 48.76 Bq/m^3 respectively (Lalmuanpuia Vanchhawng, 2009). In Serchhip district the minimum, maximum and average value were reported as 28.05 Bq/m^3, 72.49 Bq/m^3 and 43.84 Bq/m^3 respectively (P.C. Rohmingliana, 2010).

Outdoor and indoor radon concentration in dwelling place is also measured in oil refinery areas and non-oil refinery areas. The outdoor environment radon concentration in oil refinery areas varies between 46.1 Bq/m^3 to 190.3 Bq/m^3. In the dwelling place, the indoor radon concentration varies between 55.3 Bq/m^3 to 195.8 Bq/m^3. The indoor radon concentration in non oil refinery dwellings ranges from 34.5 Bq/m^3 to 129.6 Bq/m^3 respectively (Kant *et al.* 2004)

Table 4.4. shows the radon gas concentration in soil as well as dwelling areas at various regions obtained by different researchers in India, Pakistan and different districts of Mizoram. The minimum baptism depth taken by some researcher is 5cm and the maximum depth chosen is 120cm. In the present study we have chosen a baptism depth between 10cm to 70cm.

Table 4.4. Radon gas Concentration in soil, environment, indoor outdoor dwelling area at various places in Mizoram, India and Pakistan

Sl. No	**Locations**	**Concentration kBq/m^3. (5cm-120cm)**	**References**
1	Tusham ring, Haryana granitic regions	42.8 - 71.5	(Bajwa *et al.* 2010)
2	Islamabad, Pakistan, soil	17.34 - 72.52	(Ali *et al.* 2010)
3	Tusham ring, Haryana non-granitic regions	16.3 - 44.1	(Bajwa *et al.* 2010)
4	Upper Siwaliks, India, soil	11.50 - 78.47	(Singh *et al.* 2010)
5	Malwa belt, Punjab, soil	1.90 - 16.40	(Kumar *et al.* 2011)
6	Kangra district, HP, soil	1.10 - 82.20	(Singh *et al.* 2006)
7	Budhakedar, Tehri Garhwal, soil	1.10 - 31.80	(Prasad *et al.* 2008)
8	Murree, Pakistan, soil	0.61 - 3.89	(Ali *et al.* 2010)
	Islamabad, Pakistan, air	0.043 - 0.097	(Ali *et al.* 2010)
9	Southern Punjab, Pakistan, soil	0.42 - 3.56	(Mujahid *et al.* 2010)
10	***Oil field area Mizoram***	0.10 - 1.6	***Present investigation***
11	Gangadhar Dist Rajasthan, air	0.09 - 10.40	(Duggal *et al.* 2014)
12	Hamirpur district, HP, soil	0.035 - 2.28	(Mehra and Bala 2013)
13	Hamirpur district, HP, air	0.035 - 0.096	(Mehra and Bala 2013)
14	Serchhip district, Mizoram, Dwellings	0.028 - 0.072	(Rohmingliana 2010)
15	Aizawl district, Mizoram, Dwellings	0.027 - 0.085	(Lalmuanpuia 2009)
16	Kolasib district, Mizoram Dwellings	0.021 - 0.093	(Lalmuanpuia 2009)
17	Oil refinery environment,	0.046 - 0.190	(Kant *et al.* 2004)

	Haryana		
18	Oil refinery dwelling, Haryana	0.055 - 0.195	(Kant *et al.* 2004)
19	City dwelling, Haryana	0.034 - 0.129	(Kant *et al.* 2004)
20	Murree, Pakistan, air	0.018 - 0.042	(Ali *et al.* 2010)
21	Garhwal Himalaya, soil	0.012 - 2.33	(Bourai *et al.* 2013)

The radon concentration in soil gas of oil exploration areas is found to be higher than the dwelling radon concentration of non oil exploration areas. But the soil radon concentration as obtained in the study areas were found to be less than the worldwide average value of 35kBq/m^3 for outdoor radon activity recommended by United Nations Scientific committee on the Effects of Atomic Radiation (UNSCEAR 2000).

The fig. 4.14. shows minimum and maximum radon concentration in soil of some areas taken from Table 4.4. The Radon Concentration in Soil of the study areas were found to be less than the worldwide average value of 35kBq/m^3 for outdoor radon activity recommended by United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR 2000).

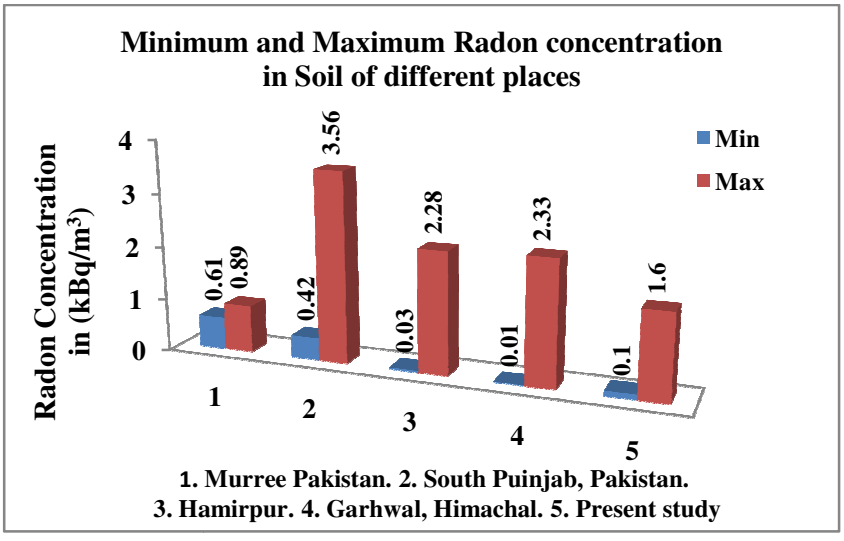


Fig. 4.14. Comparison of minimum and maximum radon concentration in soil of some areas in India and Pakistan.

The fig. 4.15. shows minimum and maximum radon concentration in dwellings and outdoor environment of some areas taken from Table 4.4 above. The Radon Concentration obtained in the study areas were very high as compared to the radon gas concentration in dwellings and environment of oil refinery areas and non oil exploration areas. This is due to the presence of fossil fuels like natural gas, liquefied petroleum gas, crude oils and many petroleum products.

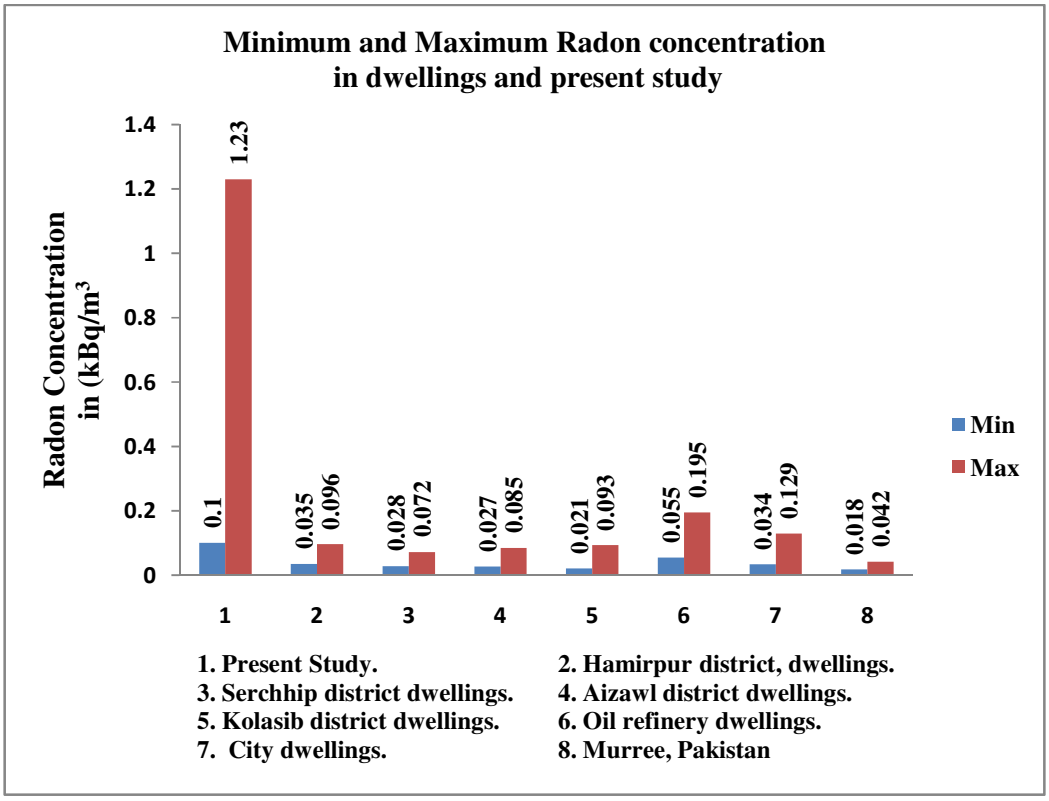


Fig. 4.15. Comparison of minimum and maximum radon concentration in dwellings of some areas in India and Pakistan with the present study

The radon concentration at 10cm deep of the present study is compared with the radon concentration of dwellings in Aizawl district, Serchhip district and Kolasib district. It is found that the radon concentration differ by a considerable value.

5

Conclusion

This chapter is the concluding part of the thesis on, "Radon Characterization in soil of oil exploration areas in Mizoram, India". Soil characterization research includes mainly, 'radon mass exhalation rate calculation; plotting the slope of radon concentration with radon mass exhalation rate; measuring the soil radioactivity using sodium iodide thulium detector and finding the activity concentration of uranium thorium and potassium radionuclides from the soil samples. It also capsule the characterization in studying the background gamma radiation and locating the global positioning system coordinate to make it accurate in many field. The soil type and grain size of the soil is also measured with different sieve mesh to find the contributing soil. Radon content in water from the nearby running water is studied and along with that the uranium content of the same water is also studied. The correlation graph radon concentration in water and the uranium or radium content in water is plotted as well.

