ALPHA PARTICLES DEPOSITION AND ITS EFFECTS ON LUNGS, MALE INFERTILITY AND BLOOD COMPONENTS

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by

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This effort dedicated

To

Soul of the messenger of Allah "Muhammad –Allah peace upon him"

Soul of my father "Haj Hamid Ismail-may Allah rest his soul in peace "

My lovely mother, brothers and sisters

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"All praises and thanks to ALLAH"

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Asaad Hamid Ismail
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ACRONYMS AND ABBREVIATIONS

Alveoli	Air sacs of the lungs
Amyloid	Is a substance which can be found in all tissue pathology.
BALF	Broncho-Alveolar Lavage Fluid
BEIR	Biological Effects of Ionizing Radiation
Breathing	Process of inhaling and exhaling air
Bronchi	Largest branch of the bronchial tree between the trachea and bronchioles.
Bronchial tree	Entire system of air passageways within the lungs formed by the branching of bronchial tubes.
Bronchioles	Smallest of the air passageways within the lungs.
C	Celsius, centigrade
c.s.	cross section (cut perpendicular to the axis, or across the structure)
c.t.	connective tissue
CBC	Complete blood count
CBRN	chemical, biological, radiological, nuclear
e.	Epithelium
EPA	Environmental Protection Agency (United States)
Epiglottis	Flaplike piece of tissue at the top of the larynx that covers its opening when swallowing is occurring.
Exhalation	Also known as expiration, the movement of air out of the lungs.

GM	Geiger-Mueller
Gy	Gray
H&E stain, HE stain or hematoxylin and eosin stain,	Popular staining method in histology. It is the most widely used stain in medical diagnosis; for example when a pathologist looks at a biopsy of a suspected cancer, the histological section is likely to be stained with H&E and termed H&E section, H+E section, or HE section.
HAZMAT	Hazardous materials
Hemoglobin	Iron-containing protein pigment in red blood cells that can combine with oxygen and carbon dioxide.
HPA	Health Protection Agency
IAEA	International Atomic Energy Agency
ICRP	International Commission on Radiological Protection
Inhalation	known as inspiration, the movement of air into the lungs.
keV	kilo electron volts
kg	Kilogram
km	Kilometer
l.s.	longitudinal section (cut parallel to the axis, or along the structure)
Larynx	Organ between the pharynx and trachea that contains the vocal cords.
Lungs	Paired breathing organs.
magnification	On most tissues and organs we used the same three magnifications that students use in lab: 40X (scanning objective lens), 100X (low power objective lens) and 400X (high power objective lens).

Nasal cavity	Air cavity in the skull through which air passes from the nostrils to the upper part of the pharynx.
NCRP	National Council on Radiation Protection & Measurements
NTDs	Nuclear Track Detectors
Pleura	Membrane sac covering and protecting each lung.
ppm	parts per million
Rad	Radiation absorbed dose
RBE	Relative biologic effectiveness
RED	Radiological exposure device
Rem	Roentgen Equivalent Man (dose equivalent)
RERF	Radiation Effects Research Foundation
Respiration	Exchange of gases (oxygen and carbon dioxide) between living cells and the environment.
SRIM	The stopping and range of ions in matter
Sv	Sievert
t.s.	transverse section (cut perpendicular to the axis or across the structure)
Trachea	Also known as the windpipe, the respiratory tube extending from the larynx to the bronchi. The nasal cavity is lined by mucous membrane containing microscopic hairlike structures called cilia.
UNSCEAR	United Nations Scientific Committee on the Effects of Atomic Radiation
w.m.	whole mount (the tissue was not cut before it was mounted on the slide)
WHO	World Health Organization

LIST OF SYMBOLS

A	Alpha particle
B	Beta
μ	Micro
Γ	Gamma ray
θc	Critical Angle
ρ	Density
η	Efficiency of the CR-39 NTDs
V_B	Velocity of bulk etch rate
V_T	Velocity of track etch rate
K	Calibration factor
F	Equilibrium factor between radon and its daughter
RBC	Red Blood Cell
WBC	White Blood Cell
PLT	Blood Platelet
C_{Rn222}	Radon concentration
^{222}Rn	Radon Gas
^{220}Th	Thoron Gas

TABLE OF CONTENTS

CHAPTER 6- Evaluation of the Risks of Deposition of Alpha Particles on Human Lungs and Male Infertility

CHAPTER 7- Risk Evaluation of Alpha Particle Deposition on the Human Blood Samples: *In vitro*

LIST OF TABLES

LIST OF FIGURES

PENGENDAPAN ZARAH ALFA DAN KESANNYA KE ATAS PARU-PARU, KETIDAKSUBURAN LELAKI DAN KOMPONEN DARAH

ABSTRAK

Pengendapan zarah alfa pada paru-paru, ketidaksuburan laki-laki dan komponen darah manusia (platelet, PLT; sel darah putih, WBC dan sel darah merah, RBC) telah dilakukan dengan menggunakan teknik pendedahan baru CR-39 NTDs. Penyelidikan ini meliputi lima bahagian utama. Pada bahagian pertama, proses penentukuran CR-39 NTD telah dilakukan. Didapati bahawa kecekapan dan masa optimum etsa CR-39 NTD adalah 80.3 ± 1.23% dan 9 jam, masing-masing.

Pada bahagian kedua, bergantung kepada faktor penentukuran gas radon, dosimeter radon optimum telah direkabentuk. Dimensi optimum dosimeter radon adalah 7 cm panjang dan 6 cm diameter pada faktor penentukuran 2.68 ± 0.03 cm.

Pada bahagian ketiga, kepekatan radon dalam udara, tanah dan air minum telah dinilai di 124 kediaman yang mana ketaksuburan adalah ketara di 31 lokasi berbeza di Kurdistan Iraq, dengan menggunakan pengesan pasif (pengesan plastik CR-39) dan aktif (RAD7). Suatu hubungan ditemui antara kepekatan radon dalam bilik, kadar pengudaraan, dan kadar ketaksuburan lelaki. Kadar tinggi kepekatan radon dalam bilik dan ketaksuburan lelaki adalah realtifnya berkorelasi dengan pergularan rendah atau buruk. Selanjutnya, kadar eskhalasi dari tanah dan air minum menyumbang kepada kadar peningkatan radon dalam bilik di sebahagian besar lokasi. Menurut faktor risiko anggaran, radon disebabkan oleh risiko kanser paru-paru untuk kediaman di beberapa lokasi terpilih adalah berubah dari 43.17 hingga 108.79 dengan purata lebih kurang 65.22 ± 20.93 per juta orang. Kadar kepekatan radon mempunyai nilai rendah (139.11 ± 17.26 Bq/m^3) untuk pengudaraan yang baik (13.7%), dan mempunyai nilai tinggi (189.78 ± 55.91 Bq/m^3) untuk pengudaraan yang buruk (56.45%). Oleh kerana itu,

pengendapan zarah alfa, yang dipancarkan daripada progeni radon, didapati meningkatkan kanser paru-paru dan ketaksuburan lelaki.

Pada bahagian keempat, pengendapan zarah alfa pada sampel darah manusia telah diukur dengan menfabrikasikan teknik penyinaran dan pendedahan. Salah satunya adalah pengkolimat penyinaran alfa dari sumber radium, digunakan untuk mengukur penyinaran dalam sampel darah manusia dengan tenaga berbeza zarah alfa. Kaedah pengagihan zarah alfa pada permukaan CR-39 NTDs telah digunakan untuk menganggarkan ketumpatan zarah alfa yang terkumpul pada permukaan sampel darah. PLT, RBC dan WBC adalah didapati agak terjejas. Namun, yang paling terjejas adalah bilangan PLT, yang menurun dengan peningkatan dos sinaran zarah alfa. Teknik kedua adalah teknik pendedahan gas radon bagi mendedahkan sampel darah manusia. Kajian perbandingan CR-39 NTD dan sampel darah manusia adalah suatu teknik baru untuk kajian *in vitro* pengionan darah. Dalam teknik pendedahan ini, kepekatan radon dikurangkan menjadi sekitar 4.9 %, dan dengan demikian, sekitar 95% dari kepekatan radon diselamatkan. Nisbah pengendapan zarah alpha didapati mencukupi untuk mengubah bilangan PLT bagi kedua-dua lelaki dan perempuan.

Dalam bahagian akhir, suatu teknik pendedahan gas radon (553.20 ± 26.87 Bq/m^3) telah direkabentuk bagi mengkaji kesan *in vivo* penyedutan radon ke atas paru-paru, trakea, dan testis arnab jantan. Pertumbuhan sel abnormal tidak kelihatan dalam paru-paru dalam masa 30 hari pendedahan tetapi muncul selepas 60 hari. Selanjutnya, didapati penyedutan gas radon purata (553.20 ± 26.87 Bq/m^3) tidak menjejaskan trakea dalam masa 30 dan 60 hari. Namun, kesannya bermula selepas 90 hari pendedahan. Di sisi lain, penyedutan kepekatan radon purata tidak menjejaskan testis dalam masa 30, 60, dan 90 hari.

ALPHA PARTICLES DEPOSITION AND ITS EFFECTS ON LUNGS, MALE INFERTILITY AND BLOOD COMPONENTS

ABSTRACT

Alpha particles deposition and its effects on lungs, male infertility and blood components (platelets, PLT; white blood cells, WBC; and red blood cells, RBC) have been performed by using new exposure techniques of CR-39 Nuclear Track Detectors (NTDs). The present research includes five main parts. In the first part, the calibration process of the CR-39 NTDs has been carried out. It was found that the efficiency and the optimum time of etching of CR-39 NTDs are 80.3 ± 1.23 % and 9 h, respectively.

In the second part, depending on the calibration factor of the radon gas, optimum radon dosimeter has been fabricated. Optimum dimensions of the radon dosimeter were 7 cm length and 6 cm diameter at the calibration factor of 2.68 ± 0.03 cm.