Radon characterization research work was carried out in all the six oil exploration areas of Mizoram, India. These includes Meidum and Zanlawn field in Kolasib district; Phulmawi, Maubuang and Keifang oil field in Aizawl district and Thenzawl oil field in Serchhip district respectively. In Kolasib district, Meidum oil field area stretches from 24º10'11.8"N to 24º10'12.9"N latitude and between 92º35'55.4"E to 92º35'58.8"E longitude with an elevation range of 291ft to 331ft from sea level. And that of Zanlawn oil field area stretches from 23º59'01.0"N to 23º59' 02.6"N latitude and between 92º42'47.8"E to 92º42'50.8"E longitude with an elevation range of 2110 ft and 2900 ft from sea level. In Aizawl district, Phulmawi oil field area stretches from 23º35'29.9"N to 23º35'33.1"N latitude and between 92º51'23.0"E to 92º51'25.0"E longitude with an elevation range of 2900 ft and 2956 ft from sea level; that of Maubuang oil field area stretches from 23º29'42.7"N to 23º29' 47.3"N latitude and between 92º42'3.6"E to

92º42'5.8"E longitude with an elevation range of 2870 ft and 2885 ft from sea level and that of Keifang oil field area stretches from 23º39'12.5"N to 23º39'14.2"N latitude and between 92º57'0.9"E to 92º57'1.7"E longitude with an elevation range of 2915ft to 2927ft from sea level. In Serchhip district, Thenzawl oil field area stretches from 23º18'08.3"N to 23º18'12.4"N latitude and between 92º42'5.8"E to 92º47'11.9"E longitude with an elevation range of 2454 ft and 2483 ft from sea level.

Firstly, the radon mass exhalation rate was measured using an active method base on scintillation instrument SMART RnDuo. Although it is suggested that the measurements are to be taken for a duration of 8 - 10 hours (Handbook on Radon Transport Models and Measurement Method, 2017); to get a more accurate result, measurement for radon mass exhalation is done for a duration of 22 hours. The experimental data are fitted using a linear square fitting and the graph shows a positive correlation in all the soil samples of all the oil field. The slope between the slope of radon concentration in soil and the radon mass exhalation rate of all the oil field also show a positive correlation. This indicates the presence of radon gas in the study area and that the instrument utilized for the study, namely the Smart RnDuo is reliable. The mass exhalation rate of radon in soil samples ranges from 7.27 mBq/kg/hr in maubuang-3 location to 23.49 mBq/kg/hr in maubuang-2 location with an average of 13.82 mBq/kg/hr. The radon mass exhalation rate obtained was found to be lower than the results obtained by other researcher using the same procedure and instrument (Kaushal *et al*., 2017; Amanjeet *et al*., 2018).

Secondly, calculation of soil radioactivity is carried out with sodium iodide (NaI) detector, having thallium (Tl) as a doping agent. Since soil is considered to be the main source of natural radioactivity, knowing the natural radioactivity present in soil is eminent. The detector was coupled with a PC based 1K Multichannel analyzer called GSPEC-SA. The radioactivity concentration was determined for three specific radionuclide, namely ^{238}U, ^{232}Th and ^{40}K from the soil samples collected from the sampling sites. The average values of activity concentration of ^{238}U is found to be

17.86Bq/kg which is well within the worldwide average value of 35 Bq/kg, given in UNSCEAR (2000). However, the average activity concentration of ^{232}Th, which is found to be 50.92Bq/kg and for ^{40}K nuclide found to be 644.38 Bq/kg exceeded the corresponding worldwide average values of 30 Bq/kg and 400 Bq/kg respectively (UNSCEAR, 2000). Although the results obtained for ^{232}Th and ^{40}K were higher than the corresponding worldwide average values, the average radioactivity concentration obtained for the three radionuclide were all found to be well within the critical value set by IAEA (2004), the critical values being 10,000 Bq/kg for ^{40}K and 1000 Bq/kg for both ^{238}U and ^{232}Th radionuclide. To represent the activity concentration of ^{238}U, ^{232}Th and ^{40}K into a single quantity with respect to exposure to radiation, the radium equivalent activity was calculated and the measured values of radium equivalent activity concentration of all the oil field area is found to be 135.78 Bq/Kg which is lower than the safe limit value of 370 Bq/kg, prescribed by OECD (1979). The result obtained in this report shows that there is no radiological health hazards from the measured activity concentration of natural radionuclide.

Thirdly, background gamma radiation detection is carried out with Gamma Survey Meter PM 1405, which is a Geiger-Muller counter based measuring instrument by a transformation of photon to electro-pulses. The background gamma radiation is taken for ground level as well as 1m above the earth surface. This is done to ensure the terrestrial contribution of gamma radiation as well as the cosmic contribution of the background gamma radiation. The ground level background gamma radiation of all the oil exploration area ranges from 162 nSv/hr in phulmawi-3 area to 202 nSv/hr in meidum-1 area. The average ground level background gamma radiation is 179 nSv/hr. The background gamma radiation at 1`m (one meter) above the earth surface of all the 18 site ranges from 140 nSv/hr at meidum-3 area to 176 nSv/hr at meidum-1 area. The average background gamma radiation at 1m above the earth surface is 156 nSv/hr. It is clearly seen that the background gamma radiation at the ground surface is higher than that at 1m above the ground surface. This indicates that the terrestrial contribution of gamma radiation is higher by a certain amount than the extra-terrestrial or the cosmic

contribution. The background Gamma radiation level obtained were all found to be higher in comparison with the values reported by UNSCEAR (2000) for different countries (mean of 59 nGy/h in the range of 18- 93 nGy/h), but was within the given range of background gamma level for India (89 nGy/h in the range of 27–3051 nGy/h) (Nambi*et al.*, 1986).

Global Positioning System location is taken for all sample spot of all the oil exploration areas. A special device called Garmin GRB 21 is utilizes for the purpose. All the six oil field are located stretches from $23^0$18'10.2"N latitude at thenzawl-1 location to 92^0 57'1.7"E longitude at keifang-2 location.

Fourthly, radon mass exhalation rate is found to be greatly affected by the soil moisture content. For identification of soil type using the process of sieving, a Mechanical Sieve Shaker was employed to enable quality assurance of the result. Different types of soil have different grain size, and the grain size determines the ability for soil to retain moisture. This is because mechanical parameters such as sieving time, speed and amplitude are carried out with exact reproducibility in a Mechanical Sieve Shaker. Out of the total 18 soil samples collected, on an average 86.74% are sand, 5.11% are silt and 8.14% are clay. On Comparison with the observed radon mass exhalation rate it is learnt that a higher quantity of smaller grain size does not necessarily indicate the higher exhalation value. In the present research work the grain size does not necessarily increase the radon mass exhalation rate, even though the rate of exhalation by radon mass is inversely proportional to the grain size of the soil. The United States Department of Agriculture (USDA) Triangular Plot for determination of soil type for oil field in Kolasib district, Aizawl district and Serchhip district respectively indicates that all the soil samples fall under "sand" and "sand loam".

Fifthly, the main instrument that led to the concluding part of this research work includes SMART RnDuo, which is a scintillation based radon and their progeny detector. It is based on the methodology of an α-particle detector. This method is highly reliable

and sensitive for the measurements of radon and their progeny. The radon concentration in water is carried out with Smart RnDuo. It is important to assess the level or radon in our habitations and water sources, as radon is a naturally occurring gas. The measured values of radon content in water ranged from 0.34 Bq/l to 4.33 Bq/l. The measured values of radon concentration in water for all the oil exploration areas were found to be well lesser than the safe limit range of 4-40 Bq/L for radon concentration in drinking water as recommended by UNSCEAR (1993). The total average radon content in water of all the oil field area was found to be 1.26 Bq/L which was far below the safe limit of 11 Bq/L prescribed by US EPA (EPA, 1998).

Sixthly, an important instrument employed for the measurement of Uranium concentration in water samples is LED Fluorimeter LF-2a, which works on the principle of the measurement of green fluorescence produced by uranium on the addition of a buffer solution. The uranium content in water of all the oil exploration area ranges from 0.213 µg/l at zanlawn-2 location to 0.643 µg/l at meidum-2 location with an average value of 0.323 µg/l. The measured values of uranium concentration in water of all the oil exploration areas were found to be well within the safe limit value of 30 µg/l for drinking water as prescribed by WHO (2011). The values obtained were also much lower than the critical value of 60 µg/l, suggested in India by the Atomic Energy Regulation Board (AERB, 2004). Hence, there is no radiological risk due to ingestion of water containing uranium in this study. Also, the measured pH values ranged from 6.80 to 7.25, with an average value of 7.025. The pH value of all collected samples were found to be well within the safe limit value of 6.5- 8.5 for drinking water, as recommended by BIS (1991).

Lastly, the heart of the study of this research work, namely, ‘an *in-situ* measurement of radon concentration inside the soil at different baptism depth is studied carefully to know the difference in the radon concentration. Soil probe provided with Smart RnDuo system is utilized for the measurement of radon gas concentration in soil. The soil probe is first baptized to 10cm deep and the radon concentration at 10cm deep is noted. The probe is further baptized to 30cm deep and the radon concentration noted.