In the third part, the concentration of radon in air, soil and drinking water has been evaluated in 124 dwellings where infertility was prevalent at 31 different locations in Iraqi Kurdistan, using passive (CR-39 plastic detector) and active (RAD 7) detectors. A relationship was found between indoor radon concentration, ventilation rate, and rate of male infertility. High rate of indoor radon concentration and male infertility was relatively correlated with low or bad ventilation. Furthermore, radon exhalation rate from the soil and drinking water contributed to increased rate of indoor radon in most of the locations. According to the estimation risks factor, the radon-induced lung cancer risks for dwellings in selected locations varies from 43.17 to 108.79 with the average of about 65.22 + 20.93 per million person. Radon concentration rate has low value (139.11 ± 17.26 Bq/m^3) for good ventilation (13.7%), and has high value (189.78 ± 55.91 Bq/m^3) for poor ventilation (56.45%). Therefore, deposition of the alpha particles, which are

emitted from radon's progenies, has been found to increase of lung cancer and male infertility.

In the fourth part, deposition of the alpha particles on the human blood samples has been estimated by fabricating irradiation and exposure techniques. One was the alpha irradiation collimator of the radium source, used to measure the irradiation in human blood samples with different energies of alpha particles. The method of distribution of alpha particles on the surface of CR-39 NTDs was used to estimate the density of alpha particles that accumulate on the surface of the blood samples. PLT, RBC and WBC counts were found to be relatively affected. However, the most was the PLT count, which decreased with increasing radiation dose of alpha particles. The second technique was the exposure technique of radon gas to expose human blood samples. Comparative study of CR-39 NTDs and the human blood samples is a new technique for *in vitro* studies of ionization of blood. In the present exposure technique, the radon concentration was reduced to around 4.9 %, and thus, around 95% of the radon concentration was saved. A ratio of the deposition of alpha particles was found to be adequate to change the PLT count in both males and females.

In the final part, an exposure technique of radon gas (553.20 ± 26.87 Bq/m^3) has been fabricated to study *in vivo* effects of radon inhalation on the lungs, trachea and testes of the male rabbits. Abnormal growth of cells was not observed in the lungs within 30 days of exposure but it appeared after 60 days. Furthermore, it was found that inhalation of the average radon gas (553.20 ± 26.87 Bq/m^3) did not affect the trachea within 30 and 60 days. However, the effects started after 90 days of exposure. On the other hand, inhalation of average radon concentration did not affect the testes within 30, 60, and 90 days.

CHAPTER 1

Introduction and an Overview

1.2 Background and Overview

Development of the techniques of irradiation and exposures to nuclear radiation in the field of medical physics started from the discovery of radioactivity. Ionizing radiation is a portion of the electromagnetic spectrum with sufficient energy to pass through matter and physically dislodge orbital electrons to form ions. These ions, in turn, can produce biological changes when introduced into the tissues, and can exist in two forms, i.e., electromagnetic wave, such as an X-ray or gamma ray, or as a particle, in the form of an alpha or beta particle, neutron, or proton (ATSDR 2005). Different forms of ionizing radiation have various abilities to generate biological damages (Hada *et al.* 2011).

Natural sources inherent to life on earth are considered to be major source of human exposure to ionizing radiation. Radon gas, gamma rays, cosmic (natural sources) radiations, and internal radiations constitute 2.4 mSv/y of the absorbed radiation dose. In addition, artificial and other sources contribute to 2.8 mSv/y (ICRP 1984, Shankarnarayanan 1998) of the absorbed radiation dose. People may be exposed to external and internal radiations by inhalation and ingestion due to background radiations that exist in the environment. Radon exposure occupies 50% of the average annual dose contribution of population radiation exposure; thus, most of the risks are from the inhalation of radon gas (Mehta 2005, Somlai *et al*. 2009).

The most significant characteristic of the radon-222 gas is the four short-lived progeny products from polonium-218 (^{218}Po) to polonium-214 (^{214}Po), which, shortly after their formation get attached themselves to aerosol particles. However, a small fraction of these particles remains in an unattached form, depending on the movement of the air mass, which in turn depends on the installed ventilation systems (Somlai *et al.* 2009). Deposition of the radon's progeny on the lungs can cause cancer, and may result in male sterility producing undirected effects, via aberration of the DNA (Shankarnarayanan 1998, Abo-Emagd *et al.* 2008, Rajamanickam 2010). The interaction mechanism of the alpha particles with the tissues has been explained in Chapter 4.

Designing and fabricating of an optimum dosimeter to detect and measure radon density in the air is attracting great interest. Furthermore, estimation of the contribution of radon in soil and water in increasing the indoor radon density is also gaining interest among researchers.

Deposition of alpha particles emitted from radon daughter particles may influence the reduction in the number of platelets in both the genders at different rates, depending on the energy of the alpha particles. Hematology studies in the field of radiation have played an active role in estimating the exposure to ionizing radiation, as it increases the number of chromosomal aberrations in human blood lymphocytes (IAEA 1997).

Nuclear track detectors (NTDs) are nuclear detectors commonly made from polyallyl diglycol carbonate (PADC), and the most common NTD material is CR-39 (Hepburn and Windle 1980, Talat and Elsayed 2010). The principle of detection using NTDs is as follows; heavily charged particles cause damage to the materials along their path due to the excitation and ionization of atoms with which they interact. This damaged region is very narrow (30-100 ^{o}A) around the particle trajectory, and consists of disordered, but continuous, damage trails in a higher energy state. These damaged regions could be visualized in the form of "tracks," using special techniques either through direct electron microscopy at a very high magnification or by optical microscopes after selective chemical etching (Dorschel *et al.* 1999). However, their size is changeable, which makes them only as a practical system in *in vitro* studies of human blood samples.

In the present study, a new irradiation and exposure techniques has been developed to evaluate the risks of the deposition of alpha particles on human lungs and its risks on male infertility, through measurement of radon concentration in indoor air, soil samples, and drinking water in the Iraqi Kurdistan. An irradiation and exposure technique to evaluate the risks of alpha particle deposition on the surface of the human blood samples was fabricated, and its methodology and results have been explained in Chapter 7.

Furthermore, a new exposure technique has been fabricated to expose male rabbits to the inhalation of radon gas (*in vivo*) and carry out the histological study of the rabbits to investigate the risks of radon inhalation (deposition of the alpha particles onto the lungs, trachea, and testis). CR-39 NTDs have been used as an essential detector, and the methodology and the results have been explained in Chapter 8.

1.2 Terminology

The main terminologies used in this investigation are as follows:

1. Evaluation of an alpha particle density (track/cm^2 per time of exposure), emitted from the radium-226 source into the human blood samples and the CR-39 NTDs.
2. Etching parameters; Bulk etch rate (V_B), track etch rate (V_T), critical angle for track registration (θc), detector efficiency (η), and the optimum time of etching.

3. Range and restricted energy loss of alpha particles in CR-39 NTDs and human blood samples.
4. Efficiency of the CR-39 NTDs (%).
5. Calibration factor between radon and its daughter.
6. An optimum dimension of the radon dosimeters (cm).
7. Track density
8. Concentrations of the radon gas (Bq/m^3).
9. Potential alpha particle concentration (mWL).
10. Annual effective dose (μSv /y).
11. Inhalation and ingestion doses (μSv).
12. Average annual dose equivalent to the bronchial epithelium, stomach, and whole body (μSv).
13. Concentrations of the blood parameters: White blood cell (WBC) count, red blood cell (RBC) count, and platelet (PLT) count.
14. The histological study of some organs of the male rabbits

1.3 Problem Statements and the Contributions

In this project, the problem statements comprise the following elements:

1. No relationships have been published between the equilibrium factor for radon and the efficiency of the NTDs. This study is the first to demonstrate this relationship.
2. Experimentally, the optimum dimension of the dosimeter of radon gas has not been improved. Therefore, some problems related to the environmental factors (humidity and storage of the detector inside the store or lab) affected track density. Thus,

depending on the calibration factor of the radon gas, a new dosimeter of the radon gas has been fabricated experimentally.

3. Relationships between radon concentration, ventilation rate, and male infertility had not established. In this study, this relationship has been established.
4. Risks of radon inhalation and the effects of the deposition of radon's progenies on lungs and trachea have not been authenticated histologically. This study presented the effect of inhalation of radon on lungs, trachea, and testes of male rabbits, histologically.
5. Old exposure techniques had problem in detecting blood exposure to radon gas (Hamza and Mohankumar 2009), because the loss of radon concentration could not be estimated and the density of the deposition of the alpha particles could not be measured. In addition, detection of blood irradiation sample by the normal incident alpha particles was impossible. Therefore, in the present work, two different techniques have been fabricated; one for normal irradiation of the alpha particles for human blood samples, and other for exposing human blood samples by the radon exposure technique.
6. Human blood has not been irradiated directly by different energies of alpha particles to determine its effects on human blood components. In this study, the theory of track registration by CR-39 NTDs has been employed to detect and measure alpha track density in the human blood samples (*in vitro*).This technique will be beneficial for blood sterilizations.

1.4 Objectives

This study comprises four overall objectives in four main stages as follows:

1. To evaluate the risk of accumulation of alpha particles (that produced from decay radon gas) on the lungs and infertility in men, via the design an optimum radon dosimeter, using CR-39 NTDs; Case study in Iraqi Kurdistan.
2. To fabricate radium (^{226}Ra) irradiation technique to evaluate risks of the normal incident of alpha particles onto the surface of human blood samples (*in vitro*) on the blood components (PLT, WBC & RBC).
3. To fabricate a suitable radon exposure technique to evaluate risks of the accumulation of the ^{218}Po, ^{214}Po and ^{210}Po (progenies of radon) onto the surface of human blood samples (*in vitro*) on the concentration of the blood components.
4. Evaluate the risk of accumulation of the alpha particles on the structure of the Rabbit's tissues (lungs, trachea and testes) via histologically study (*in vivo*) and fabricating a comfortable technique of the radon exposure.

1. 5 Scope of Research

1.5.1 Interface of the Elements

The types of user interface elements that are the subject of this study are individual terms, symbols, measurements, and indicators CR-39 NTDs in the field of radon gas. Furthermore, measurement techniques to investigate the deposition of alpha particles on human blood using this type of detector are the interface elements of this study. In addition, inhalation of low radon dose by male rabbits is another scope of this study. Thus, the scope of this study is limited to the following three interface elements:

1. Concentration of the radon gas, annual effective dose and the lifetime risks of the radon's progenies in air, soil, and drinking water, and their risks on human health (lung cancer and men infertility).