Then the probe is further baptized to 50cm deep and the concentration recorded. Finally, the probe is further baptized to 70cm deep and the concentration noted. Meidum oil exploration area has a maximum radon concentration of 0.31 kBq/m^3 at 70 cm deep and a minimum of 0.1 kBq/m^3 at a 10cm deep. Zanlawn oil exploration area has a maximum radon concentration of 0.19 kBq/m^3 at 70 cm deep and a minimum of 0.12 kBq/m^3 at a 10cm deep. Phulmawi oil exploration area has a maximum radon concentration of 0.52 kBq/m^3 at 70 cm deep and a minimum of 0.11 kBq/m^3 at a 10cm deep. Maubuang oil exploration area has a maximum radon concentration of 1.6 kBq/m^3 at 70 cm deep and a minimum of 0.15 kBq/m^3 at a 10cm deep. Keifang oil exploration area has a maximum radon concentration of 0.4 kBq/m^3 at 70 cm deep and a minimum of 0.1 kBq/m^3 at a 10cm deep. Thenzawl oil exploration area has a maximum radon concentration of 1.37 kBq/m^3 at 70 cm deep and a minimum of 0.14 kBq/m^3 at a 10cm deep. The minimum radon concentration in soil of 0.10 kBq/m^3 is observed at meidum-3 and keifang-2 locations and a maximum radon concentration of 1.60 kBq/m^3 is obtained at maubuang-2 location. The average radon concentration at 10cm deep of all the oil exploration area is 0.285 kBq/m^3 and at 30cm deep it is 0.335 kBq/m^3. The average radon concentration at 50cm deep is 0.417 kBq/m^3 and at 70cm deep it is 0.476 kBq/m^3.

In all the cases, the radon concentration thus obtained from all the study area lies well within the range reported by other investigator from India and Pakistan as shown in Table 4.4. The table also show the radon concentration in dwellings and in the environment of oil refineries and non oil refinery areas. Whereas the average radon concentration in soil at 10cm deep of the present study ranges from 0.10kBq/m3 to 1.23kBq/m^3 the radon concentration in non oil exploration areas in dwelling areas of Aizawl district ranges from 0.027 kBq/m^3 to 0.085 kBq/m^3; in Kolasib district dwelling areas it ranges from 0.021 kBq/m^3 to 0.093 kBq/m^3; and in Serchhip district dwelling areas the radon concentration ranges from 0.028 kBq/m^3 to 0.072 kBq/m^3 respectively. The Radon Concentration obtained in the study areas were very high as compared to the radon gas concentration in dwellings and environment of oil refinery areas and non oil exploration areas. This is due to the presence of fossil fuels like natural gas, liquefied

petroleum gas, crude oils and many petroleum products inside the ground. But the maximum radon concentration of 1.6 kBq/m^3 is well within the safe limit of 35 kBq/m^3 for outdoor radon activity recommended by United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR 2000).

A correlation coefficient between the background gamma radiation and radon concentration in soil at different baptism depth of all the oil exploration area shows that the correlation coefficient is best with 10cm depth and least at 70cm depth. This means that the correlation coefficient is best at 10cm deep in all the cases and started to decrease slightly at 30cm deep; followed by 50cm and minimum at 70cm deep. The finding indicates that the background gamma radiation has significant correlation with the radon concentration in soil. The best correlation coefficient of 0.995 is seen at 10cm deep in Zanlawn area; whereas the least correlation coefficient of 0.04 is observed at 70cm deep in Phulmawi area. It is thus concluded that there is a good correlation between the gamma radiation and radon concentration in soil. This is due to their similar parent source of origin, their terrestrial origin.

Research work thus conducted are useful for identifying the key sources of radon and its health consequences. Considering the adverse health effects of radioactive nuclei such as uranium, radon and their progeny, measurement of their concentration in the soil, water and atmosphere through their level of decay products in the nature population have become very essential from a radiation protection perspective. Radon and the radon decay series contribute to a major part of the radiation exposure to the general public and its progeny lead to the development of lung cancer if inhaled in high concentrations for long periods (Lubin *et al*. 1995; Miles 1998). The lung cancer in return leads to a number of deaths worldwide (Yoon *et al*., 2018). Due to short half- lives radon and radon daughter decay products, when they are inhaled, can easily deposit on the lining of the lung (Brill *et al.* 1994; Gillmore *et al.* 2000). Lung cancer in cigarette smokers is further identified as being enhanced by radon (Robertson *et al*., 2013). Therefore, the International Agency for Research on Cancer (IARC) classified Radon-222 and its decay

products as group 1 carcinogen, i.e. they are potentially carcinogenic to humans (El *et al*., 2009). Although radon in water, mass exhalation rate, uranium concentration in water and the soil radioactivity in the study area are mostly lower than the world average, cancer is a very prominent illness especially lung cancer.

The result and observation of this research work will be considered helpful in estimating the radiological exposure of the general populations residing in the oil exploration areas of Mizoram in the radiological mapping of India. It is evident that the population of dwellers in oil exploration areas is increasing day after day. The health concern of the general public needs to be attended in all respect. With this research work it is concluded that there is no risk of negative health concern originating from radiological background in all the oil exploration areas in Mizoram. The general population and dwellers of these areas are safe from any radiological nuclei originating from uranium, radon and their progeny.

REFERENCES

Abdallaha M.S., Rima R.H., Rida Y.N., Malek Chatilac, Gabriel Katuld (2007). Radon measurements in well and spring water in Lebanon. *Radiation Measurements*, **42**, 298-303.

Alaamer G.A.S. (2008). Assessment of Human Exposures to Natural Sources of Radiation in Soil of Riyadh, Saudi Arabia. *Turkish Journal of Engineering & Environmental Sciences*, **32**, 229-234.

Ali N., Khan E.U., Akhter P., Khan F. and Waheed A. (2010). Estimation of mean annual effective dose through radon concentration in the water and indoor air of Islamabad, Pakistan. *Radiat. Prot. Dosim.,* **141(2),** 183-191.

Ali N, Khan E.U., Akhter P., Khan F. and Waheed A. (2010). Estimation of mean annual effective dose through radon concentration in the water and indoor air of Murree, Pakistan. *Radiat. Prot. Dosim.,* **141(2),** 183-191.

Amanjeet Kumar Ajay, Kumar Suneel (2018). Assessment of Radon and Thoron exhalation rate from soil of historical city Panipat, India. *International Journal of Chem Tech Research*, **11(02)**, 168-175.

Anastasiou T., Tsertos T., Christofides S. & Christodoulides G. (2003). Indoor radon (222Rn) concentration measurements in Cyprus using high sensitivity portable detectors. *Journal of Environmental Radioactivity,* **68(2),** 159-169.

Bajwa B.S., Singh H., Singh J., Singh S. and Sonkawade R.G. (2010). Environmental radioactivity: A case study in HHP granitic region of Tusham ring complex Haryana, India. *Geophys. Res. Abst*., **12.** EGU2010– 1888.

Bajwa B.S., Sharma N., Walia V., Virk H.S. (2003). Measurements of natural radioactivity in some water and soil samples of Punjab state, India. *Indoor Built Environ*, **12**, 357-361.

References:

Bale, W.F. (1980). Hazard associated with radon and thoron. Memo to the file, Division of Biology and medicine, USAEC, Washington, DC, March 1951. *Health Physics*, **38,** 1061-1066.

BEIR (1999). Health effects of exposure to radon. Committee on Health Risks of Exposure to Radon. Board on Radiation Effects Research, Commission on Life Science, National Research Council, Washington, D.C. National Academy Press (BEIR VI)

Bertine K.K., Chan L.J. & Turekian K.K. (1970). Uranium determinations in deep-sea sediments and natural waters using fission tracks. *Geochim Cosmochim Acta*, **34,** 641- 648.

Bodansky, D., Robkin M.A. & Stadler R.D. (1987). Indoor radon and its hazards. London, UK: University of Washington Press.

Bottrel, S. (1991). Radon production and release from cave sediments. *Cave Science,* **18**, 169-182.

Bourai A.A., Aswal S., Dangwal A., Rawat M., Prasad M., Naithani Prasad N., Joshi V. and Ramola R.C. (2013). Measurement of radon flux and soil-gas radon concentration along the main central thrust, Garhwal Himalaya, using SRM and RAD7 detectors. *Acta Geophys.,* **61(4),** 950–957.

Bovornkitti S. (2002). Prevalence of lung cancer and indoor radon in Thailand. International Congress Series 1236: 31-33.

Brennera, David J., Doll, Richard, Goodheadd, Dudley T., Halla, Eric J., Lande, Charles E., Littlef, John B., Lubing, Jay H., Prestonh, Dale L., Prestoni, Julian R., Puskinj, Jerome S., Rone, Elaine, Sachsk, Rainer K., Sametl, Jonathan M., Setlowm, Richard B., Zaidern, and Marco (2003). Cancer risks attributable to low doses of ionizing radiation: Assessing what we really know. *PNAS,*, Vol. **100 (24),** 13765.

References:

Brill A.B., Becker D.V., Donahoe K., Goldsmith S.J., Greenspan B., Kase K., Royal H., Silberstein E.B. & Webster E.W. (1994). Radon update: Facts concerning environmental radon: levels, mitigation strategies, dosimetry, effects and guidelines. *Journal Nuclear Medicine,* **35,** 268-385.

Bureau Internl des Poids et Mesures Table of Radionuclides (2004). Monographie BIPM-5.

Chandrashekara M.S. (2017). Studies on uranium and radon concentration in bore well water of Kodagu District, India. *International Journal of Engineering Research and Development*, **13 (12),** 1-5.

Chhangte L.Z. (2018). Analysis of Radon and Thoron in dwellings with special reference to Saiha and Lawngtlai Districts of Mizoram (Doctoral dissertation, Mizoram University).

Chikasawa K., Ishii T., Ugiyama H. (2001). Terrestrial gamma radiation in Kochi Prefecture, Japan. *J Health Sci*, **47**, 361-372.

Cliff K. & Gillmore G.K., (eds) (2001). The Radon Manual (Third Edition). A guide to the requirements for the detection and measurement of natural radon levels, associated remedial measures and subsequent monitoring of results (Third Edition edn.). Shepperton, Middlesex, UK: The Radon Council.