2. Hematological studies of the alpha particles exposure (*in vitro*) using CR-39 NTDs.

3. *In vivo* histological studies of the inhalation of low doses of indoor radon. The male rabbits are the case study, and the CR-39 NTDs with RAD7 are the detection techniques used.

1.5.2 Locations of Interface Elements

Locations of the present study depended on the case study, and were as follows.

1.5.2 (a) Iraqi Kurdistan region

Iraqi Kurdistan region was the area under study for measuring the radon concentration inside the houses of infertile males (depending on the Erbil center for the infertility). In addition, samples of soil and drinking water were also collected from this region. Iraqi Kurdistan is located in the north of Iraq, with the numerous cases of infertility and cancers (blood, breast and prostate cancer) prevail. This region is largely mountainous with a current population of around six million, and covers approximately 40,643 square kilometers. The map of the Iraqi Kurdistan and the details of the data collection have been presented in Chapter 6.

1.5.2 (b) Penang Island

Some of the official locations in the Penang Island have been used for analytical laboratories for the following purposes:

(a) Medical Physics and Biophysics laboratories in the School of Physics, Universiti Sains Malaysia (USM) were used to design all the techniques employed in this study. In addition, procedures of blood irradiation and the exposure of rabbits were carried out in theses laboratories.

(b) Human blood samples were collected and analyzed from the Wellness Center of USM main campus.

(c) Histological examination of the rabbits was carried out in the Histological laboratory, School of Biological Science, USM.

1.6 Outline of the Thesis

The thesis covers risk evaluation of alpha particle deposition on lung cancer, male infertility, and human blood using new irradiation and exposure techniques. It comprises of nine chapters, classified according to the subjects.

Chapter 1 presents an introduction and overview of this thesis. Chapter 2 presents the literature review and previous research on radon inhalation, CR-39 NTDs, deposition of alpha particles on blood, and the effects of deposition of radon’s daughter ions in rabbit's lungs. Chapter 3 describes the mechanism of track formation of CR-39 NTDs, while Chapter 4 presents the mechanism of the interaction of alpha particles with the tissues. Chapter 5 presents the calibration of CR-39 NTDs, fabrication of an alpha irradiation collimator, and selection of an optimum radon dosimeter. Chapter 6 describes the evaluation of the risks of deposition of alpha particles on human lungs and male infertility. Chapter 7 presents the risk evaluation of alpha particle deposition on the surface of human blood samples. Chapter 8 describes the preliminary study on the effects of radon inhalation on lungs, trachea, and testes of male rabbits. Finally, Chapter 9 draws the conclusion and future works.

CHAPTER 2

Literature Review & Previous Research

2.1 Introduction

The aim of this chapter is to present a literature review and previous research on the effects of alpha particle deposition onto the surface of lungs, trachea, and blood samples. The focus point will be the detection techniques of nuclear track detectors (NTDs) to determine the inhalation and injection doses of alpha particles emitted from radon's progenies. The next two chapters will discuss on the principle of alpha track formation in nuclear track detectors and mechanism of interaction of alpha particles with tissues.

The risks of deposition of alpha particles (interaction) on lungs, blood, and male fertility are included in the literature review. Deposition of the alpha particles on the tissues and cells may cause damage (temporary and permanent), depending on the time of exposure, energy of the alpha particles, and quantity of the absorbed dose. Thus, studies on the risks of radiation have been carried out for a long time and research on the techniques is novel.

Alpha particles have two protons bound with two neutrons to make a helium nucleus. It is a heavy nuclear particle and is denoted by the Greek alphabet, α. It has a net spin of zero and has a highly ionization form of particle radiation, and exhibits low penetration and low velocity into the matter. Thus, it loses most of its energy in a short distance (Quseph and Nostovych 1978, NRCNA 2006).

The sources of alpha particles are the decay of radioactive nuclei, such as uranium, thorium, actinium, radium, radon and thoron, as well as, the transuranic elements (chemical elements with atomic number ≥92). In other words, spontaneous emission of the alpha particles occurs in elements with a mass number of about 150 (NRCNA 2006).

In addition, alpha decay can generate radon gas $^{222}_{88}Rn$ from radium $^{226}_{88}Ra$ .The decay of alpha particles as a process must have sufficient atomic nucleus to support it. Thus, sometimes, during the process of emission of alpha particles, the nucleus may be left in an excited state, and hence, to remove the excess energy, gamma rays will be emitted from the nucleus. The production of alpha particles is through the mechanism of Coulomb repulsion between an alpha particle and the rest of the nucleus, both having same electric charge (positive) (Maher *et al.* 2006).

The speed of the alpha particles, along with its positive charge, easily removes the electrons from the atom's orbits causing ionization of that atom. Thus, its energy of motion will be transferred to the medium and this transfer energy slows down into the target (medium), and the rate of slow down depends on the type of medium.

Alpha particles can penetrate up to 7.5 cm in air, and have a high linear energy transfer (LET). Thus, they lose most of their energy in a small range, which makes them a radiation hazard if ingested (NRCNA 2006, Maher 2006).

Health risks of the deposition of alpha particles occur from ingestion and inhalation of the radionuclide elements that emit alpha particles. Radon (^{222}Rn) and thoron (^{220}Th) are two natural radioactive gases that are colorless, odorless and tasteless. As they are radioactive gases, they will decay to their progenies by emitting alpha particles in lungs, trachea, and stomach, which get deposited onto these organs. As a result, they become a health hazard.

Techniques of an irradiation and exposure are based on their ability to detect and maintain a radiation dose during periods of exposure, as much as possible. Moreover, the rate of energy loss, the purpose of the technique, and the fields of study (hematology, histology, and environmental study) are important parameters, and has been considered in this chapter.

2.2 Literature Review

2.2.1 Alpha Particle and the Radon Gas

Radium ($^{226}_{88}Ra$) is a source of radon gas, which decays by emitting an alpha particle to the radon gas. Henri first discovered radium in 1896 as mentioned by Christie in 1909. In the years of 1899 and 1900, Paul Villard and Ernest Rutherford have separated radiation into three types: alpha, beta, and gamma, depending on their ability to penetrate objects and cause ionization. Alpha rays were defined by Rutherford based on their lowest penetration of ordinary objects (Rutherford 1900, Pohl and Pohl-Ru 1977).

Pierre and Marie Curie n 1899 observed that a radioactive gas emitted by radium remained radioactive for a month (Del and Regato 1979, Mazeron and Gerbaulet 1998, Diamantis *et al.* 2008). At that same year, Rutherford discovered variations during the measurement of radiation from thorium oxide. Rutherford noticed that the radioactive gas that was continuously emitting from compounds of thorium retained its radioactivity for several minutes. He called this gas "emanation," and later renamed it as Thorium Emanation (Th Em) (Rutherford 1900).

Friedrich from Germany was the first to discover of radon in 1900, as mentioned by Rutherford (1900). Friedrich placed radon as the fifth radioactive element, next to uranium, thorium, radium and polonium. In the same year, during his experiments on radium, he discovered an emanation from the radioactive gas from the radium compounds, and named it as Radium Emanation (Ra Em) (Rutherford 1900).

In 1901, Rutherford proved that the emanations were also radioactive (Rutherford 1901&1902, Del and Regato 1979). Radcliffe and Lond (1909) reported that in 1903, André-Louis Debierne observed similar emanations from actinium and called it as Actinium Emanation (Ac Em). Several names have been suggested for the above mentioned gases (Th Em, Ra Em & Ac Em) during the period of 1904-1920 by various scientists, as follows: in 1904 (exradio, exthorio, and exactinio), in 1918 (radon, thoron, and akton), in 1919 (radeon, thoreon, and actineon), and eventually in 1920 (radon, thoron, and action) (Kathren , 1998). In same year, Sir William Ramsay suggested that the emanations (radon, thoron, and actineon) might be an element of the noble gas family (argon, krypton, and xenon) (Radcliffe and Lond 1909, Moore 1918).

In 1910, radon gas was isolated by Sir William Ramsay and Robert Whytlaw-Gray and its density was determined (Moore 1918). They suggested that radon could be the heaviest gas known. Thus, they suggested a new name called niton (Nt). In 1912, the International Commission accepted it for Atomic Weights. In 1913, the International Committee for Chemical Elements and International Union of Pure and Applied Chemistry (IUPAC) selected the names of radon (Rn), thoron (Tn), and actinon (An), as reported by Aston et al.,(1923). Furthermore, the names of the isotopes were denoted with the number, with the most stable isotopes (radon; ^{222}Rn) taking the element name, however, thoron (tn) and action (An) became (^{220}Rn) and (^{219}Rn), respectively (Aston *et al.* 1923).

Short-term tests to test the level of radon by remaining in home for 2-90 days, depending on the device have been employed. "Charcoal canisters," "alpha track," "electric ion chamber," "continuous monitors," and "charcoal liquid scintillation" detectors are most commonly used for short-term testing. As radon levels tend to vary from day to day and season to season, a short-term test is less likely to detect the annual average radon level than long-term tests to determine year round average radon level.

2.2.2 Radon Inhalation and its Effects on the Lungs

As an inert gas, radon has a low solubility in body fluids, which leads to a uniform distribution of the gas throughout the body. Exposure to this gas, and its solid decay product, polonium-218, and -214, also result in health risks such as cancer. Once the decay products are inhaled into the lung, they undergo further radioactive decay and release small burst of energy in the form of alpha particles that cause DNA breakage or production of free radicals. Radon not only causes lung cancer, but is also likely to have toxic effects related to the health and survivability of an embryo or fetuses (NRCNA 2006).

When radon and its short-lived decay products are inhaled, the alpha particles emitted by the deposited decay products dominate the radiation dose in the lung tissues, and these products, especially those attached to small size aerosols or those which remain in an unattached form, cause damage to sensitive lung cells, thereby increasing the probability of developing cancer (Field 2011, Mole et al. 1990). The World Health Organization first drew attention to the health effects of residential radon exposures in 1979 (WHO 2009), through a European working group on indoor air quality. Further, radon was classified as a human carcinogen by IARC (1988).