Coskeran T., Denman A. R., Phillips P.S., & Gillmore G.K., (2002). A critical comparison of the cost-effectiveness of domestic radon remediation programmes in three counties of England. *Journal of Environmental Radioactivity*, **62(2),** 129-144.

Cothern C.R., Lappenbusch W.L. (1983). Occurrence of uranium in drinking water in the U.S. *Health Physics*, **45**, 89-99.

Crockett R.G.M. & Gillmore G.K. (2009). Caves, mines and subterranean spaces: hazard and risk from exposure to radon. Geophysical Research Abstracts, EGU2009-5952, EGU General Assembly, Vienna. Vol. **11,** 19th-24th April, 2009.

References:

Dang H.S., Pullat V.R. & Sharma R.C. (1995). Distribution of Uranium in Human Organs of an Urban Indian Population and Its Relationship with Clearance Half-Lives. *Health Phys*, **68,** 328-331.

Darby S., Hill D., Auvinen A., Barros J. M., Dios, Baysson H. & Bochicchio F. (2005). Radon in homes and risk of lung cancer collaborative analysis of individual data from 13 European case-control studies. *BMJ*, **330 (7485)**, 223-227.

Darko E.O., Adukpo O.K., Fletcher J.J., Awudu A.R., Otoo (2009). Preliminary studies on ^{222}Rn concentration in ground water from selected areas of the Accra metropolis in Ghana. *J Radioanal Nucl Chem,* DOI 10.1007/s10967-009-0378-y.

Denman A.R. & Parkinson S. (1996). Estimates of radiation dose to NHS workers in Northam - ptonshire from raised radon levels. *The British Journal of Radiology,* **69(1):** 72-75.

Denman A.R. (1994). The significance of raised radon levels in NHS properties in Northamptonshire. *Radiation Protection Dosimetry*, **54(1),** 65-68.

Denman A. R., Lewis G. T. R. & Brennen S. E. (2002). A study of radon levels in NHS premises in affected areas around the UK. *Journal of Environmental Radioactivity,* **63(3):** 221-230.

Denman A.R., Barker S. P., Parkinson S. & P. S. Phillips (1997). The health benefits and cost effectiveness of the radon mitigation programme in NHS properties in Northamptonshire. *Journal of Radiological Protection,* **17(4):** 253-259.

Dixon D.W. (1999). National Radiological Protection Board, United Kingdom, personal communications.

Dixon D. W., Gooding T.D. & Mc Cready-Shea S. (1996a). Evaluation and significance of radon exposure in British workplace buildings. *Environment International,* **22:** S1079- S1082.

References:

Dixon D.W., Gooding T.D. & Mc Cready-Shea S. (1996b). Evaluation and significance of radon exposure in British workplace buildings. *Environment International,* **22**: S1079-S1082.

Duggal V, Mehra R. and Rani, A. (2014). Measurement of soil-gas radon in some areas of northern Rajasthan, India. *J. Earth Syst. Sci.,* **123.** 1241-1247.

El Ghissassi F, Baan R, Straif K, Grosse Y, Secretan B, Bou-vard V, Benbrahim-Tallaa L, Guha N, Freeman C, Galichet L, Cogliano V (2009). A review of human car cinogens-part D: radiation. The Lancet Oncology. **10(8)**, 751-752.

El-Hussein A. (2005). A study on natural radiation exposure in different realistic living rooms. *Journal of Environmental Radioactivity,* **79(3),** 355-367.

Erickson B. (2004). Radiation and Health: An Overview of Radon Therapy in the United States and Europe. Proceedings of the 14th Pacific Basin Nuclear Conference; Honolulu, HI. pp. 654–661.

Etiope G. & Martinelli G. (2002). Migration of carrier and trace gases in the geosphere: an overview. *Physics of The Earth and Planetary Interiors*, **129(3-4),** 185-204.

EU (2001). European Union Commission Recommendation on the protection of the public against exposure to radon in drinking water supplies. *Office Journal of the European Community*, **L 344**, 85–88.

Faulkner K. & Gillmore G. K. (eds) (1995). Geology and radon entry into buildings. In: The Radon Manual, (2nd ed.). A Guide to the Requirements for the Detection and Measurement of Natural Radon Levels, Associated Remedial Measures and Subsequent Monitoring of Results (2.21-2.29). Shepperton, Middlesex: The Radon Council Ltd.

Franke A., Reiner L. & H. G. Pratzel (1997). Long term efficacy of radon spa therapy in rheumatoid arthritis-a randomized, sham-controlled study and follow-up. *Rheumatotology,* **39,** 894-902.

References:

FSA (2002). Food Standards Agency, Survey for irradiated foods herbs and spices, dietary supplements and prawns and shrimps. Food Survey Information Sheet, Number 25/02. June 2002. Food Standards Agency, London.

Garcia-Vindas J.R. & Monnin M.M. (2005). Radon concentration measurements in the presence of water and its consequences for Earth sciences studies. *Radiation Measurements,* **39,** 319 - 322.

García-Gaines Rubén A., Frankenstein, Susan, (2015). USCS and the USDA Soil Classification System: Development of a Mapping Scheme. ERDC/CRREL TR-15-4.5-7.

Gilliland F.D., Hunt W. C., Archer V. E. & Saccomanno G. (2000). *Health Phys,* **79**, 365-372.

Gillmore G.K., Sperrin M., Phillips P. & Denman A. (2000). Radon Hazards, Geology, and Exposure of Cave Users: A Case Study and Some Theoretical Perspectives. *Ecotoxicology and Environmental Safety,* **46(3),** 279-288.

Gillmore G.K., Phillips P. S., Denman A. R. & Gilbertson D. D. (2002). Radon in the Creswell Crags Permian limestone caves. *Journal of Environmental Radioactivity,* **62(2),** 165-179.

Gusain G.S., Prasad Ganesh, Prasad Yogesh, Ramola R C (2009). Comparison of indoor radon level with radon exhalation rate from soil in Garhwal Himalaya. *Radiation Measurements,* **44**, 1032-1035.

Hand, B. M. & Banikowski J. E. (1988). Radon in Onondaga County, New York: Paleohydrology and redistribution of uranium in Paleozoic sedimentary rocks. *Geology*, **16,** 775-778.

Handbook on Radon Transport Models and Measurement Methods, Radiological Physics and Advisory Division, Bhabha Atomic Research Centre, Mumbai, (2016). Back cover. (Unpublished).

References:

Handbook on Radon Transport Models and Measurement Methods, Radiological Physics and Advisory Division, Bhabha Atomic Research Centre, (2016), 7-8. (Unpublished).

Hess, C. T., Michael J., Horton T. R., Pritchard H. M. & Coniglio W. A. (1985). The Occurrence of Radioactivity in Public Water Supplies in the United States. *Health Physics,* **48,** 553-586.

Horton, T. R. (1983). Methods and Results of EPA's Study of Radon in Drinking Water, USEPA-520/5-83-027. 31

HSC (1988). Health and Safety Commission, Approved code of practice-part 3, exposure to radon. The ionising radiations regulations, 1985. London, HMSO.

HSE (1985). Health and Safety Executive, The ionising radiations regulations, SI 1333, HMSO, London.

HSE (1997). Safety and health in mines research advisory board Annual Review.

IAEA (2004). Application of the concepts of exclusion, exemption and clearance. Safety standards series No. RS-G-1.7.

ICRP (1987). International Commission on Radiological Protection. Lung Cancer Risk from Indoor Exposure to Radon Daughters. Pergamon Press, Oxford ICRP Publication No. 50.

ICRP (1989). International Commission on Radiological Protection. Lung Cancer Risk from Indoor Exposure to Radon Daughters. Pergamon Press, Oxford, ICRP Publication No. 50

ICRP (1984). International Commission for Radiological Protection Publication No.39, Principles of Limiting Exposure of the Public to Natural Sources of Radiation, Pergamon Press, Oxford.

References:

Ioannides, K., Papachristodoulou C., Stamoulis K., Karamanis D., Pavlides S., Chatzipetros A. & E. Karakala (2003). Soil gas radon: a tool for exploring active fault zones. *Applied Radiation and Isotopes,* **59,** 205-213.

Jaishi Hari Prasad, Singh Sanjay, Tiwari Raghavendra Prasad, Tiwari Ramesh Chandra (2015). Soil-gas Thoron Concentration Associated with Seismic Activity. *Chiang Mai J. Sci*., **41(4)**, 972-979.

Kabir K A, Islam S M A, Rahman M M, (2009). Distribution of Radionuclides in Surface Soil and Bottom Sediment in the District of Jessore, Bangladesh and Evaluation of Radiation Hazard. *Journal of Bangladesh Academy of Sciences*, **33 (1)**, 117-130.

Kainan SUN, Qiuju GUO, Jianping CHENG (2004). The effect of Some Soil Characteristics on Soil Radon Concentration and Radon Exhalation from Soil Surface. *Journal of Nuclear Science and Technology,* **41(11),** 1113-1117.

Kant K, Upadhyay S.B., Sharma G.S., Chakarvarti S.K. (2004). Measurement of inhalation dose due to radon and its progeny in an oil refinery and its dwellings. *Iran J.Radiant. Res.***1(4)**, 181-186.

Kaur Manpreet, Tripathi Pooja, Choudary Indu, Mehra Rohit, Kumar Ajay (2017). Assessment of Annual Effective Dose Due to Inhalation and Ingestion of Radon in Water Samples from Some Regions of Punjab, India. *International Journal of Pure and Applied Physics*, **13 (2)**, 193-200.

King, C. Y. (1993). Proc. 2nd Workshop on Radon Monitoring in Radio protection, Trieste (1991) World Scientific Published. Environmental and Earth Sciences, 244

Knoch-Weber, J. (1998). Braunkohle. *Surface Mining,* **50**: 347-356.

Kumar A, Kaur M, Sharma S, Mehra R (2016). A study of radon concentration in drinking water samples of Amritsar city of Punjab (India). *Radiat Prot Environ*, **39**,13-9.

References:

Kumar Manish, Kaushal Anjali, Sahoo B K, Sarin. Amit, Mehra Rohit, Jakhu Rajan, Bhalla Atul, Sharma Navjeet (2017). Measurement of uranium and radon concentration in drinking water samples and assessment of ingestion dose to local population in Jalandhar district of Punjab, India. *Indoor and Built Environment*, **0(0)**, 1-8.

Kumar S, Singh S, Bajwa B.S. and Sabharwal A.D. (2011). In situ measurements of radon levels in water and soil and exhalation rate in areas of Malwa belt of Punjab (India)*; Isotop. Environ. Health Stud*. **47(4).** 446–455.

Lekshmi R, Arunima S, Jojo P.J. (2018). Determination of Radon Exhalation Rates and Emanation Factor of Some Soil Samples Collected From Southern Seashore of Kerala, India. *JUSPS-A*, **30 (1)**, 80-85.

Lieser, K.H. (1980). Einfu¨hrung in die Kernchemie. Verlag Chemie, Weinheim, FRG. Lightfoot, D. 1996. Qantas in the Levant: Hydraulic Technology at the periphery of Early Empires Technology

Lindholm Roy C, (1987). A Practical Approach to Sedimentology, Allen & UnwinInc, 8 Winchester Place, Winchester, Mass. 01890, USA.

Lubin, J. H., Boice Jr J. D.., Edling C., Hornung R. W., Howe G., Kunz E., Kusiak R. A., Morrison H. I., Radford E. P., Samet J. M., Tirmarche M., Woodward A., Yao S. X. & Pierce D. A. (1995). Lung cancer in radon-exposed miners and estimation of risk from indoor exposure. *Journal Natural Cancer Institute,* **87,** 817-827.

Lubin, J. H., Linet M. S., Boice J. D., Buckley J., Conrath S. M., Hatch E. E., Kleinerman R.A., Tarone R. E., Wacholder S. & Robison L. L. (1998). Case-control study of childhood acute lymphoblastic leukaemia and residential radon exposure. *Journal of the National Cancer Institute*, **90(4),** 294-300.

Mahur A K, Kumar Rajesh, Sonkawade R G, Sengupta D, Prasad Rajendra (2008). Measurement of natural radioactivity and radon exhalation rate from rock

References:

samples of Jaduguda uranium mines and its radiological implications. *Nuclear Instruments and Methods in Physics Research*, **266**, 1591-1597.

Malanca A., Gaidolfi L., Pessina V. & Dallara G.(1995). What is the "true" radon concentration inside a room. *Journal of Environmental Science Health,* **30(9),** 1935-1943.

Man, C. K. & Yeung H. S. (1998). Variations of Outdoor Radon Concentrations in Hong Kong. *Journal Environmental Radioactivity,* **40(2),** 137-145.

Mehra R and Bala P (2013). Estimation of annual effective dose due to radon level in indoor air and soil gas in Hamirpur district of Himachal Pradesh. *Radiat. Prot. dosimetry.doi.,* **158,** 111-114.

Mehra Rohit, Singh Surinder, Singh Kulwant (2009). Analysis of 226Ra, 232Th and 40K in soil samples for the assessment of the average effective dose. *Indian J. Phys.,* **83 (7)**, 1031-1037.

Meinrath, A., Schneider P. & Meinrath G. (2003). Uranium ores and depleted uranium in the environment, with a reference to uranium in the biosphere from the Erzgebirge/Sachsen, Germany. *Journal of Environmental Radioactivity,* **64(2-3),** 175-193.

Miles J. (1998). Development of maps of radon-prone areas using radon measurements in houses. *Journal of Hazardous Materials,* **61(1-3),** 53- 58.

Miles J.C., Green B.M. & Lomas P. (1996). Radon affected areas: England, Wales. Documents of the NRPB 7, No 2.

Morken D. (1980). The biological and health effects of radon: a review. National Bureau of Standards Special Publication, 581. Proceedings of a round table discussion of radon in buildings held at 21- 26. NBS, Gaithersburg, MD

References:

Mujahid S A, Hussain S and Ramzan M (2010). Measurement of radon exhalation rate and soil gas radon concentration in areas of southern Punjab, Pakistan; *Radiat. Prot. Dosim*., **140(3),** 300-303.

Nambi K S, Bapat V N, David M, Sundaram V K, Santa C M, Soman S D, (1986). Natural Background Radiation and Population Dose Distribution in India. India: HPD, BARC.

NAS (1999). Risk Assessment of Radon in Drinking Water. National Academy Press, Washington, DC.

Nazaroff W.W, Nero A.V. (1988). Radon and its Decay Products in Indoor Air. John Wiley & Sons, New York. ISBN: 0-471-62810-7

Nazaroff, W. W. & Teichman K. (1990). Indoor radon: Exploring U. S. federal policy for controlling human exposures. *Environmental Science and Technology,* **24**, 774-782.

NCRP (1975). National Council on Radiation Protection and Measurements (NCRP). Natural Background Radiation in the United States NCRP Report No, 45. Bethesda, Maryland, United States.

NCRP (1984). National Council on Radiation Protection and Measurements (NCRP). Exposures from the Uranium series with Emphasis on Radon and its Daughter, NCRP Report, No 77. Bethesda, Maryland, United States.

NRC (1988). National Research Council. Report of the Committee on the Biological Effects of Ionizing Radiation: Health effects of radon and other internally deposited alpha emitters (BEIR IV). National Academy Press. Washington, DC.

NRC (1999). National Research Council (NRC). Health Effects of Exposure to Radon In N. A. Press (ed.) Committee on Health Risks of Exposure to Radon BEIR VI. Washington, DC.

References:

NRPB (1992). National Radiological Protection Board Report (NRPB). Radon affected areas, Derbyshire, Northamptonshire and Somerset. Documents of the NRPB, Chilton, NRPB 3(4)

O`Riordan, M.C. (1996). Riddle of radon. *Journal of Radiological Protection,* **16(4),** 269-273.

Oksanen, P. J. (1998). Estimated individual annual cosmic radiation doses for flight crews. *Aviation Space Environmental Medicine,* **69(7),** 621-625.

O'Riordan M.C., James A. C., Rae G. & Wrixon A. D. (1983). Human exposure to radon decay products inside dwellings in the United Kingdom. National Radiation Protection Board, R152.

Papworth D. (1997). A need to reduce the radon gas hazard in the UK. *Journal Royal Society of Health*, **117(2),**75-80.

Pentreath R. J., Camplin W. C. & Allington D.J., (1989). Individual and collective dose rates from naturally-occurring radionuclides in seafood. pp. 297-300. In: E. P. Goldfinch (Ed.). Radiation Protection Theory and Practice, Proc. 4th Int. Symp. Soc. Radiol. Prot., Malvern, 4-9 June 1989, Institute of Physics, Bristol and New York.

Phillips, J. (1992). Results of EPA's national school radon survey, Radon and Radon Reduction Technology Proc. International Symposium. Minneapolis EPA, Washington, DC.

Poffijn, A., Uyttenhove J., Drouguet B. & Tondeur F. (1992). The radon problem in schools and public buildings in Belgium. *Radiation Protection Dosimetry*, **45,** 499-501.

Prasad Ganesh, Prasad Yogesh, Gusain G S, Badoni Manjari, Rana J M S, Ramola R C (2009). Variation of radon concentrations in soil and groundwater and its

References:

correlation with radon exhalation rate from soil in Budhakedar, Garhwal Himalaya. *Indian J. of Physics.,* **83 (6)**, 887-892

Priest, N. D. (2001). Toxicity of depleted uranium. *The Lancet*, **357(9252),** 244- 246.

Pukkala, E., Auvinen A. & G. Wahlberg (1995). Incidence of cancer among Finnish airline cabin attendants, 1967-1992. *British Medical Journal*, **311,** 649-652.

Qureshi, A. A., Kakar D. M., Akram M., Khattak N. U., Tufail M., Mehmood K., Jamil K. & Khan H. A. (2000). Radon concentrations in coal mines of Baluchistan, Pakistan. *Journal of Environmental Radioactivity*, **48(2),** 203-209.

Ramachandran T V, Mayya Y S, Sadashivan S, Nair R N, Eappen K P (2003). Radon - Thoron Levels and Inhalation Dose Distribution Patterns in Indian Dwellings. BARC Report, BARC / 2003 / E / 026. Bhabha Atomic Research Centre, Mumbai, Government of India, 1-43.

Robert, K. L. (2006a). A History of Radon-1470 to 1984. Presented at the 2006 National Radon Meeting Bureau of Radiation Protection, Radon Division. Pennsylvania Department of Environmental Protection.

Robert, K. L. (2006b). A History of Radon-1470 to 1984. Pennsylvania Department of Environmental Protection. Presented at the 2006 National Radon Meeting Bureau of Radiation Protection, Radon Division.

Robertson A, Allen J, Laney R, Curnow A (2013). The cellular and molecular carcinogenic effects of radon exposure: a review. International Journal of Molecular Sciences. **14(7),** 14024-14063.

Rohmingliana P C, Vanchhawng Lalmuanpuia, Thapa R K, Sahoo B K, Singh O P, Zoliana B, Mayya Y S (2009). Measurement of Indoor Radon and Thoron Concentrations in Correlation to Geographical Location and Construction types of Buildings in Mizoram (with special reference to Aizawl, Champhai and Kolasib

References:

districts). Proc. VIth Conference of Physics Academy of North East, Tripura University, April 3-4.

Ryan T P, Sequeira S, Mc Kittrick L, Colgan P A (2003). Radon in drinking water in Co.Wicklow - a pilot study. Radiological Protection Institute of Ireland. PRII-03/1, 34p.