Historical roots of the risk of inhalation of radon on lung cancer started from the discovery of radium by Henri in 1896, and polonium (^{210}Po) by Marie and Pierre Curie in 1898. In 1901, Elster and Geitel measured the radon concentration for the first time (Jacobi 1993). The relationship between inhalation of radon and lung cancer was first noted from the incidence of workers who died of lung cancer in the mines of Schneeberg (small city in Saxony/Germany at the northern slope of the "Erzgebirge"). Schneeberg and Jachymov (Jacobi 1993) observed that the high ratio of radon concentration in the air of mines was related to the high ratio of lung cancer among workers in the mines of Schneeberger, based on some findings that have been assumed.

More precise radon measurements carried out in the 1920s in the Schneeberg and Jachymov mines supported this hypothesis. However, the role of radon as a causative factor for the Schneeberger lung cancer was not generally accepted. In a pathological summary report from Dresden in 1926, the cancer was reported to have been caused by the inhalation of toxic dusts (Walsh 1970, Jacobi 1993).

A research program in Germany provided more clarification on the relation between radon concentration and lung cancer. This was a comprehensive study and included measurements of radon concentration in the mines near Schneeberg. In addition, measurements of the alpha activity in tissue samples via histopathological analysis of lung tissues of miners who had died from lung cancer were analyzed.

It was found that the average radon concentration in most mines at Schneeberg was within the range of 70-120 kBq/m^3. It was demonstrated that most of the workers in this mine died from lung cancer, and termed it as "death mine." Because of the observations and supporting biological studies, it was concluded that the inhalation of radon must be regarded as a possible cause for the high ratio of lung cancer among miners in Schneeberg region. These results were summarized in 1945 and the data are available from Schneeberg and Jachymov, but without the mention of the possible role of inhaled short-lived decay products of radon (Walsh 1970, Jacobi 1993).

In 1988, Schiittmann considered that Miiller was the first person to recognize the causal link, as reported by Durrani (1993). Miller concluded that the Schneeberger lung cancer incident was a specific occupational disease, caused by the high radon content in the air of these mines, and when inhaled, it initiated a carcinogenic process in the airways of the lungs (Durrani 1993, Jacobi 1993).

Crameri and Burkart (1989) submitted a report on the importance of radon. They concluded that indoor exposure to radon and radon daughters particles amounted to about 40% of the total effective dose to which the population was exposed to, both from natural and manmade sources.

Studies by National Cancer Institute in 1995 presented a report on radon exposed underground miners. It was found that 40% of the 2700 lung cancer deaths that occurred in 65,000 miners were due to radon (Lubin *et al.* 1995). The Environmental Protection Agency (EPA) recommended that the level of indoor radon concentration should be 4 pCi/l, which had a 6.2% lifetime chance of lung cancer death for cigarette smokers, 2.3% for the general population, and 0.7% for those who never smoked (EPA 2003).

In addition, it provided a reliable document about the effect of smoking on the increased risk of lung cancer in parallel with the inhalation of radon gas. Among non-smokers, 70% of the lung cancer deaths are believed to be due to radon. Thus, the houses of people who smoke may have high radon levels and their risk of lung cancer is especially high (EPA 1992, Mendez 1998).

EPA 2009 and 2010 recommended that with today's technology, radon levels in most homes could be reduced to 2 pCi/l (0.02WL=74Bq/m^3) or below. Thus, it considered an optimum of indoor radon between 2 and 4 pCi/l. In fact, the emanation rate of radon gas has been found to vary from month to month, season to season and year to year, depending on the geological formation, ventilation rate, building material, rate of porosity, soil permeability, etc. (Garakani *et al.* 1988, Hubbard and Hagberg 1996**,** Gillmore *et al.* 2005, Ismail and Hussyin 2007, Prasad *et al.* 2009, Bochicchio *et al.* 2009, Groves-Kirkby *et al.* 2010, Binesh *et al.* 2011). As a result, long-term measurements of the radon gas are suitable.

2.2.3 Occupational (Physical) Exposures and Male Infertility

In general, occupational exposures are classified into physical exposures (heat and radiation), chemical exposures (solvents and pesticides), psychological exposures (distress), and exposure to metals and welding. Radiation exposure for the occupation of male is under present literature review.

Inhalation of radon and its short-lived decay products is considered to be the most common human exposure. One-third of the deposited decay products from radon are transported from the lungs into the bloodstream, causing ionization of the cells. Thus, a random deposition of the energy in the cells will produce ionization and mutation causing genetic risk. Accordingly, the effects caused by radiation are related to the dose of radiation received, regardless of whether the radiation is of natural or artificial origin.

In addition, most of this exposure comes from radon in the air (1300 µSv) (Sankaranarayana1999).

The point of importance in the context of this study is that the mutations induced by radiation of human germ cells will cause an increase in the frequency of the genetic material of the spermatozoa, in an increase in sterility, which can be identified by their respective phenotypes. Thus, human fertility is reduced due to pollution, which may be caused by gene mutation, lowered sperm counts, impairment of sperm motility, or many other reasons. Neither the average mutation rate nor the numbers of loci capable of mutating to dominant detrimental form, as well as mutations that cause sterility are known (Sutton 1975).