Sackett, W. M., Mo T., Spalding R. F. & Exner M. E. (1973). A reevaluation of the marine geochemistry of uranium. Proc. International Symp Interaction of Radioactive Contaminants with the Constituents of the Marine Environment: 757–769. Wien: IAEA.

Sahoo S K, Mohapatra S, Chakrabarty A, Sumesh C G, Jha V N, Tripathi R M, Puranik (2010). Determination of uranium at ultra trace level in packaged drinking water by laser fluorimeter and consequent ingestion dose. *Radioprotection*, **45 (1)**, 55-66.

Samet, JM. & Hornung RW. (1990). Review of radon and lung cancer risk. *Risk Anal,* **10,** 65-75.

Scott, A. G. (1994). Radon sources, radon ingress and models. *Radiation Protection Dosimetry,* **56(4),** 145-149.

Segovia N. & Bulbulian S. (1992). Radon determination in groundwater. *Revista mexicana de física*, **38(Suppl 1),** 242-248.

Segovia N., Mena M., Pena P., Tamez E., Seidel J. L., Monnin M. & Valdes C. (1999). Soil radon time series: Surveys in seismic and volcanic areas. *Radiation Measurements*, **31(1- 6),** 307-312.

Sevc, J., Kuns E. & Placek V. (1979). Lung cancer in uranium miners and long term exposure to radon daughter products. *Health Physics*, **54**, 27-46.

Singh B, Garg V K, Yadav P, Kishore N, Pulhani V (2014). Uranium in groundwater from Western Haryana, India. *J. Radioanal Nucl Chem*, **301**, 427-433.

References:

Singh J, Singh H, Singh S and Bajwa B S (2010). Measurement of soil gas radon and its correlation with indoor radon around some areas of Upper Siwaliks, India. *J. Radiol. Prot.,* **30(1),** 63–71.

Singh J, Singh H, Singh S, Bajwa B S (2008). Estimation of uranium and radon concentration in some drinking water samples. *Radiat Meas.*, **43**, 523-526.

Singh S, Sharma D K, Dhar S and Randhawa S S (2006). Geological significance of soil gas radon: A case study of Nurpur area district Kangra, Himachal Pradesh, India. *Radiat. Meas.,* **41(4),** 482–485.

Singh Surinder, Sharma Dinesh Kumar, Dhar Sunil, Kumar Arvind, Kumar Ajay (2007). Uranium, Radium and Radon Measurements in the Environs of Nurpur Area, Himachal Himalayas, India. *Environ Monit Assess.,* **128**, 301-309.

Snih, J. O. (1992). Swedish radon program. *Radiation Protectection Dosimetry,* **42,** 177- 184.

Srivastava Alok, Lalramengzami R, Laldawngliana C, Sinha C, Ghosh S, Dwivedi K.K., Saxena A, Ramachandran T.V. (1996). Measurement of Potential Alpha Energy Exposure (PAEE) of Radon and its Progenies in Dwellings in the North-Eastern Region of India. *Radiat. Meas.*, **26**, 291-295.

Steinhäusler F. (1975). Long-term measurements of 222Rn, 220Rn, 214Pb and 212Pb concentrations in the air of private and public buildings and their dependence on meteorological parameters. *Health Phys*., **29,** 705- 713.

Stranden E., Kolstad A. K. & Lind B. (1984). Radon exhalation: Moisture and temperature dependence. *Health Physics*, **47,** 480-484.

Swedjemark, G. A. & Mjones L. (1984). Radon and radon daughter concentrations in Swedish homes. *Radiation Protection Dosimetry,* **7,** 341-345.

Turekian K.K. & L.H. Chan (1971). Activation Analysis in Geochemistry and Cosmochemistry, Stockholm University Press, 311.

References:

Turk B. H., Brown K., Geisling D. A., Sobatka, Froelich D. T., Grimsrud J., Harrison J. F., Koonce R. J. & Prill K. L. (1986). Indoor Air Quality and Ventilation Measurements in 38 Pacific Northwest Commercial Buildings. Volume 1: Measurement Results and Interpretation", Lawrence Berkeley Laboratory Report, Berkeley, CA. LBL-22315.

UNSCEAR (2000). Annex B: Exposures from natural radiation sources. United Nations Scientific Committee on the Effects of Atomic Radiation, (New York: USA).

UNSCEAR (2008). Exposure to the public and workers from various sources of radiation. Report to the General Assembly. New York, United Nations, 1, Annexure B, 234.

UNSCEAR (1988). Sources, Effects and Risk of Ionising Radiation. United Nations Scientific Committee on the Effects of Atomic Radiation. Report to the General Assembly, with Scientific Annexes, United Nations, New York.

UNSCEAR (1993). Ionizing Radiation. Sources and Effects on Ionising Radiation United Nations Scientific Committee on the Effects of Atomic Radiation. Report to the General Assembly, with Scientific Annexes, United Nations Sales Publication E.94.IX.2.United Nations, New York.

UNSCEAR (2000). Sources, Effects and Risk of Ionising Radiation. United Nations Scientific Committee on the Effects of Atomic Radiation. Report to the General Assembly, with Scientific Annexes, United Nations, Sales publication, New York. II.

UNSCEAR (1993). United Nations Scientific Committee on the Effects of Atomic Radiation., Sources, Effects and Risks of Ionizing Radiation., Report to the General Assembly, United Nations, New York.

USEPA (1991). National Primary Drinking Water Regulations for Radio Nuclides US, Government Printing Office EPA/570/9-91/700.

References:

USEPA (2000a). United States Environmental Protection Agency, National Primary Drinking Water Regulations, Radionuclides Final Rule, 40 CFR Parts 9, 141, and 142, 76708-76712.

Vanchhawng Lalmuanpuia, Rohmingliana P.C., Thapa R.K., Sahoo B.K., Singh O.P., Zoliana B, Mayya Y.S. (2009). To Correlate Radon and Thoron Concentrations with Gamma Background Radiation in Mizoram (Special reference to Aizawl, Champhai and Kolasib districts), Proc. VIth Conference of Physics Academy of North East, Tripura University, April 3-4.

Vaupotic J. (2002). Search for radon sources in buildings kindergartens. *Journal of Environmental Radioactivity*, **61,** 365-372.

Webb G. A. (1992). Exposure to radon. *Radiation Protection Dosimetry,* **42,** 191-195.

Wentworth Chester K (1922). A scale of grade and class terms for elastic sediments. *The Journal of Geology,* **30(5),** 377-392.

WHO (1993). Guidelines for drinking water quality. Recommendations Vol. 1, 2nd Edition. World Health Organization, Geneva.

WHO (2004). Guidelines for drinking water quality. 3rd Edition. World Health Organization, Geneva, Switzerland.

Yoon JY, Lee JD, Joo SW, Kang DR (2016). Indoor radon exposure and lung cancer: a review of ecological studies. Annals of Occupational and Environmental Medicine.**28(1)**, 15.

Zdrojewicz Z. & Strzelczyk J. (2006). Radon Treatment Controversy. *Dose Response,* **4(2),** 106-18. Doi: 10.2203.

Publication and conferences detail

(I) **Journals**:

1. **Remlalsiama,** Z.Pachuau, Vanramlawma, Hmingchungnunga, L.Z.Chhangte, B.Zoliana, B.K.Sahoo, B.K.Sapra (2019). Study of Radon concentration at different depth in soil of oil exploration areas within Aizawl district of Mizoram, India. *Journal of Emerging technologies and Innovative Research,* **6(4),** 726-733, **ISSN-2349-5162.**

2. **Remlalsiama,** Z.Pachuau, L.Z.Chhangte, Vanramlawma, Hmingchungnunga, B.Zoliana, B.K.Sahoo, B.K.Sapra (2019). Natural Radioactivity Measurement Using NaI(Tl) Detector in Soil of Oil Exploration Areas of Mizoram, India. *International Journal of Research and Analytical Reviews,* **6(2)**, 275-280, **E-ISSN: 2348-1269, P-ISSN: 2349-5138.**

3. **Remlalsiama,** Z.Pachuau, L.Z.Chhangte, Vanramlawma, Hmingchungnunga, B.Zoliana, B.K.Sahoo, B.K.Sapra (2022). Assessment of Radon Content in water of Oil exploration areas using Smart RnDuo in Mizoram, India. *International Journal of Engineering Research and Technology,* **10(7),** 87-89, **ISSN: 2278-0181.** DOI:10.17577/IJERTCONV10IS07019.

4. **Remlalsiama,** Z.Pachuau, L.Z.Chhangte, Vanramlawma, Hmingchungnunga, B.Zoliana, B.K.Sahoo, B.K.Sapra (2022). Correlation between ground level background gamma radiation and radon gas concentration in soil at different baptism depth of oil exploration areas within Aizawl district of Mizoram, India. *International Journal of Engineering Research and Technology,* **10(7),** 83-86, **ISSN: 2278-0181.** DOI:10.17577/IJERTCONV10IS07018.

Publication and Conferences detail:

5. LZ Chhangte, PC Rohmingliana, B.K. Sahoo, B.K. Sapra, Hmingchungnunga, Vanramlawma, **Remlalsiama,** Z. Pachuau, B. Zoliana (2019). Determination of Radon Mass Exhalation Rate in the region of highest lung cancer incidence in India. *Radiation Environment and Medicine*, **8(2),** 113-117, **ISSN: 2423-9097 (PRINT)**. DOI: 10.13140/RG.2.2.14663.85922.

6. L.Z. Chhangte, P.C. Rohmingliana, B.K. Sahoo, B.K. Sapra, Hmingchungnunga, Vanramlawma, **Remlalsiama,** Z. Pachuau, B. Zoliana (2018). Comparison of Twin Cup Dosimeter with Single and Double entry in measuring indoor Radon and Thoron Concentration in Mizoram, India. *Science Vision*, **15(1)**, 51-55, **ISSN: 0975-6175** (print)/**2229-6026** (online).

7. LZ Chhangte**,** Hmingchungnunga, Vanramlawma, **Remlalsiama,** B.K. Sahoo, B.K. Sapra, B. Zoliana, Rosangliana, Z. Pachuau (2018). Measurement of primordial radionuclides in soil and building materials from Mizoram, India. In: *Perspective and Trends in the Development of Science Education and Research,* Mizoram Science Congress, 4th to 5th October 2018, Atlantis Press, Paris, France, pp186-189, **ISBN:978-94-6252-638-9. ISSN 2352-5401.** https:// doi.org/ 10.2991/msc-18.2018.36

8. Hmingchungnunga, Vanramlawma, **Remlalsiama,** Laldingngheta, LZ Chhangte, Z Pachuau, B. Zoliana, Rosangliana, B.K. Sahoo, B.K Sapra (2018). Assessment of radon content in water using SMART RnDuo in Mizoram, Northeast India. In: *Perspective and Trends in the Development of Science Education and Research,* Mizoram Science Congress, 4th to 5th October 2018, Atlantis Press, Paris, France, pp190-193, **ISBN:978-94-6252-638-9. ISSN 2352-5401.** https:// doi.org/ 10.2991/msc-18.2018.32

Publication and Conferences detail:

9. Vanramlawma, Hmingchungnunga, **Remlalsiama,** Laldingngheta, LZ Chhangte, Z. Pachuau, B. Zoliana, Rosangliana, B.K. Sahoo, B.K. Sapra (2018). Measurement of natural radioactivity using NaI (Tl) detector in soil samples collected from Aizawl, Mizoram, India, In *Perspective and Trends in the Development of Science Education and Research,* Mizoram Science Congress, 4th to 5th October 2018, Atlantis Press, Paris, France, pp207-211, **ISBN**:**978-94-6252-638-9**. **ISSN 2352-5401**. DOI: https://doi/10.2991/msc-18.2018.36. Corpus ID: 115146872.

(II) **Conferences/Workshop Attended**

(a) **International**:

1. **Remlalsiama,** Z.Pachuau, Vanramlawma, Hmingchungnunga, L.Z.Chhangte, B.Zoliana, B.K.Sahoo, B.K.Sapra (2020). Radon Gas Concentration in Soil of the Oil Exploration Areas Within Mizoram, India. *2nd Annual Convention of North East(India)Academy of Science and Technology (NEAST) & International Seminar on Recent Advances in Science and Technology (ISRAST),* during 16th to 18th November, 2020, Mizoram University, Mizoram India. **(Oral Presentation).**

2. **Remlalsiama,** Z.Pachuau, L.Z.Chhangte, Vanramlawma, Hmingchungnunga, B.Zoliana, B.K.Sahoo, B.K.Sapra (2022). Assessment of Radon Content in water of Oil exploration areas using Smart RnDuo in Mizoram, India. *XII Biennial National Conference of Physics Academy of North East (PANE 2021),* during 15th to 17th December, 2021, Department of Physics, Tripura University, Tripura, India. **(Oral Presentation).**

Publication and Conferences detail:

3. **Remlalsiama,** Z.Pachuau, L.Z.Chhangte, Vanramlawma, Hmingchungnunga, B.Zoliana, B.K.Sahoo, B.K.Sapra (2022). Correlation between ground level background gamma radiation and radon gas concentration in soil at different baptism depth of oil exploration areas within Aizawl district of Mizoram, India. *XII Biennial National Conference of Physics Academy of North East (PANE 2021),* during 15th to 17th December, 2021, Department of Physics, Tripura University, Tripura, India. **(Oral Presentation).**

(b) **National**:

1. **Remlalsiama,** Vanramlawma, Hmingchungnunga, Laldingngheta, LZ Chhangte, Z.Pachuau, B.K.Sahoo, B.K.Sapra (2020). Measurement of Natural Radioactivity Using NaI(Tl) Detector in Soil Samples of Oil Exploration areas in Mizoram, India. *National Conference on Emerging Trends in Environmental Research (NACETER 2019)*, 31st Oct. to 2nd Nov. 2019, Pachhunga University College, Aizawl. **(Oral Presentation)**

BRIEF BIODATA OF REMLALSIAMA

Name	:	Remlalsiama		
Father's Name	:	M.N. Haque (L)		
Date of Birth	:	06 - 07 - 1973		
Address	:	Type-IV, Block-2, House No. 3		
		New Capital Complex,		
		Aizawl, Mizoram, India.		
		Pin 796001.		
E-mail address	**:**	rema19992005@gmail.com		
Subject of Specialization	:	High Energy Physics		
Educational Qualification	:			
H.S.L.C	:	1988	Second Division	M.B.S.E.
P.U.C (Science)	:	1991	Second Division	N.E.H.U.
B.A	:	1993	Third Division	N.E.H.U.
B.Sc (P.C.M)	:	1994	Third Division	N.E.H.U.
B.Sc.(Physics Honours)	:	1995	Second Division	N.E.H.U.
M.Sc. (Physics)	:	1997	First Division	N.E.H.U.
Pre-Ph.D Course	:	2018	Grade O	M.Z.U.

Teaching Experience:

- Completed M.Sc. Project work (on High Energy Physics) titled "Quarks Model" at the Department of Physics, North Eastern Hill University, Shillong, Meghalaya in 1997.
- Joined as an entry grade of Lecturer in Physics department under Government of Mizoram at Govt Serchhip College on 21st May, 1998. The institution is an undergraduate college, located in Serchhip district of Mizoram. I worked there for two years.
- Transferred to Govt. Zirtiri Residential Science College, Aizawl district, Aizawl, Mizoram on 4th July, 2000. Now I am an Associate Professor in the department of Physics. I worked in this college for the last twenty two years.
- Started research works on "Radon characterisation in soil of oil exploration areas in Mizoram" since August 2017 under the supervision of Prof. Zaithanzauva Pachuau, Dean, School of Physical Science, Mizoram University, and Joint Supervision of Prof. B. Zoliana, Department of Physics, Govt. Zirtiri Residential Science College, Aizawl.
- Complete Training Course at Radiological Physics and Advisory Division, Bhabha Atomic Research Centre, Mumbai on the Measurement Techniques for Radon concentration in soil at different baptism depth of the earth surface; Measurement of radioactivity content using Gamma-ray spectrometer NaI(Tl) Scintillation Detector, Radon Mass Exhalation rate measurement using Smart RnDuo and Radon in Water measurement using Smart RnDuo.
- Working knowledge of Basic Computer Operating Systems DOS/WINDOWS 10 and FORTRAN77.

PARTICULARS OF THE CANDIDATE

NAME OF THE CANDIDATE : REMLALSIAMA

DEGREE : DOCTOR OF PHILOSOPHY

DEPARTMENT : PHYSICS

TITLE OF THESIS : RADON CHARACTERISATION IN SOIL OF OIL EXPLORATION AREAS IN MIZORAM

DATE OF ADMISSION : 09.08.2017

APPROVAL OF RESEARCH PROPOSAL

1. DRC : 03.04.2018
2. BOS : 11.04.2018
3. SCHOOL BOARD : 24.04.2018
4. MZU REGISTRATION No. : 1702102
5. Ph.D.REGISTRATION No. : MZU/Ph.D. /1101 of 24.04.2018
6. EXTENSION (IF ANY) : NIL

(Prof. ZAITHANZAUVA PACHUAU)

Head

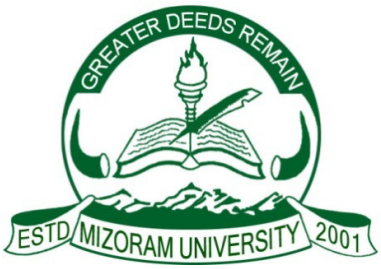
Department of Physics

ABSTRACT

RADON CHARACTERISATION IN SOIL OF OIL EXPLORATION AREAS IN MIZORAM

AN ABSTRACT SUBMITTED IN PARTIALFULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF DOCTOR OF PHILOSOPHY

REMLALSIAMA
MZU REGN. NO: 1702102
Ph.D REGN. NO: MZU/Ph.D/1101 OF 24.04.2018



DEPARTMENT OF PHYSICS
SCHOOL OF PHYSICAL SCIENCE
FEBRUARY 2023

ABSTRACT

RADON CHARACTERISATION IN SOIL OF OIL EXPLORATION AREAS IN MIZORAM

By

Remlalsiama

Department of Physics

Professor Zaithanzauva Pachuau

Supervisor

Professor B. Zoliana

Joint Supervisor

Submitted in partial fulfillment of the requirement of the Degree of Doctor of Philosophy in Physics department of Mizoram University, Aizawl.

ABSTRACT OF THE THESIS

The study of radon and its characteristics in the soil of oil exploration areas in Mizoram, India is carried out. The study mainly includes 'radon mass exhalation rate calculation' measured using an active method base on scintillation instrument called SMART RnDuo; 'measuring the soil radioactivity' using sodium iodide (NaI) detector, having thallium (Tl) as a doping agent coupled with a PC based 1K Multichannel analyzer called GSPEC-SA. The 'background gamma radiation' detection is carried out with Gamma Survey Meter PM 1405, which is a Geiger-Muller counter based measuring instrument; the 'Global Positioning System' location is taken for all sample spot of all the oil exploration areas. A special device called Garmin GRB 21 is utilized for the purpose. 'Soil type' and 'grain size' of the soil is also measured using a Mechanical Sieve Shaker. The 'radon concentration in water' is also carried out with SMART RnDuo. The 'Uranium concentration in water' is also measured using LED Fluorimeter LF-2a. Lastly an '*in-situ* measurement of radon concentration' inside the soil at different baptism depth is studied carefully with SMART RnDuo provided with a soil probe of 1m length.