Review of the effects of radiation resulting in infertility began from study on the effects of ionizing radiation causing genetic damage in human cells. Numerous occupational exposures have been linked to impairment of male fertility (Sheiner *et al.* 2003). However, studies have been limited by inadequate sample sizes, inappropriate study designs, and/or selection bias. Additionally, the use of semen measures as surrogates for male fertility has been problematic, because there is considerable intra individual variability, substantial overlap between infertile men and fertile men, and poor correlation between fertility and decrements in semen measures.

Salvin (1956) submitted a report on his research under the title 'Effect of Atomic Radiation on the Incidence of Sterility and Mutation.' He carried out his research after the atomic bombings in Hiroshima and Nagasaki, with the cooperation of the United States Atomic Energy Commission. This committee supplied funds to the Atomic Bomb Casualty Commission, which sponsored investigations of the results of the bombings.

However, owing to the following reasons, he could not obtain satisfactory results: no accurate birthrates were maintained by the Japanese authorities before the bombings took place, and it was difficult to ascertain the damage to fertility by the bombs alone, because during the war, there were other factors affecting fertility, such as fear, anxiety, and malnutrition.

1. There was the great difficulty in obtaining statistics in Japan with reference to the incidence of sterility and mutation rates related to atomic bombing.

2. There was no apparent increase in the incidence of sterility as determined by the birth rates in bombed and unbombed cities.

3. The sterility dose of radiation was approximately the same as the lethal dose of whole body radiation.

4. The fertility of men who survived the bombings returned, as a rule, after several months.

5. The number of stillbirths and abnormalities was greatly increased as the result of atomic radiation of pregnant women. Most of the abnormalities were microcephalics, which is consistent with the current known effects of X-rays on fetus in uterus.

6. There has been no appreciable effect till date on the mutation rate due to the bombings. However, the great majority of geneticists feel that there is an analogy between the mutations produced in animals and humans by radiations, and that the effects of radiation will ultimately express themselves. They also feel that we must balance the patient well at the concealed illness, and use radiation only when one would seem to outweigh the other. There can be nothing but the genetic disadvantage for man in artificially raising his mutation rate above that which sufficed for his evolution till

date. The effects of atomic radiation are destructive by increasing the incidence of sterility temporarily.

In 1959, Oakberg submitted his experiment about irradiation of mouse by the doses of 20 rads of gamma rays and 100, 300, and 600 rad of X-rays. He concluded that the killing of cells, rather than inhibition of mitosis, was the primary factor responsible for radiation-induced depletion of spermatogonia.

In 1960, Heller and Rowley investigated some excellent cell data available with regard to the men testes. They studied the radiation effects on human spermatogenesis in biopsies and ejaculates from a group of 67 volunteers administered with testicular doses of 8-600 rad of X-rays. They found that the spermatogonia in the mouse were most radiosensitive cells for doses under 50 rad (Rowley *et al.* 1974, Gaulden 1983).

In 1971, Léonard submitted his research entitled "Radiation induced translocations in spermatogonia of mice." He found that the many years of radiation translocation would cause heritable semi-sterility.

In 1974 Rowley *et al.,* carried out made an experiment on uniform irradiation of the human testes. A portable unit was developed to provide uniform irradiation of the human testes. The device had built-in radiological protection and provided a dosage independent of the subject geometry, uniform to within ±5%. Single doses, between 8 and 600 rad were administered to the testes of human subjects. Dose-response relationships and recovery times were determined for each dose range studied. In 1975 Sutton (1975) found that mutations will cause sterility.

In 1979, Evans *et al,* explained that the nuclear radiation in nuclear dockyard had induced aberrations of the chromosome of the worker. In 1986, Germai submitted his paper about the situation of radioactive patients. He found that the given therapeutic amounts of radionuclide represent sources of exposure and contamination to personnel providing care. Thus, the workers inside those hospitals were found to receive enough dose of radiation.

In 1987, Searle in his report titled "Review: Radiation and the genetic risk, trends in Genetics," concluded that the ionizing radiation can induce mutations and chromosome structural changes, leading to lethality. In 1988, a number of new reports have appeared which dealt with health risks of radon and other internally deposited alpha emitters (NRC 1988).

In 1994, Roger *et al.,* submitted their article, "Relative biological effectiveness of alpha-particle emitters in vivo at low doses." They found that the therapeutic potential of radionuclides that emit alpha particles and their associated health hazards have attracted considerable attention. In addition, they considered that the above mentioned relationships are based on *in vivo* experimental data, and could be valuable in predicting the biological effects of alpha particle emitters.

In 1995, Hagelström *et al,* submitted their results about ionizing radiation and the chromosomal damage in workers occupationally exposed to chronic low-level ionizing radiation. They found a 4-fold increase in the level of chromosomal aberrations between the exposed and control groups, without qualitative or quantitative cytogenetic differences between X-rays and nuclear medicine exposed workers**.**

In 2005, Gracia *et al,* submitted their results of their experiments on the effects of occupational exposures on male infertility. They determined the association between male occupational exposures and infertility. They performed their experiments with the