Radon characterization research work was carried out in all the six oil exploration areas of Mizoram, India. These includes Meidum and Zanlawn field in Kolasib district; Phulmawi, Maubuang and Keifang oil field in Aizawl district and Thenzawl oil field in Serchhip district respectively. In Kolasib district, Meidum oil field area stretches from 24º10'11.8"N to 24º10'12.9"N latitude and between 92º35'55.4"E to 92º35'58.8"E longitude with an elevation range of 291ft to 331ft from sea level. And that of Zanlawn oil field area stretches from 23º59'01.0"N to 23º59' 02.6"N latitude and between 92º42'47.8"E to 92º42'50.8"E longitude with an elevation range of 2110 ft and 2900 ft from sea level. In Aizawl district, Phulmawi oil field area stretches from 23º35'29.9"N to 23º35'33.1"N latitude and between 92º51'23.0"E to 92º51'25.0"E longitude with an elevation range of 2900 ft and 2956 ft from sea level; that of Maubuang oil field area stretches from 23º29'42.7"N to 23º29' 47.3"N latitude and between 92º42'3.6"E to 92º42'5.8"E longitude with an elevation range of 2870 ft and 2885 ft from sea level and that of Keifang oil field area

stretches from 23º39'12.5"N to 23º39'14.2"N latitude and between 92º57'0.9"E to 92º57'1.7"E longitude with an elevation range of 2915ft to 2927ft from sea level. In Serchhip district, Thenzawl oil field area stretches from 23º18'08.3"N to 23º18'12.4"N latitude and between 92º42'5.8"E to 92º47'11.9"E longitude with an elevation range of 2454 ft and 2483 ft from sea level.

The mass exhalation rate of radon in soil samples ranges from 7.27 mBq/kg/hr in maubuang-3 location to 23.49 mBq/kg/hr in maubuang-2 location with an average of 13.82 mBq/kg/hr. The radon mass exhalation rate obtained was found to be lower than the results obtained by other researcher using the same procedure and instrument (Kaushal *et al*., 2017; Amanjeet *et al*., 2018).

The average values of activity concentration of ^{238}U is found to be 17.86Bq/kg which is well within the worldwide average value of 35 Bq/kg, given in UNSCEAR (2000). However, the average activity concentration of ^{232}Th, which is found to be 50.92Bq/kg and for ^{40}K nuclide found to be 644.38 Bq/kg exceeded the corresponding worldwide average values of 30 Bq/kg and 400 Bq/kg respectively (UNSCEAR, 2000). Although the results obtained for ^{232}Th and ^{40}K were higher than the corresponding worldwide average values, the average radioactivity concentration obtained for the three radionuclide were all found to be well within the critical value set by IAEA (2004), the critical values being 10,000 Bq/kg for ^{40}K and 1000 Bq/kg for both ^{238}U and ^{232}Th radionuclide. To represent the activity concentration of ^{238}U, ^{232}Th and ^{40}K into a single quantity with respect to exposure to radiation, the radium equivalent activity was calculated and the measured values of radium equivalent activity concentration of all the oil field area is found to be 135.78 Bq/Kg which is lower than the safe limit value of 370 Bq/kg, prescribed by OECD (1979).

The ground level background gamma radiation of all the oil exploration area ranges from 162 nSv/hr in phulmawi-3 area to 202 nSv/hr in meidum-1 area. The average ground level background gamma radiation is 179 nSv/hr. The background gamma radiation at 1m (one meter) above the earth surface of all the 18 site ranges from 140 nSv/hr at meidum-3 area to 176 nSv/hr at meidum-1 area. The average background gamma radiation at 1m above the earth surface is 156 nSv/hr. It is clearly

seen that the background gamma radiation at the ground surface is higher than that at 1m above the ground surface. This indicates that the terrestrial contribution of gamma radiation is higher by a certain amount than the cosmic contribution. The background Gamma radiation level obtained were all found to be higher in comparison with the values reported by UNSCEAR (2000) for different countries (mean of 59 nGy/h in the range of 18- 93 nGy/h), but was within the given range of background gamma level for India (89 nGy/h in the range of 27–3051 nGy/h) (Nambi *et al.*, 1986).

Global Positioning System location is taken for all sample spot of all the oil exploration areas. A special device called Garmin GRB 21 is utilized for the purpose. The located of all the six oil field are stretches from $23^0$18'10.2"N latitude at thenzawl-1 location to 92^0 57'1.7"E longitude at keifang-2 location.

Out of the total 18 soil samples collected, on an average 86.74% are sand, 5.11% are silt and 8.14% are clay. On Comparison with the observed radon mass exhalation rate it is learnt that a higher quantity of smaller grain size does not necessarily indicate the higher exhalation value. In the present research work the grain size does not necessarily increase the radon mass exhalation rate, even though the rate of exhalation by radon mass is inversely proportional to the grain size of the soil.

The measured values of radon concentration in water ranged from 0.34 Bq/l to 4.33 Bq/l. There values were found to be well lesser than the safe limit range of 4-40 Bq/L for radon concentration in drinking water as recommended by UNSCEAR (1993). The total average radon content in water of all the oil field area was found to be 1.26 Bq/L which was far below the safe limit of 11 Bq/L prescribed by US EPA (EPA, 1998).

The uranium content in water of all the oil exploration area ranges from 0.213 μg/l at zanlawn-2 location to 0.643 μg/l at meidum-2 location with an average value of 0.323 μg/l. The measured values of uranium concentration in water of all the oil exploration areas were found to be well within the safe limit value of 30 μg/l for drinking water as prescribed by WHO (2011). The values obtained were also much lower than the critical value of 60 μg/l, suggested in India by the Atomic Energy

Regulation Board (AERB, 2004). Hence, there is no radiological risk due to ingestion of water containing uranium in this study. Also, the measured pH values ranged from 6.80 to 7.25, with an average value of 7.025. The pH value of all collected samples were found to be well within the safe limit value of 6.5- 8.5 for drinking water, as recommended by BIS (1991).

The soil probe is baptized to 10cm, 30cm, 50cm and 70cm deep in all the oil exploration areas and the corresponding radon concentration is noted. Meidum oil exploration area has a maximum radon concentration of 0.31 kBq/m^3 at 70 cm deep and a minimum of 0.1 kBq/m^3 at 10cm deep. Zanlawn oil exploration area has a maximum radon concentration of 0.19 kBq/m^3 at 70 cm deep and a minimum of 0.12 kBq/m^3 at 10cm deep. Phulmawi oil exploration area has a maximum radon concentration of 0.52 kBq/m^3 at 70 cm deep and a minimum of 0.11 kBq/m^3 at 10cm deep. Maubuang oil exploration area has a maximum radon concentration of 1.6 kBq/m^3 at 70 cm deep and a minimum of 0.15 kBq/m^3 at 10cm deep. Keifang oil exploration area has a maximum radon concentration of 0.4 kBq/m^3 at 70 cm deep and a minimum of 0.1 kBq/m^3 at 10cm deep. Thenzawl oil exploration area has a maximum radon concentration of 1.37 kBq/m^3 at 70 cm deep and a minimum of 0.14 kBq/m^3 at 10cm deep. The minimum radon concentration in soil of 0.10 kBq/m^3 is observed at meidum-3 and keifang-2 locations and a maximum radon concentration of 1.60 kBq/m^3 is obtained at maubuang-2 location. The average radon concentration at 10cm deep of all the oil exploration area is 0.285 kBq/m^3 and at 30cm deep it is 0.335 kBq/m^3. The average radon concentration at 50cm deep is 0.417 kBq/m^3 and at 70cm deep it is 0.476 kBq/m^3. In all the cases, the radon concentration thus obtained from all the study area lies well within the range reported by other investigator from India and Pakistan as shown in Table 4.4. In all the cases, within the study area and with the maximum study depth of 70cm, the radon concentration increases with depth. Deeper the baptism depth higher the radon concentration and vice versa.

A correlation coefficient between the background gamma radiation and radon concentration in soil at different depth shows that the correlation coefficient is best with 10cm depth and least at 70cm depth. The gamma radiation and radon

concentration show a good correlation which is due to their same source of origin from the terrestrial source.

The result and observation in this research work will be considered helpful in estimating the radiological exposure of the general populations residing in the oil exploration areas of Mizoram in the radiological mapping of India. It is evident that the population of dwellers in oil exploration areas is increasing day after day. The health concern of the general public needs to be attended in all respect.

The table 4.4 also show the radon concentration in soil and dwellings and in the environment of oil refinery and non oil refinery areas. Whereas the average radon concentration in soil at 10cm deep of the present study ranges from 0.10kBq/m^3 to 1.23kBq/m^3, the radon concentration in non oil exploration areas in dwelling areas of Aizawl district ranges from 0.027 kBq/m^3 to 0.085 kBq/m^3; in Kolasib district dwelling areas it ranges from 0.021 kBq/m^3 to 0.093 kBq/m^3; and in Serchhip district dwelling areas the radon concentration ranges from 0.028 kBq/m^3 to 0.072 kBq/m^3 respectively. The Radon Concentration obtained in Soil in the study areas were very high as compared to the radon gas concentration in dwellings and environment of oil refinery areas and non oil exploration areas. This is because the radon concentration inside the earth is high as compared to the radon concentration in dwellings and open environment. Also that the maximum radon concentration of 1.6 kBq/m^3 is well within the safe limit of 35 kBq/m^3 for outdoor radon activity recommended by United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR 2000).

With this research work it is concluded that there is no risk of negative health concern originating from radiological background in all the six oil exploration areas in Mizoram. The general population and dwellers of these areas are safe from any radiological nuclei originating from uranium, radon and their progeny respectively. But the radon concentration in Soil is quite higher as compared to dwelling, air and environment in oil exploration areas as well as non oil exploration areas.